



Coating Inspector Program

Level 2

Student Manual

December 2007
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**Your CIP Level 2
Instructors are:**

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Policy on Use of Laptop Computers and Camera Phones

In order to be pro-active and provide students with the best opportunity for them to be as fully prepared for the course as possible; NACE has recently implemented a new policy of sending a CD-ROM of the student manual to each student when they register for a CIP course. We are hoping that this process will provide students the opportunity to review and (hopefully) study the manual prior to arriving at the class.

As a result, we have started experiencing students arriving at class with their CD-ROM and a laptop computer. In order to bring ourselves into the 21st Century, the CIP Committee has made the decision to allow students to use their laptops to follow along electronically versus working from their student manual and to also use their laptop to take notes of the class lecture.

In order to make this work, the following guidelines have been put into place:

1. Students are not allowed to be on the internet or connect with the outside world through their computer.
2. Students are not allowed to record any portion of the classroom/lab activities (including lectures)
3. All laptops must be kept in "silent" mode so as not to disturb others in the class.
4. Laptops cannot be used while quizzes or exams are taking place
5. Laptops cannot be used during the Peer Review

In addition, with the use of more and more camera cell phones, students are forbidden to use their cell phone to take pictures while in the class.

Thank you,

NACE CIP Committee



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NACE Standard RP0402 (latest revision), “Field-Applied Fusion-Bonded Epoxy (FBE) Pipe Coating Systems for Girth Weld Joints: Application, Performance, and Quality Control”

NACE Standard RP0287 (latest revision), “Field Measurement of Surface Profile of Abrasive Blast-Cleaned Steel Surfaces Using a Replica Tape”

NACE Standard RP0288 (latest revision), “Inspection of Linings on Steel and Concrete”

NACE Publication 6A192/SSPC-TR 3 (latest revision), “Dehumidification and Temperature Control During Surface Preparation, Application, and Curing for Coatings/Linings of Steel Tanks, Vessels, and Other Enclosed Spaces”

Coatings by Industry

Passive Fireproofing Materials

International Maritime Organization Resolution MSC.215(82)



Instructions for Completing the ParSCORE™ Student Enrollment Sheet/Score Sheet

1. Use a Number 2 pencil.
 2. Fill in all of the following information and the corresponding bubbles for each category:

- ✓ ID Number: Student ID, NACE ID or Temporary ID provided
 - ✓ PHONE: Your phone number. The last four digits of this number **will be your password for accessing your grades on-line**
 - ✓ LAST NAME: Your last name (surname)
 - ✓ FIRST NAME: Your first name (or name by which you are called)
 - ✓ M.I.: Middle initial (if applicable)
 - ✓ TEST FORM: This is the version of the exam you are taking
 - ✓ SUBJ SCORE: This is the version of the exam you are taking
 - ✓ NAME: _____ (fill in your entire name)
 - ✓ SUBJECT: _____ (fill in the type of exam you are taking, e.g., CIP Level 1)
 - ✓ DATE: _____ (date you are taking exam)

3. The next section of the form (1 to 200) is for the answers to your exam questions.

 - **All answers MUST be bubbled in on the ParSCORE™ Score Sheet.** Answers recorded on the actual exam will NOT be counted.
 - If changing an answer on the ParSCORE™ sheet, be sure to erase completely.
 - Bubble only one answer per question and do not fill in more answers than the exam contains.

ParSCORE™
STUDENT ENROLLMENT SHEET

WEB INSTRUCTIONS FOR ACCESSING STUDENT GRADES

It is NACE policy to not disclose student grades via the telephone, e-mail, or fax. Students will receive a grade letter, by regular mail or through a company representative, in approximately 6 to 8 weeks after the completion of the course. However, in most cases, within 7 to 10 business days following receipt of exams at NACE Headquarters, students may access their grades via the NACE Web site. The following are instructions for this process:

To access grades on the NACE Web site go to: www.nace.org

Choose: **Education**
Students Only
Grades
Access Scores Online

Find your Course ID Number

(Example 07C44222 or 42407002) in the drop down menu.

Type in your Student ID or Temporary Student ID

(Example 123456 or 4240700217)*.

Type in your 4-digit Password

(Normally the last four digits of the telephone number entered on your exam form)

Click on **Search**

Prior to leaving the class, write down your course and student information in the spaces provided below:

STUDENT ID _____	COURSE CODE _____
PASSWORD (Only Four Digits) _____	

*Note that the Student ID number for NACE members will be the same as their NACE membership number unless a Temporary Student ID number is issued at the course. For those who register through NACE Headquarters, the Student ID will appear on their course confirmation form, student roster provided to the instructor, and/or students' name badges.

For In-House, Licensee, and Section-Registered courses, a Temporary ID number will be assigned at the course for the purposes of accessing scores online only.

For In-House courses, this information may not be posted until payment has been received from the hosting company.

Any questions, please contact Carol Steele at carol.steele@nace.org or at 281-228-6244.

NACE COATINGS NETWORK (NCN)

NACE has established the NACE Coatings Network, an electronic list serve that is *free* to the public. It facilitates communications among professionals who work in all facets of corrosion prevention and control.

If you subscribe to the NACE Coatings Network, you will be part of an E-mail-driven open discussion forum on topics A-Z in the coatings industry. Got a question? *Just ask.* Got the answer? *Share it!* The discussions sometimes will be one-time questions, and sometimes there will be debates.

What do you need to join? An E-mail address. *That's all!* Then:

1. **To Subscribe**, send a blank e-mail to:
Join-coatings@nacecorrosionnetwork.com
2. **To Unsubscribe**, send a blank e-mail to:
Leave-coatings@nacecorrosionnetwork.com
3. You're done! You'll get an e-mail back telling you how to participate, but it's so easy that you'll figure it out without any help.

PARALLEL PATH TO CERTIFICATION FOR CORROSION TECHNOLOGIST AND SENIOR CORROSION TECHNOLOGIST

Traditionally, NACE certification has been awarded to candidates who have met work and educational requirements and have successfully completed an open book exam.

“Parallel Path” is an alternative route to achieving certification. Under the Parallel Path, NACE certification is achieved by earning credits through successful completion of specified NACE training courses.

The Parallel Path Menu has been included in the CIP Level 2 Notebook because successful completion of CIP Level 2 is one of the courses listed on the parallel path plan for Corrosion Technologist and Senior Corrosion Technologist certifications.

Technician	Technologist		Senior Corrosion Technologist		
	Option #1	Option #2	Option #1	Option #2	Option #3
Basic Corrosion	Basic Corrosion 1 from Menu A 1 from Menu B	Technician Cert 1 from Menu A 1 from Menu B	Basic Corrosion 1 from Menu A 1 from Menu B 1 additional course from Menu A or B Design for Corrosion Control Chemical Treatment Test	Technician Certification 1 from Menu A 1 from Menu B 1 additional course from Menu A or B Design for Corrosion Control Chemical Treatment Test	Technologist Certification 1 additional course from Menu A or B Design for Corrosion Control Chemical Treatment Test
					Note: You can not obtain multiple credit from a single course.

Menu A

- CP 1-Cathodic Protection Tester Class & Certification*
- CP 2-Cathodic Protection Technician Class & Certification*
- CP 3-Cathodic Protection Technologist Class & Certification
- CP 4-Cathodic Protection Specialist Class & Certification

* must meet work experience requirements

Menu B

- Basic Protective Coatings & Linings
- Advanced Protective Coatings & Linings
- Coating Inspector Program Level 1

Paul Knobloch Scholarship Information

March 2007

Background

The Coating Inspector Program (CIP) Task Group of PDC voted to establish an annual honoree scholarship entitled "The Paul Knobloch Scholarship".

Purpose

The Paul Knobloch Scholarship is a discretionary scholarship awarded on merit by the CIP Task Group in honor of one of their founding members, Mr. Paul Knobloch. Paul was generous with his time throughout the development of the CIP, and was a member of the committee that implemented the program. He was particularly interested in training development for individuals with a practical, hands-on background.

Eligibility

- People who have successfully completed Level 1 of the Coating Inspector Program shall be eligible for the scholarship.
- Successful completion of each subsequent course (i.e., CIP Level 2 or Peer Review) shall be the criterion for continuation of the scholarship. Failure to achieve a passing grade in any examination shall terminate the scholarship award.

Who May Nominate

Nominations must be submitted jointly by two persons, each of whom must be associated with the Coating Inspector Program, i.e., individuals currently holding NACE Coating Inspector-Level 3 Certification (this can include NACE CIP Instructors).

How to Obtain Nomination Forms

Forms may be obtained by the following methods:

Phone: Carmen Wisdom at +1-281-228-6233
Fax: Carmen Wisdom at +1-281-228-6333
E-mail: carmen.wisdom@nace.org



Paul Knobloch Scholarship

Background

The Coating Inspector Program (CIP) Task Group (formerly ETC-40 Subcommittee and later the NICITCP Task Group) of PDC voted to establish an annual honoree scholarship entitled "The Paul Knobloch Scholarship".

The subcommittee chairman appointed a Scholarship Committee (now to be known as Scholarship Task Group) to develop recommendations related to such a scholarship. They are as follows:

Purpose

The Paul Knobloch Scholarship is a discretionary scholarship awarded on merit by the CIP Task Group in honor of one of their founding members, Mr. Paul Knobloch. Paul was generous with his time throughout the development of the CIP, and was a member of the committee that implemented the program. He was particularly interested in training development for individuals with a practical hands-on background.

Resolution

Be it hereby resolved that the Coating Inspector Program Task Group may offer an annual scholarship entitled "The Paul Knobloch Scholarship". A maximum of two (2) scholarships may be granted each calendar year solely at the discretion of the CIP Task Group. It is understood that the scholarship is not an official award of NACE International, but is offered in order to honor the efforts of Paul Knobloch on behalf of the Coating Inspector Program. Granting of such a scholarship shall be subject to the following rules.

Eligibility

- People who have successfully completed Level 1 of the Coating Inspector Program shall be eligible for the scholarship.
- Successful completion of each subsequent course (i.e., CIP Level 2) shall be the criterion for the continuation of the scholarship. Failure to achieve a passing grade in any examination shall terminate the scholarship award.



Scholarship Committee

Each year at the NACE Annual Conference, the Chairman of the CIP Task Group shall appoint a Scholarship Task Group. The Scholarship Task Group shall consist of three members with one being designated as Chairman. All three members must be CIP Task Group members.

Nominations

At the time the Scholarship Task Group is formed (NACE Annual Conference), nominations shall be considered for the scholarship. Nominations must be made in writing on the proper Nomination Form (example attached) and shall be submitted to the CIP Scholarship Task Group Chairman (c/o NACE Education Division).

The Scholarship Chairman shall maintain a list of nominations received.

The Scholarship Task Group shall review nominations for complete and accurate data. The Scholarship Task Group will not consider incomplete or inaccurate nominations.

The Scholarship Task Group will only consider information provided in writing on the proper forms. Information provided to the Task Group will not be disclosed to any third party, and shall remain confidential.

The Scholarship Task Group will consider all valid nominations, and will make their decision based on the criteria stated below. All decisions of the Task Group are final, and reasons for the selection will not be disclosed.

The Scholarship Task Group will submit the name of the recipient(s) to NACE and the CIP Committee within 30 days of the closing of nominations, unless otherwise determined by the chairman of the CIP Committee.

Criteria for Nomination

In making its decision, the Scholarship Task Group shall consider the following criteria:

- Financial need
- Leadership potential
- Technical knowledge
- Examination results in CIP Level 1. Successful completion of Level 1 is a mandatory requirement. The examination results achieved will be a contributory factor to any successful application.

Who May Nominate

Nominations must be jointly submitted by two persons, each of whom must be associated with the Coating Inspector Program, i.e., individuals currently holding NACE Coating Inspector-Level 3 Certification.

The Scholarship

The scholarship program shall consist of the following:

1. **Letter of Notification:** The recipient shall be officially notified of the receipt of the scholarship by letter from the CIP Committee Chairman.
2. **Certificate:** A certificate for the scholarship will be awarded to the recipient.
3. **Tuition:** The recipient shall be granted a scholarship to attend one (1) or two (2) eligible training courses as defined in item 4 below. The value of the scholarship shall consist of course registration fees only, at actual cost.
4. **Eligible Training Courses:** The scholarship may be applied to registration fees for any or all of the following, provided the candidate has not already successfully completed them:
 - Level 2
 - Peer Review
5. **Payment of Tuition Costs:** Registration fees shall be paid to NACE International, and not paid directly to recipient.
6. **Scholarship Tuition Fee Payment/Registration:** The scholarship recipient shall notify the NACE Education Division at least thirty (30) days in advance of the course offering which the recipient wishes to attend. The recipient shall be added to the class roster provided that the class is not fully booked.

It shall be the responsibility of the recipient to make all other arrangements related to attendance at the course. These arrangements include, but are not limited to, transportation, lodging and meals.

Time Limit

The recipient shall make use of the provisions of the scholarship within two (2) calendar years of award of scholarship. Should recipient fail to make use of the scholarship within two years, the CIP Task Group may, at its own discretion, vote to extend the benefit period, or the recipient will be declared ineligible for further use of the scholarship.

If a scholarship recipient is unable to use the scholarship due to circumstances such as their work schedule, illness or lack of company support that might not permit its full use, they may make application to the CIP Task Group to postpone the award of scholarship. In such circumstances, the CIP Task Group may, at its own discretion, agree to extend the benefit period.



NOMINATION FORM FOR PAUL KNOBLOCH SCHOLARSHIP

Nomination guidelines and required information:

1. In order for a person to be eligible, a written nomination form and required documents must be submitted to the CIP Scholarship Task Group, c/o NACE Education Division.
2. Nominee must have successfully completed NACE International Coating Inspector Program Level 1.
3. A resume of work experience and education must accompany the nomination package. The Scholarship Task Group Chairman will verify Work experience.

This nomination requires that two (2) people complete the attached forms. They must both be associated with the Coating Inspector Program (subcommittee member, peer, instructor, or person holding NACE Coating Inspector Certification).

Please use the Submission CheckList to make certain that your nomination package is complete.

We hereby nominate the following person for consideration for the Paul Knobloch Scholarship as a result of outstanding performance in Level 1 of the NACE International Coating Inspector Program:

Nominee Name: _____

Address: _____

City, State, Country, and ZIP: _____

Telephone Number: _____

Fax Number: _____

E-mail Address: _____



Nomination Form for the Paul Knobloch Scholarship:

Submitted by:

Signature: _____

Date: _____

NACE Certified Coating Inspector-Level 3 Certification Number: _____

Signature: _____

Date: _____

NACE Certified Coating Inspector-Level 3 Certification Number: _____

Mail to:

CIP Knobloch Scholarship
Task Group
c/o NACE Education Division
1440 South Creek Drive
Houston, TX 77084-4906

For HQ Use Only

Level 1 Date: _____ Work Experience Verified: _____

Written Exam Grade: _____

Practical Exam Grade: _____

Logbook Grade: _____

Level 2 Date: _____

Scholarship Task Group Chairman

Written Exam Grade: _____

Practical Exam Grade: _____

KNOBLOCH SCHOLARSHIP NOMINATION SUBMISSION CHECK LIST

Please use this form to be certain that you are forwarding a complete information package. Incomplete submissions will be returned to the nominators with a request that all items be submitted in one package.

- Nomination Form
- Information Form #1
- Information Form #2
- Scholarship Nominee Form
- Resume



INFORMATION FORM #1

Please answer the following based upon your knowledge of, or personal experience with the nominee,
(nominee's name):

1. The nominee's completion of Coating Inspection Certification will further the integrity or enhance the Coating Inspection Program because of the following reasons:
 - A.
 - B.
 - C.
2. How would the Knobloch Scholarship aid this individual in receiving his/her certification:

Nominator #1:

Signature: _____

Date: _____

NACE Certified Coating Inspector-Level 3 Certification Number: _____

Telephone No.: _____ Fax Number: _____

E-mail Address: _____

Address: _____

City, State, Country, ZIP Code _____





INFORMATION FORM #2

Please answer the following based upon your knowledge of, or personal experience with the nominee,
(nominee's name):

1. The nominee's completion of Coating Inspection Certification will further the integrity or enhance the Coating Inspection Program because of the following reasons:
 - A.
 - B.
 - C.
2. How would the Knobloch Scholarship aid this individual in receiving his certification:

Nominator #2:

Signature: _____

Date: _____

NACE Certified Coating Inspector-Level 3 Certification Number: _____

Telephone No.: _____ Fax Number: _____

E-mail Address: _____

Address: _____

City, State, Country, ZIP Code _____





FOR THE KNOBLOCH SCHOLARSHIP NOMINEE

Please give this page to the nominee. It must be completed and returned with the complete scholarship nomination package.

To the Knobloch Scholarship nominee:

If you were awarded the Knobloch Scholarship, how would this benefit you as an individual?

How will you use this scholarship to enhance the coatings industry as a whole?

Nominee Signature: _____

Print Name: _____

Address: _____

City, State, Country, Zip: _____

Phone/Fax: _____

E-mail address: _____



CIP Level 2 Course Outline

DAY ONE	
Chapter 1	Introduction, Welcome, Overview
Chapter 2	Case Study A
Chapter 3	Dehumidification
Chapter 4	Centrifugal Blast Cleaning
Chapter 5	Waterjetting
Chapter 6	Self-Study Questions
Chapter 9	Practical Math Assignment

DAY TWO	
Chapter 7	Personal Profile System
Chapter 8 Case Study B	
Quiz 1	
Chapter 10	Nondestructive Test Instruments
Chapter 11	Destructive Test Instruments
Chapter 12	NACE Standards
Chapter 13	Peer Review Procedure
Chapter 14	Case Study C
Quiz 2	
Chapter 15	Self-Study Questions

CIP Level 2 Course Outline

DAY THREE	
Chapter 16	Linings & Special Coatings
Chapter 17	Specialized Application Equipment
Chapter 18	Concrete and Inspection
Chapter 19	Surface Preparation, Coating, and Inspection of Special Substrates
Chapter 9	Review Practical Math
Chapter 20	Thick Barrier Linings
Chapter 21	Maintenance Coating Operations
Chapter 22	Practice Practical
Chapter 23	Self-Study Questions

DAY FOUR	
Chapter 24	Pipeline Coatings
Chapter 25	FBE Pipeline Coatings
Quiz 3	
Chapter 26	Inspection & Reporting
Chapter 27	Case Study D
Chapter 28	Hot-Dip Galvanizing
Chapter 29	Spray Metallizing
Chapter 30	Self-Study Questions

CIP Level 2 Course Outline

DAY FIVE	
Chapter 31	Cathodic Protection
Chapter 32	Case Study E
Chapter 33	Coating Types & Inspection Criteria
Chapter 34	Specialized Coatings
Chapter 35	Specialized Applications
Chapter 36	Coating Survey
Chapter 37	Specialized Tests and Test Equipment
Quiz 4	
Chapter 38	Self-Study Questions

DAY SIX	
Course Review and Exam Briefing	
FINAL WRITTEN EXAMINATION	
FINAL PRACTICAL EXAMINATION	



Level 2

Chapter 1

Introduction

Introduction

Welcome to the NACE International Coating Inspector Program, Level 2.

By the end of the day, we will have accomplished several things.

Objectives

- Review Certification Program

In Level 1, we discussed the NACE International Coating Inspector Program Mission Statement, which details what this program is all about and what the inspector trainee should be able to expect from each of the two courses.

We will revisit that Mission Statement today. Also, we will review the NACE policy regarding the use of the certification number and title, and we will define the policy for updating and renewing certification.

- Review this week

We will identify the topics of discussion and other activities for the week.

- Introductions

As in Level 1, we will ask each of you to introduce yourself to the group and to describe your job functions and your hobbies.

- Form teams

Previously we emphasized that the inspector's role is part of a team effort. Today, we will form teams, and we will work in teams throughout the week.

- Review corrosion

Corrosion (electrochemical corrosion) was defined and the mechanism of corrosion was discussed in Level 1. Today, we will review briefly the four parts of a corrosion cell and view a portion of the film on the fundamentals of corrosion.

- Dehumidification

Previously, we looked at the effects of dew point and relative humidity on the coating process. We will discuss the principles and types of dehumidification and explore the value of dehumidification to the user and the applicator.

- Centrifugal blast (wheel blast) cleaning

We will discuss centrifugal blast cleaning, which is commonly used in stationary coating shops and can be adapted for use with certain portable units.

Coating Inspector Program

Introduction

Let us begin this workshop with an overview of the Coating Inspector Program.

In Level 1, we stated that:

- The Coating Inspector Program is designed to accommodate the inexperienced candidate.
- No prior knowledge of, or experience in, inspection is required to commence any CIP course (although the two courses must be taken and successfully completed in sequence: CIP Level 1 and then CIP Level 2).
- In addition to successfully completing Level 1 and Level 2, the candidate must have a minimum of 24 months' field experience in coating inspection, or other coating-related experience, before taking the Peer Review.

Coating Inspector Program Mission Statements

In Level 1, the CIP mission statement outlined what the inspector trainee would be able to do upon completion of each course. These are restated here:

CIP Level 1—Mission Statement

Upon completion of CIP Level 1, the inspector should be able to:

- Undertake simple coating inspection of structural steel, at site, under direct supervision of a qualified (Level 3) inspector.
- Read and comprehend a coating specification for new or maintenance painting of structural steel.

- Use simple inspection equipment, including but not limited to:
 - Sling psychrometer and weather tables (psychrometric charts)
 - Wet-film thickness (WFT) gauges
 - Nozzle aperture gauge
 - Hypodermic needle pressure gauge
 - Magnetic pull-off dry-film thickness (DFT) gauges with National Institute of Standards and Technology (NIST) calibration standards
 - Electromagnetic DFT gauges
 - Low-voltage (wet-sponge) holiday detector
 - High-voltage holiday detector
- Comprehend and use surface preparation standards (NACE, SSPC, ISO) to attain specified surface cleanliness.
- Recognize the inspector's job as part of a team effort.
- Recognize the importance of pre-job meetings and the need to maintain good working relationships on site.
- Recognize the need to determine his or her responsibilities and authority.

The inspector, upon successful completion of Level 1, will attain recognition as NACE Coating Inspector Level 1—Certified.

CIP Level 2—Mission Statement

Upon successful completion of CIP Level 2, the inspector should be able to perform all tasks listed in CIP Level 1 and:

- Undertake coating inspection work in a fixed coatings facility (shop).
- Use destructive coating inspection equipment, including paint inspection gauges, adhesion testers, impressors, and pencil hardness testers.
- Use eddy-current-type electronic DFT gauges.
- Test for water-soluble chemical salts contamination (ferrous and chloride ions) on the substrate.
- Recognize some sophisticated coating techniques used in special circumstances, including pipeline coatings, sheet linings, monolithic linings, etc.
- Recognize the personality types present on most coating projects and learn some techniques for reducing friction and improving work relationships.
- Recognize some specialized coating techniques, including spray metallizing, hot-dip galvanizing, etc.
- Understand basic differences in generic types of coatings and recognize various failure modes.
- Understand the role of product technical data sheets and material safety data sheets (MSDS) in the communication of coatings information.
- Recognize some laboratory test methods used to establish coating performance criteria as well as to evaluate coating failures.

ONLY after successful completion of CIP Level 1 and Level 2 and the Peer Review Examination can the participant attain recognition as a NACE-Certified Coating Inspector—Level 3.

NACE Policy—Use of Logo, Certification Number, and Title

NACE has a firm policy regarding the use of its logo and certification numbers and titles. The certification number and category title may be used only by individuals who are NACE Coating Inspector Level 1—Certified, NACE Coating Inspector Level 2—Certified, and NACE-Certified Coating Inspector—Level 3 and may not be used by any other persons.

All active CIP card holders are permitted to use the term “NACE Coating Inspector Level 1—Certified,” “NACE Coating Inspector Level 2—Certified,” or “NACE-Certified Coating Inspector—Level 3” (whichever level of certification attained), and their certification number on business cards.

This example illustrates how this information can be used by an individual who is **NACE Coating Inspector Level 1—Certified**.

John Smith
NACE Coating Inspector Level 1—Certified
Cert. No. 9650
ACE Inspections, Inc., Knoxville, TN

This example illustrates how this information can be used by a **NACE-Certified Coating Inspector—Level 3**.

John Smith
NACE-Certified Coating Inspector—Level 3
Cert. No. 9650
ACE Inspections, Inc., Knoxville, TN

Individuals who are NACE Coating Inspector Level 1—Certified, NACE Coating Inspector Level 2—Certified, or NACE-Certified Coating Inspector—Level 3, who are members in good standing of NACE International may display the NACE Logo for the purpose of identifying the individual as having achieved NACE Certification.

Update/Renewal

Certification updates or renewals must be completed every three years.

The **Update Program** applies to individuals who have not passed Peer Review. The update process can be completed by selecting one of two methods:

- Attending the next CIP course or Peer Review
- Completing a home-study program.

If another stage of the Coating Inspector Program is attended and successfully completed in a three-year period, an update will be required three years from the most recent course completion date.

The **Renewal Program** applies to Level 3 inspectors. The renewal process can be completed by selecting one of three methods, depending upon the number of work-experience points accumulated in the three years following Level 3 achievement or last renewal:

- 73 points or more: requires only work documentation.
- 36 to 72 points: requires work documentation and completion of the home-study program.
- Fewer than 36 points: requires work-experience documentation and class attendance with successful completion of CIP Level 2 at a regularly scheduled offering.

Appendix A contains work-experience documentation forms and instructions for completing the forms.

Notification will be mailed 90 days prior to the expiration date of recognition to the address on file at NACE. It is important that addresses be current at all times. The notification packets supply all the information and forms necessary for the update or renewal process.

Code of Conduct

Requirements for certification under the CIP include the signing of a Code of Conduct. Failure to comply with the Code of Conduct at any time may result in the loss of the individual's CIP Certification.

Level 2 Overview

For those of you who are pursuing Level 3, this workshop is the second you must attend and successfully complete.

Let's review the course outline so you will have a clear idea of what we will be doing this week. I recommend that you refer to the outline frequently so you can see what is on the agenda.

In a few minutes, we will form teams because many of our activities are done in small groups. Except for the time spent on the Personal Profile System, you will stay with your team all week.

From time to time, there will be presentations, and each team will select someone from their group to present the results of team projects. We want each of you to make at least one presentation to the class.

Personal Profile System

This discussion helps us recognize various personality types and enables us to develop some techniques that can be used on the job to reduce friction and improve working relationships.

The ability to work well with people on the job is a big factor in the role of an inspector. A case-study exercise is designed to help you understand how to cope with and handle such situations in the field.

Test Equipment and Test Methods

This discussion will focus on certain destructive test instruments and equipment, the eddy-current gauge, and methods for determining soluble chemical salts (ferrous and chloride ions) contamination.

Time will be set aside for a practice practical exam so you can get some hands-on practice with the test equipment.

Special Application Methods

This section will include information on:

- Air-assisted airless
- HVLP (high-volume low-pressure) spray pumps
- Plural-component spray units
- Electrostatic spray systems
- Centrifugal spray units
- Guniting systems

Linings and Special Coatings and Inspection Issues

- Powder coatings
- Pipeline coatings
- Thick-barrier linings
- Concrete and cementitious surfaces
- Maintenance coatings
- Hot-dip galvanizing
- Thermal spray metallizing

- Coating types and failure modes
- Technical standards (NACE, SSPC, ASTM, ISO)
- Specification and report writing
- Specialized coatings
- Cathodic protection
- Laboratory instruments

Examinations

At the end of the week, there will be two final examinations.

NACE requires that to advance to the Peer Review, you must pass both exams.

The written exam is closed-book and consists of true/false and multiple-choice questions. About 20% of the questions relate to material presented in Level 1. You may wish to review your Level 1 material. The exam will take about 2.5 hours.

The practical exam covers the tools and techniques for inspections. You will be required to demonstrate how well you know how to perform the coating inspection tests covered this week.

During the week, we will have short written quizzes, all closed-book, to help you prepare for the final written exam.

To help you prepare for the practical exam, we will have lectures and practice sessions using the basic inspection tools and techniques listed in Level 2.

In order to pass Level 2, you must pass both the written final exam and the practical test with a minimum grade of 70 on each test.

We will send you written notification of your exam results as quickly as possible.

With the exception of those students taking the Peer Review, we will not be able to tell you your test results on Friday. Your test results will be mailed from NACE Headquarters within two to three weeks. DO NOT CALL NACE for your results because the staff is NOT ALLOWED to give this information over the telephone. Your test results will be available on the NACE Web site.

You also will be responsible for:

- Your own learning, and
- Managing your own time.

Before we go on, let's stop for a minute to answer any questions [5 to 10 minutes to answer questions].

Introductions

I know we all had a chance to get somewhat acquainted at registration, but before we get started, I'd like to make sure we learn more about each other.

I would like each of you to stand, one at a time, and introduce yourself to the class.

Tell us:

- Your name
- Company name and location
- Your job function, particularly any inspection-related aspects
- Your experience in coating inspection
- Your hobbies

Team Formation Exercise

Now, let's form teams.

You'll be working in these teams for the rest of the week, so right now we'll make a permanent shift in the seating arrangement.

In your notebooks are instructions for the first team exercise. Basically, you are to:

- Pick a name for your team; it's not very exciting to go a whole week being known as Team 1, 2, or 3.
- Design a logo or trademark for your team and draw it on the flip chart.
- As a team, develop a list of expectations and reservations about the course.
- Write your list on a flip chart, and choose someone to present this information to the rest of the group.

Let's get started now; it's now _____.

You have 20 minutes; let's finish by _____.

If you have any questions, the instructors will be available to answer them.

[Team Presentations]

From time to time during the week, we will look at these expectations and reservations to mark our progress.

Level 1 Review

Introduction

Today we will review briefly some of the major points of Level 1. If you brought your Level 1 materials to this workshop, you may want to refer to them from time to time.

In Level 1, we were concerned primarily with the inspection of coatings applied to steel for protection against corrosion. We reviewed the role of the coating inspector and practiced using many of the inspection tools and methods available to the inspector for the various elements of the coating scheme.

In this course, we will continue our study of corrosion, and we will look at controlling corrosion on other substrates, such as concrete and nonferrous metals. We will also learn about additional inspection test equipment and procedures for the inspection of coatings and linings on concrete and steel.

A closer look at the corrosion process may enable us to better understand why the inspector executes the various inspection tests and procedures in the continuing fight against corrosion.

Corrosion

The four elements of a corrosion cell—anode, cathode, metallic pathway, electrolyte—and the effect of oxygen on the corrosion process are well illustrated in the film, *Corrosion*, which we are about to review.

The Coating Specification—A Review

There are six fundamental elements of a successful coating system, which form the basis for a well-written coating specification, the inspector's guidelines on a coating job.

These elements are:

- Scope or description of the work
- Materials (product selection)
- Surface preparation
- Application
- Inspection
- Documentation

Specifications may vary from a single-page document to a document consisting of several hundred pages, depending on the nature and complexity of the project. Specifications also vary in style and arrangement. This can be seen by comparing sample specifications presented in Level 1 with the one to follow here.

This illustrates the variations in the drafting of specifications by different specifiers. However it is styled, the inspector must be able to comprehend the specification and obtain all the necessary documents required by or related to the specification.

Let's review a typical specification, first in outline, then in detail.

The Coating Specification

- Scope
 - Description of project
 - Safety
 - Pre-job conference
 - Administrative provisions
- Materials (Product Selection)
 - Coating systems
 - Coating schedule
 - Approved supplier(s)
 - Handling
- Surface Preparation
 - Reference standards
 - On-site technical service
 - Environmental requirements
 - Coating manufacturer's requirements
- Application (Execution)
 - Safety
 - Approved method(s)
 - Environmental limitations
 - Workmanship
 - Work schedule

- Inspection (Quality Assurance)
 - Inspection standards
 - Inspection procedures
- Documentation (Reporting)
 - Required information
 - Format
 - Frequency

Scope

Description of Project

Usually a general description of the overall project is included under “Description of project,” and may include such a statement as **“to provide all materials, labor, and equipment to paint/coat the facilities described in these specifications.”** The details usually are found in the other provisions of the specification.

Maps, plans, or drawings also may be provided.

Safety

Personal safety is very important to the coating inspector, who should be aware of and watchful for the many potentially dangerous conditions that could occur around a coating operation.

For this reason, we have included a copy of the *“Safety Checklist”* from Level 1. It is included at the back of this chapter.

Pre-Job Conference

A pre-job conference to review standards and procedures can be very helpful to the inspector. Before he or she attends one, the inspector should read the specification and prepare a list of questions regarding any phase of the job that is not clear.

The inspector should not leave the pre-job conference without a crystal-clear understanding of:

- The specification
- His or her authority on the job
- His or her responsibilities on the job

Administrative Provisions

Administrative provisions may include such items as contract administration, arbitration procedures, etc., or other provisions that the inspector should know.

The inspector should ensure that he or she has been granted the authority to meet the designated responsibilities.

For example, does he or she have the authority to stop work for deviation from the specification?

There may or may not be some specific administrative provisions included in the scope. The inspector should pay careful attention to these provisions.

Materials (*Product Selection*)

The inspector should ensure that all materials used, especially coatings, are:

- As specified
- In good condition

- Correctly used

Coating System(s)

Generally, coatings are applied in more than one coat although the inspector occasionally may find a single-coat system.

When more than one coat is required, the inspector should be sure the coatings used are those specified and that they are compatible.

Mixing different manufacturers' coatings in a system, even though they are the same generically, is usually not allowed.

In most specifications, the approved or required coating systems, as well as individual coating materials, will be listed.

Coating Schedule

The coating schedule is a specific and exact list of items to be coated, and often, items not to be coated. This information may sometimes be found in the scope or as an appendix to the specification.

The inspector should know where all the items to be coated are located.

If more than one inspector is on the job, the inspectors should be sure everyone knows which items they are responsible for, and that each item is assigned to someone for inspection.

Approved Supplier(s)

Most specifications include a list of the approved supplier(s) or manufacturer(s) of the specified coatings.

When public funds support a project, as many as three manufacturers may be required, or an **equal/approved equal** clause may be included in the specification. This

allows competitive tendering based on performance and technical equivalency, if not identical product formulations.

Handling

The inspector may be required to ensure that all materials received are in good condition (no broken packages, etc.) and that each container is appropriately marked with a batch or control number.

In addition to getting the correct material in good condition, storage and handling instructions in the specification should be carefully followed.

Surface Preparation

Reference Standards

Standards relating to surface preparation have been written by a number of standards-writing organizations. Some of these were referred to in Level 1. Those that will be covered in this course are:

Joint NACE/SSPC: NACE International and The Society for Protective Coatings.

ASTM International

ISO: International Organization for Standardization

We will discuss relevant standards as they relate to particular surface preparation methods.

Comparative listing of NACE, SSPC, and ISO surface preparation standards.

Note: This chart is **comparative only**, since many standards are **not equivalent**.

	NACE	SSPC	ISO 8501-1	
NONABRASIVE CLEANING				
Solvent Cleaning		SSPC-SP 1		
Hand Tool Cleaning		SSPC-SP 2	St2 or St3) ¹	
Power Tool Cleaning		SSPC-SP 3	St2 or St3 ¹	
Power Tool Cleaning to Bare Metal		SSPC-SP 11		
Flame Cleaning		SSPC-SP 4 ²	F1	
Pickling		SSPC-SP 8		
ABRASIVE BLAST CLEANING/WATERJETTING	Joint Surface Preparation Standards			
White Metal	NACE No. 1/SSPC-SP 5		Sa 3 ("Blast-Cleaning to Visually Clean Steel")	
Near-White Metal	NACE No. 2/SSPC-SP 10		Sa 2 ½ ("Very Thorough Blast-Cleaning")	
Commercial Industrial Blast Cleaning	NACE No. 3/SSPC-SP 6 NACE No. 8/SSPC-SP 14		Sa 2 ("Thorough Blast-Cleaning")	
Brush-Off	NACE No. 4/SSPC-SP 7		Sa 1 ("Light Blast-Cleaning")	
Water jetting	NACE No. 5/SSPC SP 12			

¹ ISO St is for hand and power tool cleaning. The two grades, St 2 and St 3 are shown as attainable with either hand or power tool cleaning.

² WITHDRAWN

NOTE: ISO 8501-1 has been widely adopted as a national standard in various countries, including Australia, New Zealand, Sweden, Japan.

A chart on page 1:21 shows some of the surface preparation standards available as of the revision of this course.

NOTE: The Joint NACE/SSPC abrasive blast standards are identical in wording, and are not exactly equivalent to ISO standards but are comparable.

One key element of surface preparation is the removal of unseen contamination, i.e., the presence of soluble chemical salts, which produce the chloride ion and the ferrous ion, as well as nitrates and sulfates. Many users are concerned with the presence of these ions on the surface, coated or uncoated.

Some industry users are considering creating a standard relating to the detection of an acceptable level of this contamination but, to date, none exist. As a result, the surface preparation section of a particular specification may refer to test methods to determine the presence of ferrous and chloride ions, nitrates, and sulfates on the surface before and after abrasive blasting or other cleaning methods. This section should also spell out methods for the removal of soluble salts. Test methods for the detection and quantifying of ferrous and chloride ions, nitrates, and sulfates will be covered later in this course.

On-Site Technical Service

Because of the complex nature of many modern coatings, especially new systems with little or no field-application history, it is often highly desirable for the specification to require that the coating manufacturer provide on-site technical service. The responsibility of the technical service representative is, in many ways, similar to that of the coating inspector; i.e., to affirm:

- Correct surface preparation
- Correct ambient conditions

- Correct application, etc.

The technical service representative also functions as a sort of “live data sheet,” providing judgment and direction on questions as they arise.

Environmental Requirements

Many local and state regulators in the United States, and some in Europe, prohibit the use of silica. Volatile Organic Compounds (VOCs) are regulated. Such regulations may be cited in the specification.

Coating Manufacturers' Requirements

Surface cleanliness standards previously listed are, in part, dictated by the coating. Anchor pattern or surface profile also depends largely on the coating.

Application

Safety

Describes the specific safety requirements for the inspection function. These may include:

- Actions the inspector may be required to perform, such as monitoring the environment for toxic or explosive gases or ensuring the workers are wearing appropriate safety equipment.
- Safety issues to implement when making inspections (generally when other work is not taking place). For example, an inspector should not enter an enclosed space without alerting the site supervisor that he/she is doing so, nor without bringing a watchman with a safety line for those spaces considered to be confined.

Approved Application Methods

This section may indicate approved methods of application such as:

- Air spray
- Airless spray
- Brush
- Roller (hand or power)

In certain areas, such as those around sensitive equipment, etc., the applicator may be required to apply coatings by brush or roller rather than by spraying.

If the specification calls for a stripe coat on welds and edges, bolt heads, nuts, or other irregularities, the inspector should ensure it is properly applied. One purpose of a stripe coat is to make sure all undercuts and other irregular and hard-to-penetrate areas receive a layer of coating. Also, organic coatings tend to pull back from edges, corners, welds, etc., and become thinner. Stripe coating may be used to build additional thickness in these areas and should be done with a brush for better wetting and penetration.

WFT should be determined if required by the specification.

DFT is determined according to the specifications. SSPC-PA 2 is a guideline frequently cited for taking magnetic DFT readings.

The inspector must know exactly what DFT tolerances are allowed.

Environmental Limitations

The inspector should ensure that during application the environmental conditions meet the specification, particularly:

- Substrate temperature as measured with a steel surface thermometer.
- Ambient temperature as measured with a regular thermometer.
- Relative humidity and dew point as determined by using a sling psychrometer and psychrometric charts or another approved method.

The surface should not have turned or flash rusted or become contaminated since the initial surface preparation operation.

Coatings should be the correct temperature, correctly proportioned and agitated, and thinned (if allowed) with the specified solvent.

Some coatings may be brushed, rolled, or sprayed, while others have limitations on how they may be applied. The specification and/or Product Data Sheets should address such limitations.

Workmanship

The specification should include references to standards of workmanship and the coating inspector should:

- Understand the nature of the work to be performed.
- Know specified performance standards for workmanship.
- Observe work as it is being performed, and report any unacceptable work to his or her supervisor, the owner's representative, or the contractor.
- Have the experience and knowledge to judge the standards of work performed.

Work Schedule

The specification should include a timetable for the coating operation listing the specific order in which the job is to be accomplished, including:

- Inspection of surfaces to be coated before any surface preparation
- Pre-cleaning
- Repair of defects
- Cleaning
- Coating application
- Inspection intervals
- Recording and reporting

Inspection

The specification generally will provide information regarding the application parameters of the coating system (e.g., surface preparation standard, DFT, etc.) in the relevant sections. Many specifications repeat some information in sections dedicated to inspection, or quality control.

Inspection Standards

It is helpful and serves as a useful check list if the specification lists the inspection testing activities. In every case, it is useful if the test method can be linked to a known standard. At the same time, the permissible results of inspection tests and the frequency of testing may be stated, if the listing does not conflict with the quoted standard. Examples linking test methods to standards might be:

- Anchor profile: Three individual readings should be taken on any given local area and averaged to

determine the surface profile measurement. The number of such measurements to be taken on a given area should be as agreed, or specified, by contracting parties.

- DFT should be measured using the method and frequency specified in SSPC-PA 2.
- The coating film shall be allowed to cure for at least four days, and shall then be tested in accordance with NACE Standard RP0188 using a DC holiday detector.

Inspection Procedures

Many specifications, particularly those produced by owners with formal Quality Assurance systems, are likely to require the contractor (or a subcontractor) to provide a written inspection procedure. This would be a formal document which lists the inspection steps, and states the importance of each step. Some steps may be routine measurement by the operator, which require only monitoring by the inspector (e.g., measurement of WFT); others may be considered hold points, which demand that the inspector make a satisfactory inspection before work proceeds.

Documentation (Reporting)

Without documented evidence, much of the inspector's work would be wasted. It is not uncommon for specifications to require that a document package be produced to state exactly what is required.

Required Information

Inspection reports may include:

- Daily reports
- Weekly reports
- Nonconformance reports (where appropriate)

- Special (occasional) reports addressing specific subjects such as progress, equipment, manpower, paint usage, problems, etc.

Other documents a specification may require include “as-built” drawings to be produced and a “punch-list” of defects found at or near completion of the project.

Format

The format of inspection reports may be dictated by the specification, as is likely when the owner wants an inspector to use their (the owner's) report forms. In other cases, the inspector may devise his own report format, particularly for occasional reports.

Frequency

It is important that the specification state not only which reports are required, but what should be done with the reports and when. If copies of reports are to be circulated, a circulation list should be provided. Some owners consider it good practice to provide inspection reports to the contractor; others do not. A common specification clause might say:

“Daily reports should be produced each day, then compiled and forwarded to the owner's representative at least once each week. Additional copies of daily reports should be sent to the owner's head office at xxxx,xxxx and copies should be kept in a file at the job site.”

Coating Inspector's Job

Introduction

The specification should include a detailed section on the required inspection/quality assurance and record keeping.

The focus of the CIP is to look at the coating process from the viewpoint of the coating inspector. In order for you to do this, you must adopt the role of a third-party independent inspector. The coating inspector's primary role and responsibilities discussed in Level 1 are repeated here.

The coating inspector ensures that the coating system is applied according to the coating specification, and accurately and objectively reports the results of all inspection observations.

If environment, time, or other constraints make compliance with the coating specification impossible, the inspector obtains and assures clear written authority for permitting deviations from the specification.

Coating Inspector's Responsibilities

The coating inspector's job responsibilities may vary from job to job, but general duties always include:

- To obtain, read, and fully understand the coating specification, and raise any questions with the supervisor to resolve them.
- To obtain a clear definition of the authority delegated to him/her by the supervisor and/or detailed in the coating specification, particularly regarding the control of contractors working on the project.
- To determine, by measurement and observation, that each clause of the specification is met by the applicator within the scope of the inspector's authority.

- To ensure that all essential raw materials, especially coatings, are stored correctly and used in batches within the manufacturer's recommended shelf life.
- To maintain records of all work done, of the conditions under which it was done, and of any other appropriate items required by his or her supervisor.
- To avoid directing or even appearing to direct the work of a contractor's employees.
- To bring deviations from the specification to the attention of his or her supervisor. Deviations should be reported to the contractor only if the inspector has been given such authority.
- To check that every item and area listed in the coating schedule has been completed.
- To ensure that the required test instruments and standards are available at all times, and that every instrument is fully functional and properly calibrated.

Inspection Tests

Dry-Film Thickness (DFT)

A variety of tests and test instruments used to ensure applications meet specifications were discussed in detail in Level 1. Two test instruments were:

- Type-I magnetic pull-off DFT gauge
- Type-II fixed-probe electromagnetic DFT gauge

The calibration of these gauges must be checked against known standards such as: NIST test blocks for the type-I gauge; calibrated plastic shims for the type-II gauge, or according to the gauge manufacturer's instructions before each use, and as often as necessary to ensure accurate measurements.

Film Integrity

When specified, the coating should be checked for holidays using:

- Low-voltage wet-sponge holiday detector
- High-voltage DC holiday detector

Any other tests required by the specification should be made.

Application Flaws

The inspector must inspect for application defects, including:

- Runs
- Blisters
- Sags
- Blushing
- Uncoated areas
- Other flaws

Record Keeping

The inspector must make sure all paperwork is completed and in order, according to the specification.

The coating inspector's checklist provided in Level 1 is reproduced here.

A Coating Inspector's Checklist is included at the back of this chapter.

Safety Checklist

The following safety checklist may be helpful to you as you observe work or if you should be called on to monitor safety practices on a coatings project.

General safety

- Locate nearest telephone
- Identify restricted areas
- Locate fire alarm
- Locate fire extinguisher and fire blankets
- Locate moving objects, cranes, and traffic
- Identify and observe safety warning tags and signs
- Learn facility alarms, evacuation procedures, and general emergency protocols

Ladders

- Periodically inspect for loose, worn, or damaged rungs
- Wear shoes with heels
- Do not carry any tools in hand while climbing
- Face ladder while climbing; never jump from a ladder
- Guard against danger of metal ladder coming in contact with electric power lines
- Tie off ladder

Scaffolding

- Periodically inspect for damage or deterioration
- Ensure scaffolding is plumb and level
- Ensure handrailing is provided on all scaffolding
- Do not ride scaffolding on rollers when it is being moved

- Verify inspection tags are valid and in place

Power Tools

Verify that:

- Safety guards are fitted and operational
- Dust collection systems are operational when working with hazardous materials

Abrasive Blast

Ensure that the following are installed and in working order:

- Deadman valve
- Pressure control valves
- Adequate moisture and oil separators
- Protective clothing (hoods and gloves)
- Filtered and regulated air-supplied respirator

Make certain that:

- Entire system is grounded, including hoses, operator, and work piece
- Hose couplings are wired shut
- Abrasive hose is stored in a dry place
- Abrasive hose is curved around, not bent at 90° angle
- Nozzle is never pointed at human body or breakable object
- Abrasive hose is inspected for damage and wear

Spray Application

To prevent fire hazards, see that:

- No ignition sources are present when flammable materials are used
- Applicator minimizes use of low flash point materials
- Adequate ventilation is provided
- Spray booth is clear of exhaust fumes from previous spraying
- No rags become soaked with flammable liquid in spray area

Personal Protection

Make certain that:

- Goggles and safety glasses are worn
- Regulated air respirator is used
- Operator is positioned upwind of object being sprayed

Hose and Gun

Determine that:

- Hoses are inspected periodically for weak and worn spots
- Hose connections are correct and tightened
- Hose is never disconnected or recoupled while under pressure
- Pressurized unit is never left unattended
- Gun is grounded through hose connections
- Gun is never pointed at human body
- Gun has required trigger guard
- Operator uses electrically conductive hose in airless applications

THE COATING INSPECTOR'S CHECKLIST	
Subject	Check Here (✓)
Specification	
<ul style="list-style-type: none"> • Have it • Read it • Understand it 	
Pre-job Conference	
<ul style="list-style-type: none"> • Request one • Attend it • Participate actively • Know and understand safety rules 	
Coating Schedule	
<ul style="list-style-type: none"> • Know where coating activities will take place 	
Pre-inspection	
<ul style="list-style-type: none"> • Locate areas that will be hard to coat • Weld splatter • Weld flux • Skip welds • Rough welds • Sharp corners • Laminations 	
Surface Preparation	
<ul style="list-style-type: none"> • Observe safety rules • Correct abrasive • Anchor pattern as specified • All dust removed • Neutral surface • Surface as called for in specification • Surface defects corrected • Weather suitable for abrasive blasting 	
Coatings	
<ul style="list-style-type: none"> • Observe safety rules • Coatings are those specified • Coatings are correctly mixed and agitated • Coatings are correctly thinned • Coatings have not exceeded pot life 	

Coating Application	
• Observe safety rules	
• Weather OK	
• Ambient conditions OK	
• Clean surface	
• Correct WFT	
• Correct DFT	
• No flaws	
• Runs	
• Dry spray	
• Holidays	
• Other	
• Brush over welds	
Report	
• Take all measurements required	
• Record and report as required	



Level 2

Chapter 2

Case Study A

Introduction

Generally, most specifying engineers are conscientious in their efforts to draft a coating specification that reflects the needs of the owner for a given coating project, and that at the same time provides the contractor with realistic guidelines to follow in doing the work.

At times, however, even the “best-prepared” specification may contain conflicting requirements, unclear statements, or other problem areas that could lead to conflict between the owner and contractor. The coating inspector should thoroughly review the specifications for any problem areas and work to get them resolved at a pre-job conference.

The following is an example of a problem area taken from an otherwise well-prepared specification

“Surface shall be blast-cleaned with ABC black beauty grade D, to an anchor profile of 3.0 mils (76 μm).”

You are the inspector who spotted this problem. What do you think are the possible conflicts or consequences for the specifier?

You might advise the specifier as follows:

1. “If you specify the abrasive type and size, you effectively have pre-determined the profile you will get. Specifying **both** type and size may lead to conflict.”
2. “To properly specify surface profile, you should require a range. For example, the specification should state something like this: “The surface profile shall be no less 2.5 mils (63 μm); and no greater than 3.5 mils (89 μm).”
3. “A profile may appear different with different methods of measurement. To eliminate confusion, you should state what method of measurement is to be used. For example, when measured using

replica tape, method is in accordance with NACE Standard RP0287, Field Measurement of Surface Profile of Abrasive Blast-Cleaned Steel Using a Replica Tape.”



Case Study

You are the coating inspector on a construction project. While reviewing the coating specification prior to the pre-job meeting, you mark up a series of statements that require some discussion and/or clarification.

You have worked for the construction company before and know that the engineer's response to your questions will be to ask for your opinion as the best course of action to resolve your technical questions.

Review each of the following statements; state what is wrong with each one, and suggest a solution to the problems you have seen:

1. Apply one coat of Flyer Epoxyclad # 3 or equivalent, to a DFT of 5.0 mils (127 μ m).
2. Ensure the finished coating is holiday-free.
3. Ensure blast-cleaned surface is free of dust and debris.
4. After removing the old coating with chemical stripper ABC, clean the surface with clean water to ensure surface is chemically clean prior to coating.
5. Workmanship

“Work shall be performed in accordance with good industry practice.”





Level 2

Chapter 3

Dehumidification

Dehumidification

Introduction

Dehumidification is defined as the removal of moisture vapor from the air to lower its dew point. This section will focus on dehumidification as a means of controlling the working environment, and describes how dehumidification impedes the corrosion of steel and inhibits flash rusting.

Humidity and temperature impact surface preparation and coating operations

Environmental (ambient) conditions, such as humidity and temperature, have a significant impact on surface preparation and coating operations and ultimately on the long-term performance of coatings.

In normal environmental conditions, coatings must be applied to surfaces within a few hours of cleaning to avoid flash rusting. Coating work is often delayed because of high humidity and/or low temperatures. This necessary cycle of blasting and coating on the same day can affect the quality of the coating work. Applicators often hurry to try to beat the weather. Mistakes can add to the overall cost.

In many cases, such environmental controls as heating, ventilation, use of protective enclosures, lighting, and dehumidification can improve the economics and quality of coatings work.

Present-day coatings can reach their maximum protective potential only when applied to a high-quality surface. After proper removal of oil and grease, steel surfaces are usually blasted to remove old coatings, rust, and scale. Coatings must be applied before the surface loses its bright surface appearance and before flash-rusting begins.

A well-written coating specification requires close monitoring of the surface preparation phase of the coating operation so the full potential of the high-performance coatings may be achieved.

Corrosion and Corrosion Rate

It has been established that corrosion can occur on steel when the four elements of a corrosion cell (anode, cathode, metallic pathway, and electrolyte) are present. The most common source of electrolyte affecting most paints in atmospheric exposure is atmospheric moisture in the form of rain or condensation.

Steel temperature changes the corrosion rate in much the same way as it affects a typical chemical reaction. Higher temperatures generally create higher corrosion rates. Atmospheric humidity and pollution control the corrosion rate, first by creating an electrolyte, then by affecting the efficiency of the electrolyte. Research shows that steel exposed to high humidity and high levels of atmospheric pollution, such as in an industrial area at a sea coast site, will corrode 15 to 20 times faster than steel exposed in a rural area of high moisture and low pollution.

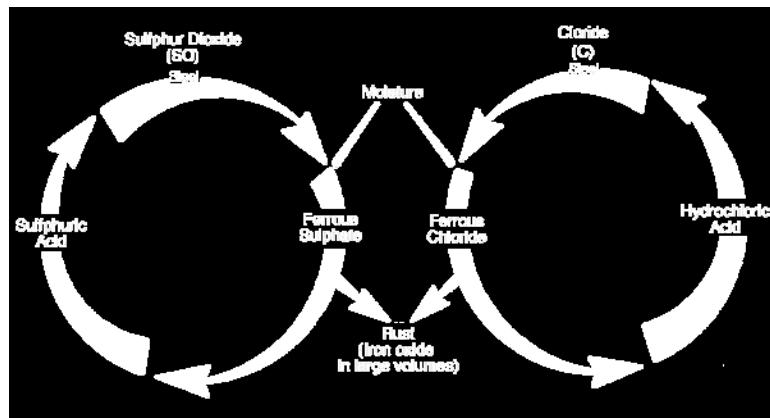


Figure 3.1: Air Pollution and the Corrosion Cycle

In a rural area the steel may frequently be wet, but the film of relatively clean water produces a low rate of corrosion. In an industrial area, such atmospheric pollution as sulfur dioxide, chlorides, and sulfates cause

the water to become acidic, which improves the function of the electrolyte and accelerates the rate of corrosion.

Either way, moisture is a prime contributor to the corrosion process. However, the presence of moisture does not necessarily mean the steel will feel wet. Contaminants on the surface can absorb moisture from the air and hold it on the steel surface in a microscopic layer of water. It would be a mistake to think that keeping the surface apparently dry by stopping condensation is enough to stop corrosion. Rather, to stop corrosion it is necessary to keep the air dry enough to prevent the contaminants on the steel surface from absorbing moisture.

Moisture and Humidity

In normal conditions, all air contains some moisture, and the amount it contains depends on the temperature and pressure of the air. Generally, pressure is not a significant factor, so only temperature needs to be considered.

Relative humidity =

$$\frac{\text{amount of water vapor in a given volume of air}}{\text{maximum amount of water vapor (if air is saturated)}} \times 100\%$$

at the same temperature

Air can have relative humidity in the range of 0 to 100%. At 0%, the air would be perfectly dry; at 100% it is completely saturated.

Warm air can contain or “hold” more moisture than cold air. The amount of vapor held in the air in the summer may be three times greater than that in the winter. When the air contains the maximum amount it can hold at a given temperature, it is said to be “saturated.” If it contains less, say one-half as much, it is said to be partially (50%) saturated, or is said to have a relative humidity of 50%.

Heating the air does not change its moisture content, which is a quantity of vapor, but it does improve its

ability to hold more moisture vapor; and thus, it decreases its relative humidity. Cooling the air reduces the ability to hold moisture vapor and, thus, increases its relative humidity.

When air is cooled, its saturation level is reduced, and the relative humidity is increased toward 100% until the air finally becomes totally saturated. When the air is further cooled, the quantity of moisture vapor present exceeds the ability of the air to hold moisture; and the excess moisture vapor, which it can no longer hold, will condense as a fog, mist, or dew on any surface exposed to the air.

Whatever the humidity level, it is always possible to cool the air enough to reach saturation and then produce condensation. The temperature to which the air has been cooled enough to be saturated and capable of producing dew is called the *dew point temperature*.

As relative humidity decreases, water tends to evaporate faster because the air can absorb more of it. As relative humidity increases, water evaporates more slowly. The same is true of most solvents. Most coatings cannot be applied successfully when the relative humidity is greater than 90% because the solvent evaporation rate decreases at higher relative humidity and reaches zero evaporation rate at 100% relative humidity.

This condition can result in solvent entrapment in the applied coating film, together with an impaired cure process, and is likely to cause subsequent coating failure in the form of blistering or severe peeling.

The relationship between relative humidity, temperature, and dew point can be found in charts and tables or with special slide rules or calculators. The use of the psychrometric chart is illustrated in the following example:

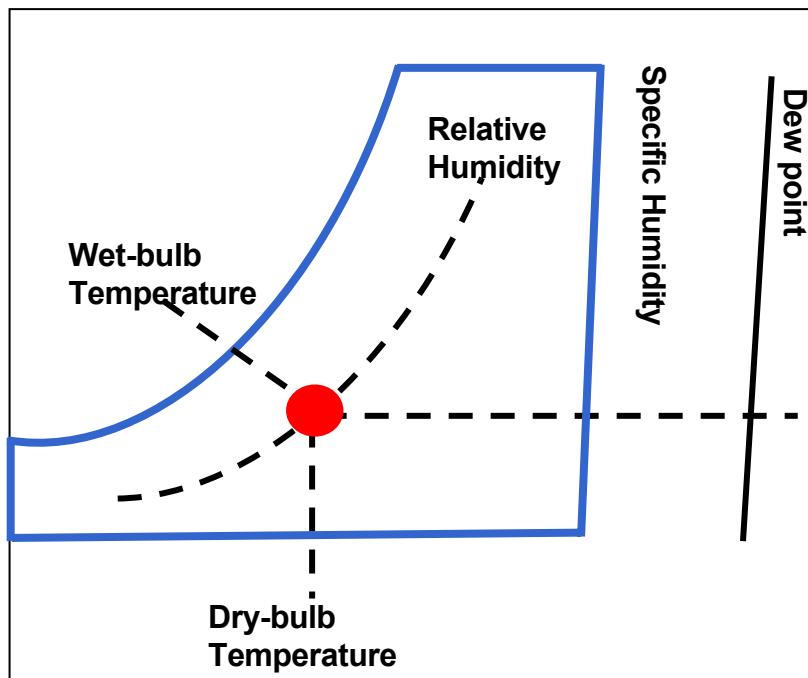


Figure 3.2: Psychrometric Chart (Mollier Diagram)

The chart shows 21°C (70°F), 50% relative humidity and a wet-bulb temperature of 16°C (58.5°F). The dew point can be seen to be 10°C (50°F), which means this air contains the same weight of water vapor as does the saturated air at 10°C (50°F).

By cooling the air from 21°C (70°F) to 16°C (60°F), the weight of vapor is not changed, so by definition the dew point is unchanged, i.e., 10°C (50°F). The relative humidity can be seen to have increased to 73%.

Relative humidity and dew point can be calculated by measuring temperatures with direct reading instruments. A practical instrument to use is the sling psychrometer, with which the temperature is measured using wet- and dry- (thermometer) bulb readings. These measurements can be used to calculate humidity and dew point from psychrometric tables or with special slide rules or calculators.

It should be noted that if the air were cooled to below its original dew point of 10°C (50°F), then the air would be saturated at all temperatures below 10°C (50°F), and

relative humidity would be steady at 100%. Condensation would form as the temperature dropped, and the weight of vapor held by the air would be steadily reduced. Increasing quantities of dew (condensation) would form on any affected surface.

Effects of Humidity on the Corrosion Rate

High humidity can promote rapid corrosion. Normal daytime humidity is typically 50 to 90%, depending on location. Studies show that corrosion is slowed greatly if the humidity is below 60% and virtually ceases below 50%. By holding the relative humidity to a low level (say, below 40%, to allow a safety margin), blast cleaned surfaces can be “held” for a long time before coating without the blast deteriorating.

The corrosion rate is governed by the relative humidity of the air in contact with the metal (steel) surface. This can be different from the relative humidity of air only a few millimeters away, especially if the steel surface and the air are at different temperatures. The air next to the steel is called *the boundary layer*. Unless water is evaporating from, or actually condensing on the steel, this air layer will be in moisture equilibrium with the metal surface.

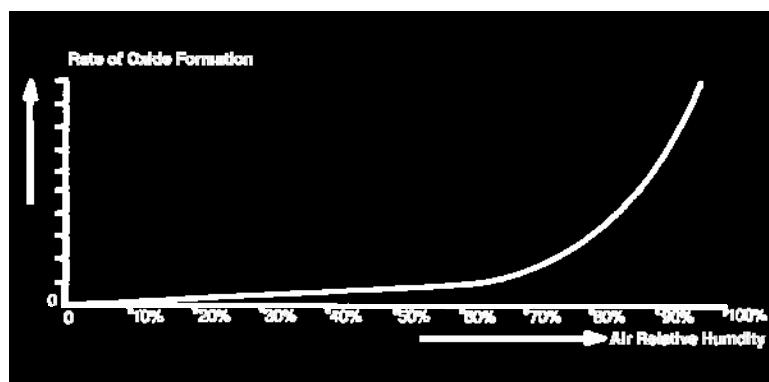


Figure 3.3: Corrosion Rate (Oxide Formation) vs. Percent of Relative Humidity

In general, it is not practical to measure conditions within the boundary layer, but measurements can be made close

to the location by using a sling psychrometer. The temperature of the steel surface can be measured using a contact thermometer.

There are two ways to reduce the relative humidity of the boundary layer:

- Increase the surface temperature
- Reduce moisture content by dehumidification

Use of Heat To Increase Surface Temperature

The method chosen to increase surface temperature depends on relative cost.

With small work pieces, it is possible to heat surfaces using a radiant heater. This method would not be effective for large pieces or in a large enclosed area, such as a tank, unless insulation can be provided. Many radiant heaters would be required to combat heat losses from the steel surface to the outside air.

Another common technique is to heat the air in order to raise the ambient temperatures, including the steel surface temperature. This can be expensive because heat transfers poorly from air to steel and also because of the steel's large heat capacity. Most of the heat put into the air goes to waste and only a little into the steel.

The heat source is an important factor. The use of gas-burning direct heaters can be unsafe and may also be counterproductive. When 4 L (1 gal) of propane is burned, it produces 4.5 kg (7.8 lb) of moisture, achieving exactly the opposite effect than is needed (i.e., less water vapor).

Refrigeration

Previously, dehumidification was defined as the removal of moisture vapor from the air to decrease the dew point temperature.

The objective of dehumidification is to reduce the rate of corrosion to minimal levels by reducing the moisture content of the air to a safe level, 50% or less, at the prevailing temperature. A flow of air through the working area is always required, and it is this air that must be dehumidified. The amount of moisture vapor can be reduced by refrigeration or by the use of desiccants.



Figure 3.4: Dehumidification Units

Using refrigeration to remove moisture vapor from air is a common and economical method of dehumidification.

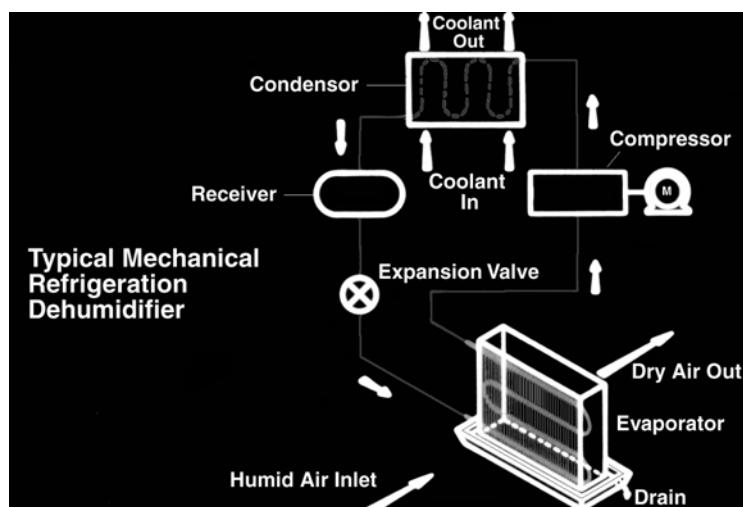


Figure 3.5: Typical Refrigeration System

Ambient air is circulated over a system of refrigeration coils. The surface temperature of these coils is set at a temperature considerably lower than that of the dew point of the incoming ambient air. The air chills, reaches saturation, and condensation occurs.

This condensation is collected and pumped out of the system. The air exits the cooling coil section of the dehumidifier at a reduced temperature, but more important, with lower dew point and humidity. Low-temperature air then can be adjusted simply by adding (dry) heat to the air stream based on the particular application requirements.

This method is advantageous when the air is comparatively warm with a high moisture content, and the outlet dew point is above 0°C (32°F), but is less effective as temperatures and humidity levels decrease in the winter months or in northern climates. In some cases, the cooling coil may freeze, reducing the efficiency of the dehumidifier to zero because the ice effectively insulates the coil.

Frequently, refrigeration is used in combination with adsorption dehumidifiers to obtain an extremely low dew point at a low cost.

Refrigeration is often used in combination with absorption and adsorption dehumidifiers.

Desiccants

Desiccants are substances that naturally have a high affinity for water, so high they can draw moisture directly from the surrounding environment. Desiccants absorb moisture until they are saturated; then they must be regenerated by a heated air stream or by a chemical process.

Most desiccants are solids in their normal state, though there are some liquid desiccants, such as common sulfuric acid (used in the chemical manufacturing industry),

lithium chloride, or polymeric materials, such as triethylene glycol. These liquid materials are called *absorbent desiccants*.

Desiccants in solid form are called *adsorbent desiccants*. Moisture is adsorbed onto the surface of a granular material, such as silica gel, which is capable of holding large quantities of moisture. These materials also can be dried easily and removed and recycled for further use.

For the coating industry, the rotating-bed silica gel adsorbent dehumidifiers are most prevalent. The solid desiccant is put into a large rotating drum or wheel (10 to 12 revolutions per hour) that contains structured air contact media in the form of a honeycomb.

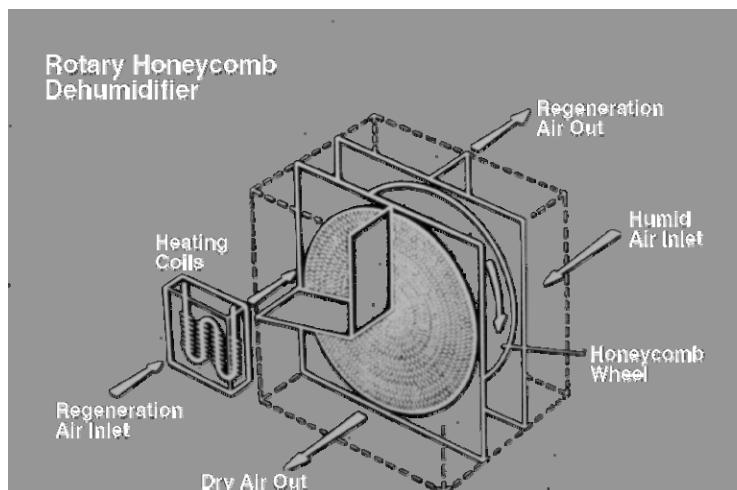


Figure 3.6: Rotary Honeycomb Dehumidifier

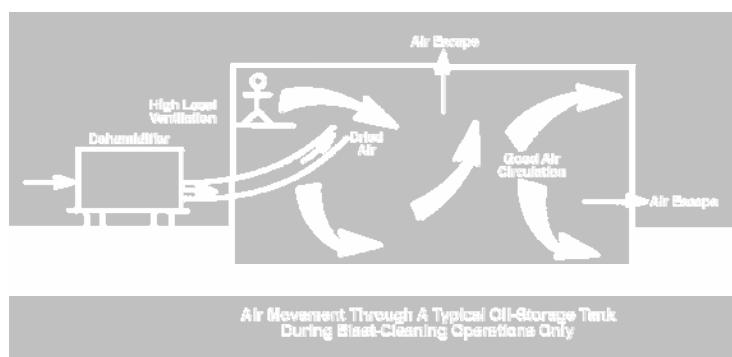


Figure 3.7: Air Movement Using Dehumidification

Process air (i.e., the air that is to be dried and introduced into the area where blasting and coating is taking place), passes through the open flutes in the media and releases its moisture to the silica gel desiccant contained in the media walls.



Figure 3.8: Dehumidification in Tank

The moist media then rotates into a separate compartment, passing through a hot reactivation (regeneration) air stream, which removes the moisture from the silica gel. The process air and reactivation air streams are separated by a partition.

The portion of the honeycomb where the moisture has been removed is exposed again to the process air stream to adsorb more moisture. This is a closed-loop continuous process, and it can operate automatically with little or no manpower required for its operation.

Some weak points need to be considered:

- If the heat source for the reactivation air stream is interrupted, the honeycomb will continue to operate and the silica gel desiccant will become saturated with adsorbed moisture. At this point, the unit becomes an air handler and ceases to function as a dehumidifier. Frequent checks should be made to ensure the reactivation air stream is fully operable.

- As a result of the heated air reactivation process, the drum (wheel) becomes heated; and this heat energy is transferred to the process air stream and the air itself becomes heated. The normal operating temperature increase is +28°C (50°F), which means, for 27°C (80°F) ambient temperature, the process air stream outlet air temperature would be about 55°C (130°F). This temperature would create an unacceptable working environment in summer time; therefore, a refrigeration chiller must be installed downstream of the honeycomb, in the process air stream, to reduce the temperature to suitable levels.
- Large volumes of process air may be moved, so care must be taken to prevent the silica gel from becoming contaminated with dirt, blasting dust, solvent vapors, or oil fumes. Once the silica gel is contaminated, it will no longer adsorb moisture.

This protection can be accomplished by the installation and frequent change of filter media on both the process air and reactivation air inlets in the dehumidification unit.

Benefits of Dehumidification to the Coating Contractor

Contractors can use dehumidification to dry the air (reduce dew point) in a tank, blast the entire surface, hold the blast with dry air, clean the surface (i.e., remove the abrasive and dust), and then apply the coatings. Additional benefits include:

- Crews can start earlier in the day and work later.
- Contamination of previously applied coatings by the blasting operation can be eliminated.
- Overlaps from one coated surface onto another (in the daily blast-then-coat routine) are eliminated.
- If more than one coat is applied, then all can be done in ideal conditions.

- Extended over-coating intervals can be avoided.
- Contractor can guarantee, with reasonable accuracy, when the job will be completed.
- Dehumidification extends the coating season in some areas by many months.
- The contractor can control ambient conditions and not be a victim of weather and atmospheric changes.

Dehumidification During Post-Application Curing

The problem of low-solvent evaporation in high-humidity environments was mentioned earlier. Dehumidification equipment should be used whenever possible through the curing period to ensure a complete solvent release from the applied coating.

Typical solvents used in coatings are heavier than air, and they tend to settle to the bottom of a structure, tank, etc., and saturate the air. Once the air at the boundary layer next to the coating becomes saturated, evaporation is retarded or stopped. When this occurs, solvent will remain in the film during curing. The only way to prevent this situation is with constant ventilation of the solvent-laden air during the coating operations.

If the make-up air is already at 85% relative humidity or greater, solvent evaporation will not improve or may be retarded. Ideally, the make-up air should be dehumidified air to enhance the amount of solvent, which can be removed per cubic foot of make-up air. The more air which can be dried (50% relative humidity, or less), the more solvent can be evaporated from the applied coating with the same volume of ventilation air.

Post-application ventilation and dehumidification processes should be routinely monitored by the inspector and all parameters recorded in the daily records. Documenting these processes will ensure that a suitable coating application and cure period is maintained.

Dehumidification

Applications

Dehumidification equipment commonly is used in the coatings industry for tank-lining projects in adverse weather conditions. The ambient atmosphere in the tank can be controlled throughout the project. It is not uncommon to allow blast cleaned steel to stand for days, or even weeks before coating, provided low relative humidity can be maintained. The prudent applicator will keep a standby dehumidifier on site because any equipment failure may result in the loss of days of surface preparation work, particularly if the equipment fails at night and the problem is not found until the following day.

Buried tanks are particularly appropriate for the dehumidification process because of the high-insulation factor of the surrounding earth. Blasting and painting ships' ballast tanks or cargo tanks are other common applications.

Dehumidification equipment can be helpful in tropical climates throughout the year, provided it is sufficiently powerful to cope with sometimes extremely high temperatures and moisture levels.



Level 2

Chapter 4

Centrifugal Wheel Blast

Cleaning

Centrifugal Wheel Blast Cleaning

Introduction

Centrifugal blast cleaning, or *wheel blasting*, is used in a variety of cleaning, finishing, and peening operations. The coating inspector generally will be most concerned with such blast cleaning operations in:

- Shop operations, where a variety of steel plates, pipes, and fabricated pieces are cleaned.
- Field operations, where new or used large, flat concrete or steel surfaces are cleaned.



Figure 4.1: Centrifugal Blast Cabinet for Pipe



Figure 4.2: Portable Wheel Blast Unit

Basic Elements of the Blast System

Although configurations may vary somewhat from machine to machine, generally, centrifugal blast systems are composed of the following:

- The heart of the system, the centrifugal abrasive throwing wheel, which throws the abrasive in a controlled pattern against the work to be cleaned
- The blast cabinet (enclosure), which confines the abrasive as it is thrown from the wheel and prevents the fines and dust generated by the blast from escaping
- In fixed systems, some type of material handling system which conveys the work piece to the wheel(s)
- The abrasive recycling system, which separates and returns the good abrasive to a storage hopper for reuse through the wheel
- A dust collector and vent-pipe system for ventilating the blast cabinet and operating the air-wash separator
- Abrasives of the proper type, size, and mix for the job to be done

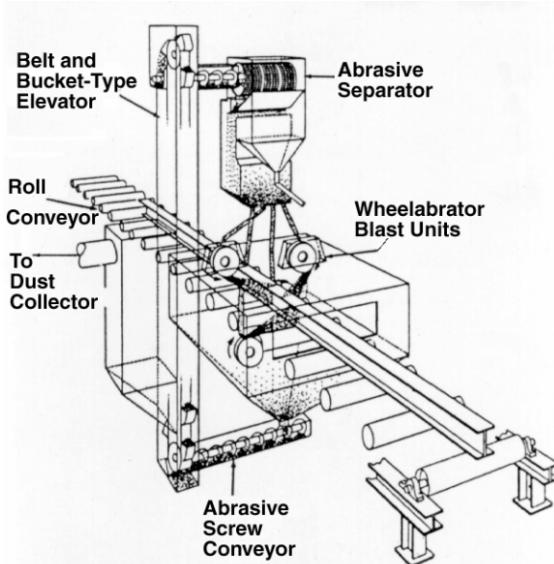


Figure 4.3: Blast Cleaning System

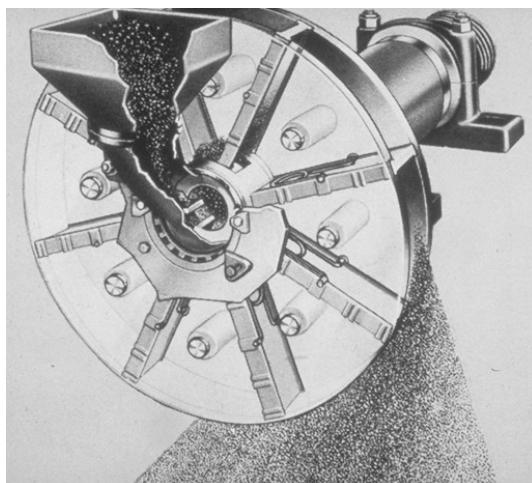


Figure 4.4: Centrifugal Blast Wheel

Basic Operating Principles

In the simplest terms, the centrifugal blast system operates as follows:

- Abrasive flows by gravity from an overhead storage hopper through a feed spout and into a rotating impeller.
- The quantity of the flowing abrasive is controlled by metering valves in the supply line.

- The impeller directs the abrasive through an opening in the impeller case onto the rotating vanes of the blast wheel.
- The motor-driven wheel throws the abrasive by centrifugal force against the work piece.
- After striking the work piece, the abrasive falls into a recovery hopper along with such contaminants as sand, scale, old coatings, etc., which have been removed from the work piece being cleaned.
- The abrasive-handling system lifts the contaminated abrasive up into the air wash separator above the blast machine.
- The air-wash separator removes the contaminants and any abrasive particles that have become too small to be useful.
- The cleaned and sized abrasive is returned to the storage hopper for reuse, completing the cycle.

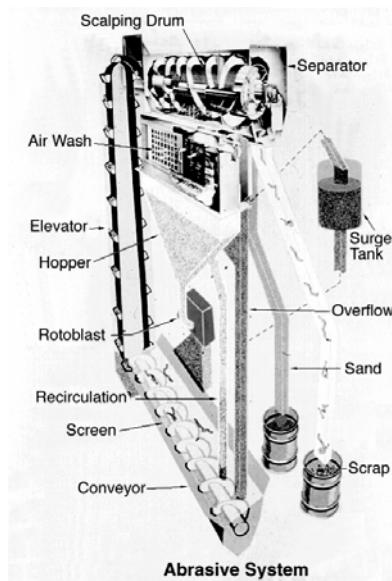


Figure 4.5: Abrasive System

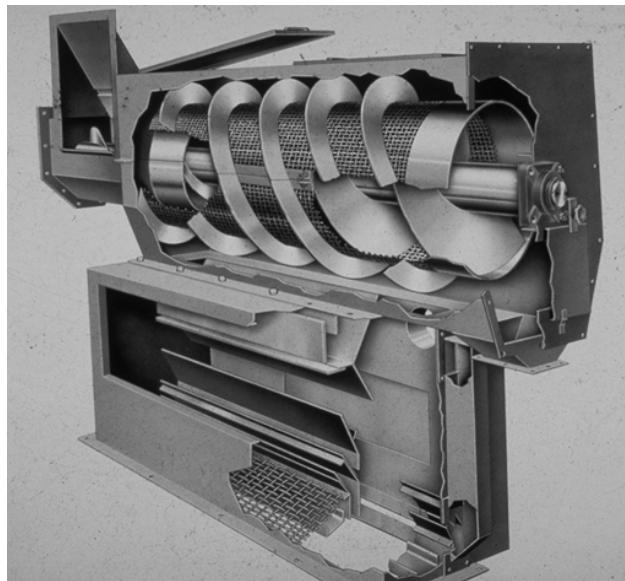


Figure 4.6: Scalping Drum over Abrasive Separator

Air-Wash Separator

Medium- or large-capacity units for descaling operations are usually equipped with a distributing screw above the air-wash separator, which evenly distributes the abrasive mixture along the entire length of the separator lip.

For foundry applications with coarse scrap or core wires in the abrasive mixture, the separator may be fitted with both a distributing screw and a scalping drum. The drum, fitted with an internal screw, provides an additional screening process for removal of scrap, while the external screw gives total distribution along the separator lip.

The functions of the separator are:

- To control the sizing of the abrasive mix, which influences cleaning efficiency.
- To remove sand, spent abrasives (fines), rust, dirt, and any other contaminants from the abrasive stream so that only good, clean abrasive is fed to the blast machine.
- To control abrasive consumption, which can be measured by the size of abrasive pellets removed from the machine.

Most separators are equipped with secondary skimmer plates, which direct some of the abrasive mixture for recirculation and permit only clean abrasive to pass to the feed hopper.

In operations, the abrasive mixture flows by gravity over the separator lip. High-velocity air flow pulls the falling mix inward, where stationary and adjustable skimmer plates skim off the contaminants which are diverted to a collector. A final screen tray protects the blast wheel from large foreign objects, and airborne contaminants are exhausted to a dust collection system.

An adjustable metering gate is designed to prevent contaminant overloads from entering the air wash during periods of surge. If a surge should occur, the separator's overload bypass system removes and recycles the contaminated abrasive before it can enter the air wash.

A properly functioning separator assures that good, clean, properly sized abrasives fall into the hopper, ready for use.

A wheel blast machine cleans best when there is a range of abrasive sizes. The largest abrasive size in the mix will be that of the newly added abrasive, with others varying down to the discard point for the particular application or finish required.

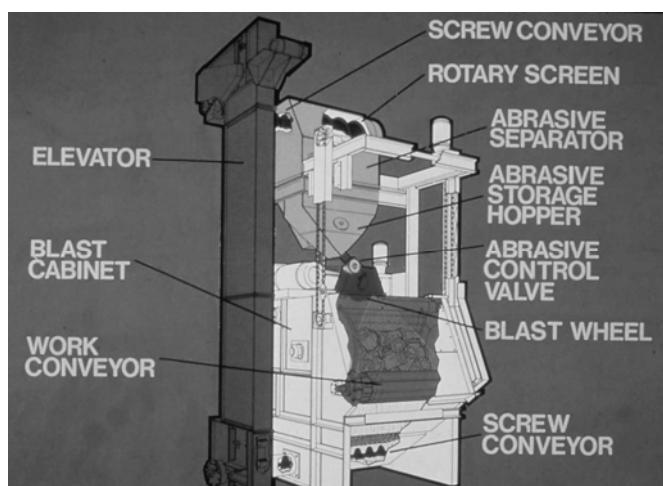


Figure 4.7: Abrasive Handling System

The largest particles are used to impact the surfaces of the work piece, loosening sand or scale and other contaminants. The smaller particles clean the irregularities in the work piece and provide additional coverage.

The coating inspector may be required to periodically perform or monitor a sample screen test to check the efficiency of the separator and to see that the abrasive operating mix is maintained.

Samples of the abrasive may be taken:

- From the abrasive curtain in the separator before air wash and skimmer plate.
- To check the fine refuse, the inspector should take samples from the exit side of the fines refuse pipe, never from the fines refuse receptacle, since this abrasive could be contaminated.
- To check the dry-dust collector for good abrasive, the inspector should open the hopper gate closest to the inlet/duct and allow about 19 L (5 gal) to flow, forming a cone. Samples should be taken from the sides of the cone, never from the top or bottom of the cone. The results of random screen checks will determine the adjustments to the abrasive handling system, including air flow necessary to maintain the proper operating abrasive mix.

Advantages of centrifugal blast cleaning are:

- Dust and fines from the blast operation are contained and held for easy disposal.
- Abrasive is easily recycled.
- In some shops, the process of blasting and priming can be handled with an in-line operation.
- In general, centrifugal blast cleaning is more economical compared with air or nozzle blast cleaning.



- Air compressors, piping, and air-control equipment are not needed for the actual wheel blast operation.

Disadvantages of centrifugal blast cleaning include:

- The initial cost of shop equipment is relatively high.
- The equipment is mechanically complex, with high wear on the moving parts.
- Surface contaminants may be driven into the work piece, particularly when steel shot is used.
- It may be difficult to completely clean complex fabricated shapes.

Components of the Blast System

Blast Wheel

The wheel design may vary with the individual manufacturer; however, they all function in the same manner, as described below:

- The AC- or DC-motor-driven wheel, fitted with adjustable, removable vanes, hurls the abrasive by centrifugal force onto the surface of the work piece.
- Abrasive from an overhead hopper is fed to the center of the wheel unit, which is rotating at high speed.
- A cast-alloy impeller rotates with the wheel, imparts initial velocity to the abrasive particles, and carries the abrasive to an opening in the stationary cage from which it is discharged onto the wheel vanes.
- The abrasive is picked up by the inner ends of the vanes and is rapidly accelerated as it moves to the outside edge of the wheel and onto the surface of the work piece.

The location of the opening at the edge of the control cage establishes the direction of the blast pattern



generated by the wheel. As little as 10% misalignment of the pattern location can reduce cleaning efficiency by 25% or more.

Efficiency of the Wheel

Because the wheels are central to proper functioning of the wheel blast unit, they must be properly adjusted and maintained. The efficiency of the wheel(s), however, depends upon other factors, including:

- Abrasive operating mix
- Size of the abrasive
- Velocity of the abrasive coming off the wheel
- Quantity and direction of the thrown abrasive
- Condition of the feed parts (feed spout, impeller, impeller case, and vanes)

Ammeter as a Performance Guide

The quantity of the abrasive being thrown by the wheel is determined with an ammeter, which shows the loading on the drive motor. The difference between the “no-load” amperage reading and “full-load” amperage reading equals 100% of the throwing capacity of the wheel. Most wheel units are designed to run at “full load amperage.”

Abrasive flow to the wheel can be adjusted to achieve maximum efficiency. As the amount of the abrasive being fed through the wheel increases, the ammeter reading goes up. The reading goes down as less abrasive is fed to the wheel.

For peak efficiency when blasting, the ammeter should indicate that a full-rated motor capacity is being used. An ammeter showing a reading of less than full load indicates a need for adjustment.

Low amperage readings could signify:

- An abrasive-starved wheel, one that does not pull full amperage because it does not receive enough abrasive.
- A flooded or choked wheel, one that is fed abrasive at too rapid a rate, thus choking the feed spout with abrasive.

Such factors as a worn impeller, worn impeller case, worn vanes, obstructions in the feed spout, etc., affect the amount of abrasive fed to the wheel, and, thus, can influence the efficiency of the wheel.

Targeting the Wheel for Proper Blast Pattern

Unless the thrown abrasive directly strikes the work, it cannot clean. Blasting efficiency is greatly affected by the percentage of abrasive thrown onto the work, which is determined primarily by the position of the impeller case.

The impeller case is a sleeve that fits around the impeller. The impeller is cast with blades resembling those on the blast wheel, although much smaller; and it is attached to the same drive shaft that powers the wheel. The impeller receives abrasive from the feed spout and propels it toward the vanes of the wheel. The abrasive feed supply to the vanes is controlled by the size and shape of the impeller case.

The concentrated area of blast is called the *hot spot*. A stationary piece of work or a target plate mounted in line with the blast will become hot when subjected to a blast for 30 seconds or longer.

To precisely target the abrasive, the operator can:

- Disengage the conveyor mechanism so a target plate can stay stationary.
- Install target plate and blast it for 30 seconds.

- Stop blast and locate hot spot on target plate.
- Adjust impeller clockwise or counter-clockwise as indicated by hot spot to achieve desired blast pattern.
- Remove target and re-engage conveyor.

Effects of Part Wear on Blast Pattern

- Wear on any one of the wheel elements, i.e., impeller vanes, impeller case, or wheel vanes, can move the hot spot and reduce efficiency of the wheel.
- Wear on the impeller case opening can alter the hot spot, because it allows more room for the abrasive to be thrown.
- Wear on the impeller case and vanes affects the location and size of the hot spot.
- Badly grooved or worn wheels can lead to wheel imbalance, resulting in a deteriorating blast pattern and the reduction of machine efficiency.
- If the blast stream is not directly on the work, unnecessary wear to machine components will result.

Abrasives

The abrasive blast machine cleans best with use of a range of abrasive. The largest particle size will be that of the newly added abrasive. The smallest particle size is determined by filter meshes in the recycling equipment.

Large particles impact the surface to loosen scale, sand, etc., and the smaller particles clean small irregularities and scour the surface, removing loosened particles so the work is thoroughly and uniformly cleaned.

Maintaining a well-balanced operating mix (sometimes called a *working mix*) of various size abrasives will:

- Provide consistency of finish on work being cleaned.

- Ensure uniform abrasive coverage of the work.
- Ensure conditioning of the abrasive for optimum cleaning.
- Minimize lowest abrasive and machine part-wear and reduce downtime for maintenance.

A periodic sieve analysis conducted on the abrasive can assist the operator and inspector to maintain the proper operating mix.

Abrasive Selection

Wheel blast operations make use of a wide variety of blast media, including agricultural products and synthetic products such as glass beads, aluminum oxide, and slags. However, steel shot and grit are used most commonly in preparing steel and concrete for coating.

The work to be cleaned and the desired finish determine the use of steel shot or grit.

Steel shot may be the best blast cleaning, peening, or descaling abrasive available. Shot breaks up heat treat and such scales as mill scale, or will wear sand away from castings. Because of its toughness and ideal hardness (44 to 46 Rockwell c [Rc]), steel shot does not fracture readily. Shot is round when new and, after fracturing, again balls up to a round shape after repeated impacts.

Steel grit is best for etching, i.e., creating surface profile prior to painting or plating, or for cleaning hard alloys, brightening nonferrous parts, for mill rolls or heat-treated parts, or any application where a roughened grit blast surface is required or desired. Angular steel grit can range in hardness from 45 to 65 Rc.

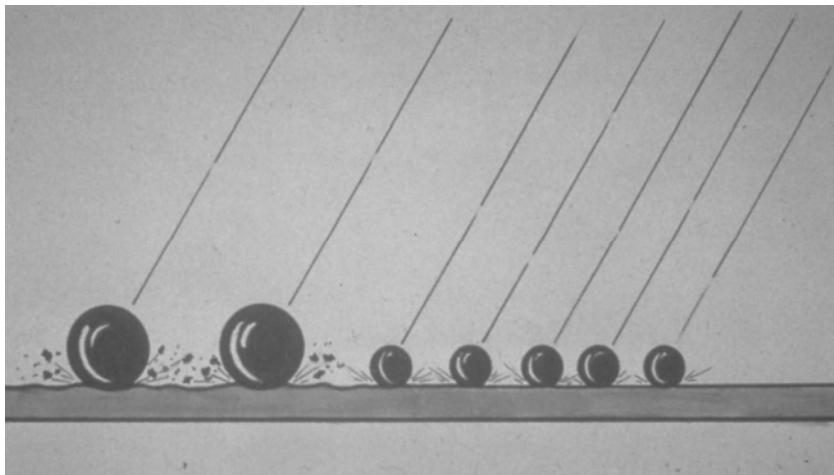


Figure 4.8: Steel Shot Impacting Surface

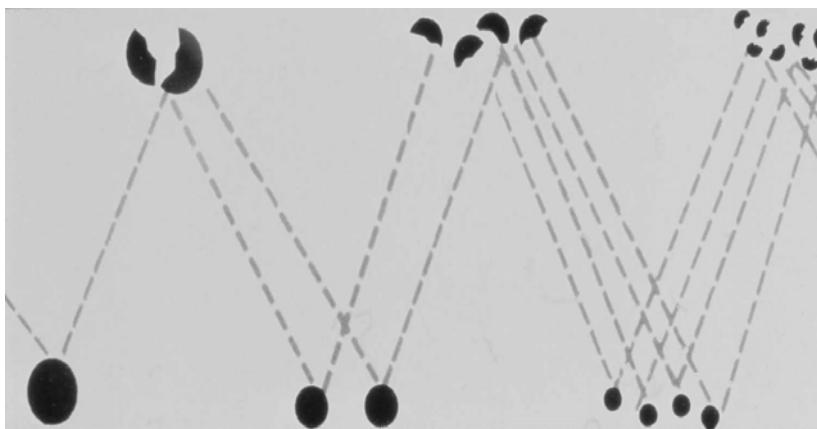


Figure 4.9: Steel Shot Breaking Up then Rounding Up

Because steel shot tends to peen, rather than scour, the surface, an operating mix of shot and grit frequently is used to achieve greater cleanliness and surface profile.

Steel grit often is substituted for shot. Medium-hardness grits are used to obtain a sharper etch on the steel surface, or for removing tenacious scale from alloy steels. Brittleness of the abrasive increases the hardness so the harder grits fracture readily, retain angularity, and result in higher abrasive consumption and wear of machine parts.

Ferrous abrasives may leave trace amounts of metal on the substrate and should not be used on substrates on which they could induce corrosion. For example, if a

stainless steel substrate is blast cleaned with an iron or steel abrasive, the stainless steel may corrode due to the loss of passivation, as shown in the video *Corrosion in Action*, viewed earlier.

Abrasive Replenishment

Abrasive wear creates a finer particle size, and the desirable operating mix will be maintained if the mix is replenished frequently with small amounts of the coarsest abrasive used in the machine.

Replenishment can be done by an automatic replenisher or by hand. If the mix is replenished by hand, make regular additions in small quantities to avoid upsetting the balance of sizes in the mix.

The abrasive supply should not become so low that large additions of new material drastically alter the wheel pattern, cleaning speed, abrasive consumption, or resulting finish.

Abrasive consumption is determined by the size of abrasive being removed by the separator, not the purchased size of abrasive. Normally the separation is adjusted to retain abrasive particles five sizes smaller than the purchased size.

Wheel Blast Shop Systems

Wheel blast shop systems, equipment, and applications differ mainly in the means by which the work is conveyed through the blast and in the type of abrasive used.

Although the combinations of machine types and applications are almost innumerable, there are several general basic setups, including:

- Tumbling mill
- Multi-table



- Plain table, which generally has been replaced by multi-table and swing-table machines
- Swing table
- Custom-designed systems for continuous high-volume production cleaning of steel plate, fabricated beams, rolled shapes, rods, piping, etc.

Tumbling Mill

These systems usually are used for batch load cleaning of parts. The wheel units normally are mounted on the roof of the cabinet for blast cleaning of parts as they tumble in the mill. Various sizes of machines are available for handling from 0.06 m³ (2 ft³) up to 2.8 m³ (100 ft³) of parts per load. Cleaning and descaling castings, forgings, and heat-treated parts are common applications. Cleaning batch loads normally requires only 5 to 10 minutes, depending on the type of work. Steel shot or grit is normally the blasting media used.

Multi-Table

Multi-table machines have a series of independent revolving work tables mounted on a rotating platform or "spider." The individual tables rotate as they are moved beneath the blast of the abrasive-throwing wheel. Models are available with varying numbers and diameters of tables, depending on the size of the work to be cleaned. Multi-tables are used most commonly for relatively flat or fragile work not suitable for tumbling action.

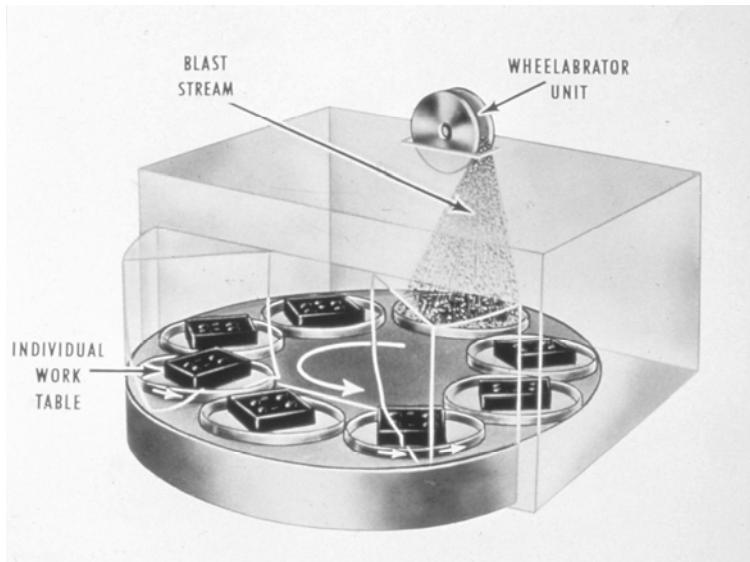


Figure 4.9: Multi-Table

Swing Table

Swing-table blast cleaning equipment offers a high degree of work-handling flexibility and can accommodate very large and heavy work pieces of up to 9,000 kg (10 tons). The work table, which rotates under the blast of one or more abrasive throwing wheels, swings out with the door as the door is opened, making the full table accessible for loading and unloading by fork-lift truck, chain hoist, or overhead crane.

Models available range in size from 1.2-m (4-ft) to 3.0-m (10-ft) diameter work tables. Double-door designs permit one load to be cleaned while the other work table is unloaded and reloaded for almost continuous production cleaning.

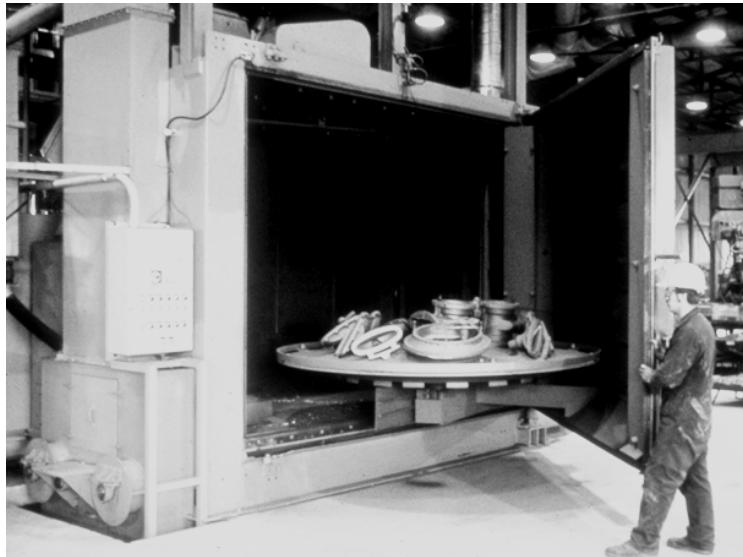


Figure 4.10: Swing Table

Custom-Designed Systems

A wide variety of semi-standard and special automated blast cleaning machines include spinner hanger, monorail, shot peening, straight and skewed roll conveyor, traveling work car, and continuous tumbling mills.

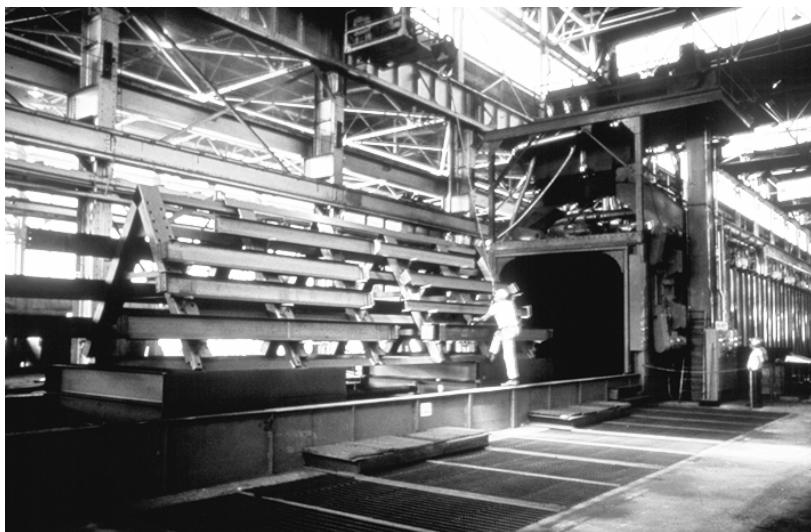


Figure 4.11: Custom System for I Beams

Some of the largest machines ever built are used to clean massive fabricated ship subsections. One such installation

utilizes 40 centrifugal wheels that propel a total of about 13,600 kg (30,000 lb) of abrasive per minute.

Railroad cars are cleaned in enclosed rooms during new construction as well as during refurbishing and repainting. Blast cleaning in such cases is accomplished with as many as twenty centrifugal wheel units.

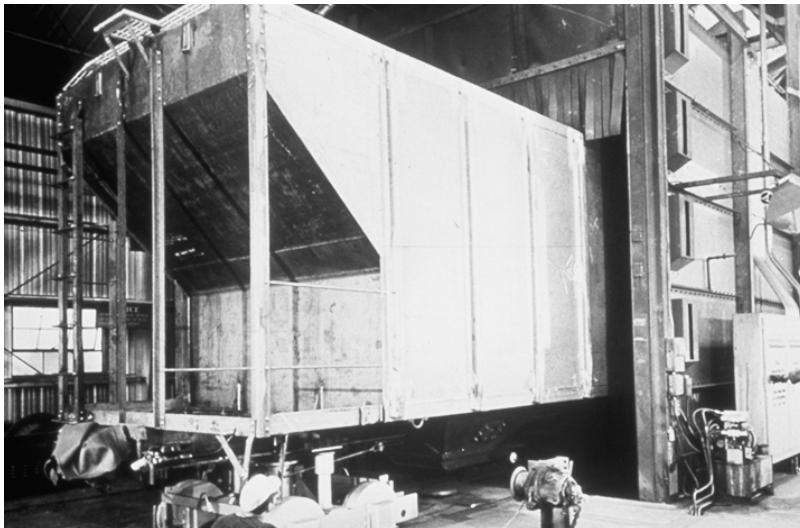


Figure 4.12: Custom System for Rail Car

Automated wheel blast systems are available for all types of hot-rolled bar stock, wire-rod castings, hot-rolled steel strip, plate and structurals, and for fabricated components and weldments to be coated.

Four-wheel conveyor systems commonly are used for prefabrication cleaning of plate and rolled structural shapes. Larger machines, with a variety of work conveyor systems and typically using eight wheels, may be used for post-fabrication cleaning of large trusses, girders, and other large structural parts.

In these machines, batches of small parts, such as gusset plates, weldments, etc., often are loaded into baskets which are placed on the conveyor rolls, or in the larger machine, perhaps suspended from overhead crane hooks, so that numerous and varied shapes of work may be cleaned. Larger parts may be hung on special racks and cleaned in batches.

Portable Wheel Blast Cleaning Systems

Portable wheel blast equipment permits on-site wheel blast cleaning during new construction and maintenance of steel, concrete, and wood surfaces which includes:

- Ship decks, hull sides, and bottoms
- Storage tanks
- Concrete floors
- Highways and bridge decks

In these systems the abrasive is recycled, and the material removed from the surface and the dust generated by the blast is collected for subsequent disposal.

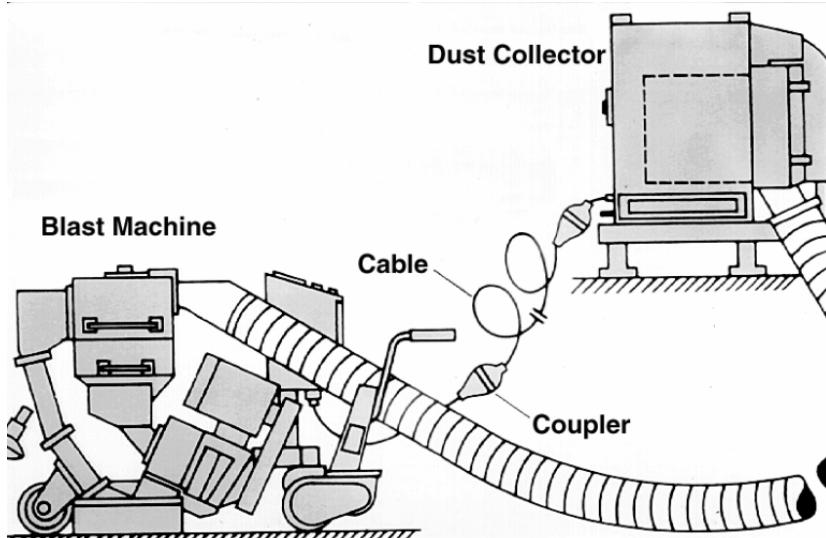


Figure 4.13: Portable Blast Unit

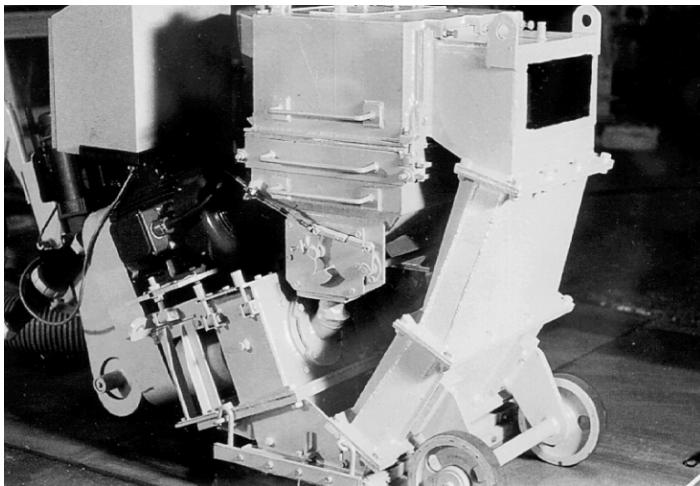


Figure 4.14: Portable Blast Unit

Wheel Blast Inspection

Pre-Cleaning

Snow, ice, and standing pools of water are removed from work pieces before blast cleaning. Likewise, oil, grease, and dirt must be removed from the work piece before blasting to prevent contaminating the abrasive.

Additional Tests

Tests for anchor pattern, contamination, and abrasive residue are conducted in the same way as those for air or abrasive blast cleaned steel with sand or other abrasives. This information may be found in Level 1 materials.

Durasteel Shot

“Q” Shot

“Malla-Q” Shot

“Super-Q” Shot

S.A.E. Shot Specifications

S.A.E. Shot Number	Max. % retained	Screen number and aperture	Max. % retained	Screen number and aperture	Min. % retained	Screen number and aperture	Max. % retained	Screen number and aperture	Max. % to pass
S-1320	0	4 (0.187)	-	-	90	6 (0.132)	7	7 (0.111)	3
S-1110	0	5 (0.157)	-	-	90	7 (0.111)	7	8 (0.0937)	3
S-930	0	6 (0.132)	-	-	90	8 (0.0937)	7	10 (0.0787)	3
S-780	0	7 (0.111)	-	-	85	10 (0.0787)	12	12 (0.0661)	3
S-660	0	8 (0.0937)	-	-	85	12 (0.0661)	12	14 (0.0555)	3
S-550	0	10 (0.0787)	-	-	85	14 (0.0555)	12	16 (0.0469)	3
S-460	0	10 (0.0787)	5	12 (0.0661)	85	16 (0.0469)	11	18 (0.0394)	4
S-390	0	12 (0.0661)	5	14 (0.0555)	85	18 (0.0394)	11	20 (0.0331)	4
S-330	0	14 (0.0555)	5	16 (0.469)	85	20 (0.0331)	11	25 (0.0280)	4
S-280	0	16 (0.0469)	5	18 (0.0394)	85	25 (0.0280)	11	30 (0.0232)	4
S-230	0	18 (0.0394)	10	20 (0.0331)	75	30 (0.0232)	12	40 (0.0165)	3
S-170	0	20 (0.0331)	10	25 (0.028)	75	40 (0.0165)	12	50 (0.0117)	3
S-110	0	30 (0.0232)	10	35 (0.0197)	70	50 (0.0117)	10	80 (0.007)	10
S-70	0	40 (0.0165)	10	45 (0.0138)	70	80 (0.007)	10	120 (0.0049)	10

Durasteel Shot**“Q” Shot****“Malla-Q” Shot****“Super-Q” Shot****S.A.E. Shot Specifications**

S.A.E. Grit Number	MAX. LIMIT SCREEN		NOMINAL SCREEN		MIN. LIMIT SCREEN	
	Max. Grit retained %	Screen number and aperature	Min. Grit retained %	Screen number and aperature	Max. Grit to pass %	Screen number and aperature
G-10	0	7 (0.111)	80	10 (0.0787)	10	12 (0.0661)
G-12	0	8 (0.937)	80	12 (0.0661)	10	14 (0.0555)
G-14	0	10 (0.0787)	80	14 (0.0555)	10	16 (0.0469)
G-16	0	12 (0.0661)	75	16 (0.0469)	15	18 (0.0394)
G-18	0	14 (0.0555)	75	18 (0.0394)	15	25 (0.0280)
G-25	0	16 (0.0469)	70	25 (0.0280)	20	40 (0.0165)
G-40	0	18 (0.0394)	70	40 (0.0165)	20	50 (0.0117)
G-50	0	25 (0.0280)	65	50 (0.0117)	25	80 (0.0070)
G-80	0	40 (0.0165)	65	80 (0.0070)	25	120 (0.0049)
G-120	0	50 (0.0117)	60	120 (0.0049)	30	200 (0.0029)
G-200	0	80 (0.0070)	55	200 (0.0029)	35	325 (0.0017)
G-325	0	120 (0.0049)	20	325 (0.0017)	-	-

Test for Oil and Grease Contamination on Metallic Abrasives

Often centrifugal blasting is performed on a contract basis by operators blasting and priming steelwork for various clients. In these cases, the objects to be blasted are not always rigorously inspected for freedom from oil and grease prior to blasting. This can cause the abrasive to become contaminated with oil or grease. Because the oil or grease is spread as a thin film on the metallic abrasive, it will adhere to the metal surface and cannot be determined with the "Vial Test."

Test Procedure

A solvent test is necessary to remove the thin film of oil or grease from the metallic abrasive surface.

A representative sample of the metallic abrasive of about 0.23 kg (1/2 lb) is placed in a clean glass or metal container. The abrasive is then covered with a chlorinated hydrocarbon solvent, 1.1.1. trichloroethane¹ (NOT trichlorethylene). This is the best solvent for oil or grease, and has a rapid evaporation rate, which is important. This solvent is used to dry clean clothing and is sold as a solvent for removing grease spots from clothing. It is sometimes sold diluted with mineral spirits, which retards the evaporation rate.

After the solvent has been in contact with the abrasive for three to four minutes, it should be decanted into a clean shallow container such as a saucer; this gives a larger area for evaporation. If the metallic abrasive is contaminated with finely dispersed rust, etc., it may be necessary to filter the solvent during the decantation

¹ 1.1.1 Trichlorethane is the correct IUPAC (International Union of Pure and Applied Chemistry) name for this liquid, which has a formula of CH_3CCl_3 . It is the only chlorinated hydrocarbon solvent considered safe for normal use.

process by passing it through a paper towel or other paper filter.

The solvent should remain in the shallow container until the residual volume is under about 7 to 8 ml (0.25 to 0.27 fl. oz). With unadulterated 1.1.1 trichlorethane, this should not take much longer than about five minutes.

This remaining liquid should be poured onto a clean glass surface (a mirror is best). In a short time, all the solvent will evaporate and the oil or grease will be seen as a residual deposit on the surface of the mirror.

- Blank Test

Before this test is conducted, it is very important to conduct a “Blank” test on the solvent. This involves conducting the test without any metallic abrasive and allowing the solvent to be reduced in volume before pouring onto the mirror.

Note: In conducting this “blank” test, it is NOT acceptable to just test a few drops of the solvent. The solvent must be reduced in volume by evaporation!



Level 2

Chapter 5

Waterjetting

Waterjetting

Introduction

Dry abrasive blasting is one of the most commonly used methods of surface preparation because:

- It is fast and economical; and
- Most coating users want to see a definite etch or surface profile.



Figure 5.1: Dry Abrasive Blasting

Surface preparation standards initially were written, and visual standards adopted, based on sand as the abrasive. Ancillary visual standards have been based on the use of:

- Other nonmetallics, such as garnet, copper slag, nickel slag, coal slag, or olivine sand.

- Metallics, including steel shot, steel grit, or a combination of the two.

There are some problems associated with dry abrasive blasting. In the case of sand, health problems include silicosis, which is caused by breathing silica.

In general with abrasive blasting the resultant flying abrasive particles and drifting dust may damage sensitive rotary equipment and clog filters, damaging instruments and metering devices, or contaminate the environment.



Figure 5.2: Abrasive Dust in Air

Dry abrasive blasting also may trap contaminants on the surface of the substrate being cleaned.

Current government regulations require certain safety equipment, which includes respirators, for workers in the vicinity of open-air abrasive blasting and, in the case of lead removal, total containment.

Under the continuing influence of government regulations, the coatings industry is working to develop environmentally sensitive and user-friendly methods of surface preparation. In more recent years, the use of waterjetting has been found to be a viable method of surface preparation. As a result, NACE and SSPC have developed and published a joint surface preparation standard, NACE No. 5/SSPC-SP 12, *Surface Preparation and Cleaning of Metals by Waterjetting Prior to Recoating*.

This standard was revised in July 2002.

The committee that drafted the standard has prepared visual standards for steel surfaces prepared by high- and ultrahigh-pressure waterjetting. These visual standards are available as NACE VIS 7/SSPC-VIS 4, *Guide and Reference Photographs for Steel Surface Preparation by Waterjetting*. Much of the information presented here is excerpted from the joint NACE No. 5/SSPC-SP 12 standard as revised. This standard provides color photographs for the various grades of surface preparation as a function of the initial condition of the steel. The latest issue of the reference photographs should be used.

Waterjetting Defined

Waterjetting is the use of a high-energy water stream to strip off existing coatings and to clean surfaces. This method has certain advantages over dry abrasive blasting, especially with respect to worker safety and worker air quality. With waterjetting, respiratory requirements may be less stringent than those for other methods of surface preparation.



**Figure 5.3: Operator Waterjetting on Steel Surface—
Note PPE**

Waterjetting uses water only, without the addition of solid particles such as sand or garnet in the water stream, with operating pressures up to 414 MPa (60,000 psig).

However, as technology and equipment develops, higher pressures may be used. This method of cleaning is particularly suited to the process industry, power plants, and other plants where high-performance coatings require extensive surface preparation and/or surface decontamination, and is widely used in the marine industry for removal of marine growth and preparation of tank/hold interiors.

Waterjetting is effective for removing:

- Surface oil and grease
- Rust
- Concrete (shotcrete) spatter
- Existing coatings
- Deleterious amounts of water-soluble contaminants that cannot otherwise be removed by abrasive blasting alone, especially in the bottom of pits, cracks, crevices, and craters in corroded metallic substrates such as steel.



Figure 5.4: Waterjetting on Tank

Waterjetting does not produce an etch or profile as abrasive blasting does; rather, it exposes the original abrasive-blasted surface profile. Therefore, waterjetting

generally is used on coating and lining projects where the substrate has an adequate preexisting profile.

To be an effective cleaning medium, the water used for waterjetting should be pure so it does not contaminate the surface being cleaned. To avoid damage to the equipment, the water should be free of such solid particles as sediment. For example, drinking-quality water used for 240 MPa (35,000 psig) waterjetting equipment is generally filtered through 5 μm or smaller filters.

To better appreciate waterjetting as a method of surface preparation and for those using the new NACE/SSPC standard, it is necessary to introduce some definitions and descriptions of *surface cleanliness*.

Definitions

Waterjetting (WJ) is the use of standard jetting water discharged from a nozzle at pressures of 70 MPa (10,000 psig) or greater to prepare a surface for coating or inspection. Waterjetting uses a pressurized stream of water with a velocity that is greater than 340 m/s (1,100 ft/s) when exiting the orifice. Waterjetting does not produce an etch or profile of the magnitude currently recognized by the coatings industry. Rather, it exposes the original abrasive blasted surface profile if one exists.

Water Cleaning (WC): Use of pressurized water discharged from a nozzle to remove unwanted matter from a surface.

Standard Jetting Water: Water of sufficient purity and quality that it does not impose additional contaminants on the surface being cleaned and does not contain sediments or other impurities that are destructive to the proper functioning of waterjetting equipment.

In comparing water *cleaning* with *waterjetting*, these definitions apply:

Low-Pressure Water Cleaning (LP WC): Cleaning performed at pressures below 34 MPa (5,000 psig). This is also called “power washing” or “pressure washing.”

High-Pressure Water Cleaning (HP WC): Cleaning performed at pressures of 34 to 70 MPa (5,000 to 10,000 psig).

High-Pressure Waterjetting (HP WJ): Waterjetting performed at pressures from 70 to 210 MPa (10,000 to 30,000 psig).

Ultrahigh-Pressure Waterjetting (UHP WJ): Waterjetting performed at pressures above 210 MPa (30,000 psig).

Nonvisible Contamination (NV): Nonvisible contamination is the presence of organic matter, such as very thin films of oil and grease, and/or soluble ion materials such as chlorides, ferrous salts, and sulfates that remain on the substrate after cleaning.

Visible Surface Cleanliness (VC): Visible surface cleanliness is the visible condition of the substrate, when viewed without magnification, after cleaning.

The entire surface to be prepared for coating shall be subjected to the cleaning method.

Surface cleanliness conditions with waterjetting are defined in terms of:

- Visible contaminants: WJ-1 to WJ-4
- Nonvisible contaminants: NV-1 to NV-3

It would not be accurate or appropriate to try to make a direct correlation between dry abrasive blasting standards and the capabilities and results of waterjetting.

The joint NACE/SSPC standards for abrasive blast cleaning are complete and clearly define the surface conditions to be achieved. However, when writing specifications for surface preparation with waterjetting, the specifier should use one of the visual surface

preparation definitions (WJ-1 to WJ-4) and one of the non-visual surface preparation definitions (NV-1 to NV-3) to specify the degree of visible and nonvisible surface matter to be removed

Photographs may be specified to supplement the written definition. In any dispute, the written standards shall take precedence over visual reference photographs or visual standards such as NACE VIS 7/SSPC-VIS 4.

An example of such a specification statement would be: "All surfaces to be recoated shall be cleaned in accordance with NACE No. 5/SSPC-SP 12 WJ-2/NV-1. The method of HP WJ or UHP WJ ultimately selected by the contractor will be based on his confidence in the capabilities of the equipment and its components."

The specifier and contractor must agree on the test method to be used for determining the amount of nonvisible contaminants; and obviously, the coating manufacturer should be consulted to determine the coating's tolerance to the surface conditions after waterjetting, commensurate with the in-service conditions.

The following tables are reproduced from the joint standard NACE No. 5/SSPC-SP 12.

Table 1
Visual Surface Preparation Definitions

Term	Description of Surface
WJ-1 Clean to Bare Substrate.	A WJ-1 surface shall be cleaned to a finish which, when viewed without magnification, is free of all visible rust, dirt, previous coatings, mill scale, and foreign matter. Discoloration of the surface may be present. ^(A,B,C)
WJ-2 Very Thorough or Substantial Cleaning	A WJ-2 surface shall be cleaned to a matte (dull, mottled) finish which, when viewed without magnification, is free of all visible oil, grease, dirt, and rust except for randomly dispersed stains of rust, tightly adherent thin coatings, and other tightly adherent foreign matter. The staining or tightly adherent matter is limited to a maximum of 5% of the surface. ^(A,B,C)
WJ-3 Thorough Cleaning	A WJ-3 surface shall be cleaned to a matte (dull, mottled) finish which, when viewed without magnification, is free of all visible oil, grease, dirt, and rust except for randomly dispersed stains of rust, tightly adherent thin coatings, and other tightly adherent foreign matter. The staining or tightly adherent matter is limited to a maximum of 33% of the surface. ^(A,B,C)
WJ-4 Light Cleaning	A WJ-4 surface shall be cleaned to a finish which, when viewed without magnification, is free of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose coating. Any residual material shall be tightly adherent. ^(C)

^(A) NOTE: Surfaces cleaned by LP WC, HP WC, HP WJ, or UHP WJ do not exhibit the hue of a dry abrasive-blasted steel surface. After waterjetting, the matte finish color of clean steel surface immediately turns to a golden hue unless an inhibitor is used or environmental controls are employed. On older steel surfaces that have areas of coating and areas that are coating free, the matte finish color varies even though all visible surface material has been removed. Color variations in steel can range from light gray to dark brown/black.

Steel surfaces show variations in texture, shade, color, tone, pitting, flaking, and mill scale that should be considered during the cleaning process. Acceptable variations in appearance that do not affect surface cleanliness include variations caused by type of steel or other metals, original surface condition, thickness of the steel, weld metal, mill fabrication marks, heat treating, heat-affected zones, and differences in the initial abrasive-blast cleaning or in the waterjet cleaning pattern.

The gray or brown-to-black discoloration seen on corroded and pitted steel after waterjetting cannot be removed by further waterjetting. A brown-black discoloration of ferric oxide may remain as a tightly adherent thin film on corroded and pitted steel and is not considered part of the percentage staining.

^(B) Waterjetting at pressures in excess of 35,000 psig (240 MPa) is capable of removing tightly adherent mill scale, but production rates are not always cost effective.

^(C) Mill scale, rust, and coating are considered tightly adherent if they cannot be removed by lifting with a dull putty knife. (See NACE No. 4/SSPC-SP 7).



Table 2
Flash-Rusted Surface Definitions

Term	Description of Surface
No Flash Rust	A steel surface that, when viewed without magnification, exhibits no visible flash rust.
Light (L)	A surface that, when viewed without magnification, exhibits small quantities of a yellow-brown rust layer through which the steel substrate may be observed. The rust or discoloration may be evenly distributed or present in patches, but it is tightly adherent and not easily removed by lightly wiping with a cloth.
Moderate (M)	A surface that, when viewed without magnification, exhibits a layer of yellow-brown rust that obscures the original steel surface. The rust layer may be evenly distributed or present in patches, but it is reasonably well adherent and leaves light marks on a cloth that is lightly wiped over the surface.
Heavy (H)	A surface that, when viewed without magnification, exhibits a layer of heavy red-brown rust that hides the initial surface condition completely. The rust may be evenly distributed or present in patches, but the rust is loosely adherent, easily comes off, and leaves significant marks on a cloth that is lightly wiped over the surface.

Table 3
Description of Non-visible Surface Cleanliness Definitions (NV)

Term	Description of Surface
NV-1	An NV-1 surface shall be free of detectable levels of soluble contaminants, as verified by field or laboratory analysis using reliable, reproducible test methods.
NV-2	An NV-2 surface shall have less than $7 \mu\text{g}/\text{cm}^2$ (0.0007 grains/in. ²) of chloride contaminants, less than $10 \mu\text{g}/\text{cm}^2$ (0.001 grains/in. ²) of soluble ferrous ion levels, or less than $17 \mu\text{g}/\text{cm}^2$ (0.0017 grains/in. ²) of sulfate contaminants as verified by field or laboratory analysis using reliable, reproducible test methods.
NV-3	An NV-3 surface shall have less than $50 \mu\text{g}/\text{cm}^2$ (0.005 grains/in. ²) of chloride or sulfate contaminants as verified by field or laboratory analysis using reliable, reproducible test methods.

There are recommended test procedures for extracting and analyzing soluble ferrous salts, chlorides, and sulfate contaminants of surfaces to be cleaned and/or coated. Later in the week, certain test methods for determining the presence of and quantifying any existing soluble ferrous salts and chlorides will be discussed and demonstrated.

The coating inspector should obtain, read, and understand all requirements of the standard when called upon to inspect surface preparation performed by waterjetting.

Waterjetting Equipment and Operations

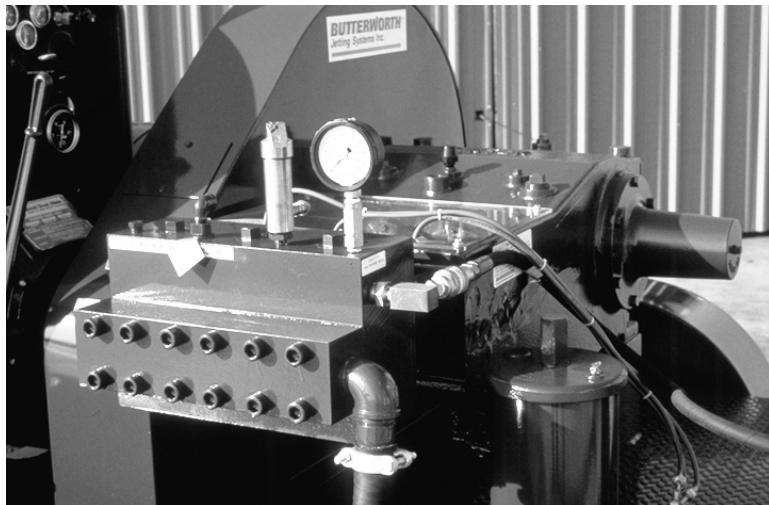


Figure 5.5: Waterjetting Unit

Introduction

The commercial waterjet unit can be skid-, trailer-, or truck-mounted and usually consists of pumps, hoses, a prime mover (diesel, electric, etc.), and various tools such as guns, nozzles, lances, etc.

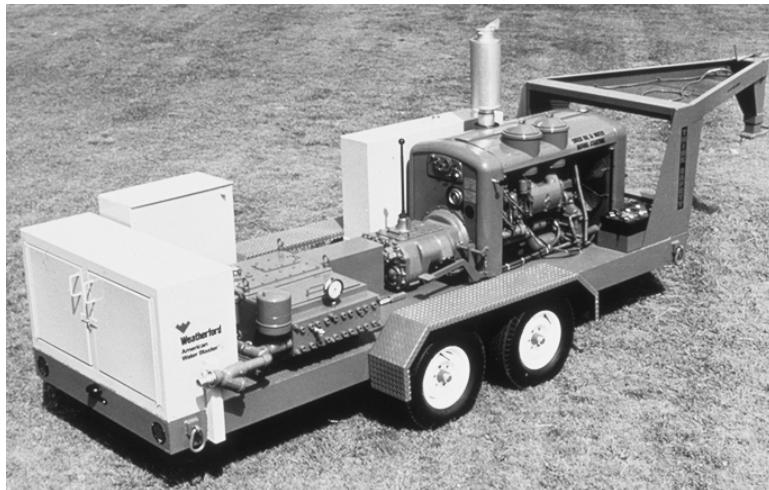


Figure 5.6: Trailer-Mounted Waterjetting Unit

- **Hoses**

The (high-pressure) hose, hose connections, and all other equipment, including the nozzle control valve, lance, and nozzle, should have a minimum burst strength of 2-1/2 times the capability of its maximum-rated operating strength.

The high-pressure hose is fitted with a safety device known as a *whiplock*, which is a short length of cable or wire looped over each end of two hoses connected by a coupling. The whiplock is designed to prevent the ends of the hose from whipping around if the coupling breaks.



Figure 5.7: Waterjetting Gun with Nozzle

The section of hose next to the gun is fitted with a hose shroud, which usually is a short length of heavy-duty hose placed over the high-pressure hose to provide

instantaneous protection if the hose bursts. A hose shroud also can be used over the hose connections. The shroud, however, will not form a permanent barrier to the flow of water from a damaged hose or broken connection.



Figure 5.8: Waterjetting Hand Gun



Figure 5.9: Waterjetting Gun (Two-Handed)



Figure 5.10: Waterjetting Unit Hose and Nozzle

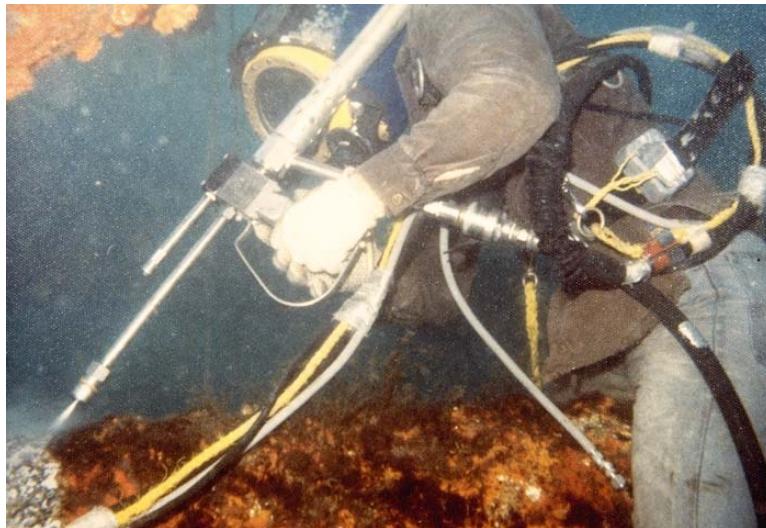


Figure 5.11: Waterjetting Under Water



Figure 5.12: Waterjetting Gun and Nozzle with Hose Shroud

A separate steel-braided hose is used for an air-operated, fail-safe system and is designed to prevent the fail-safe system from being activated accidentally by someone stepping on the hose or running over it.

- Tools

The tools can be hand held or mounted on a robot. Water can be propelled through a single jet, a fan jet, or multiple rotating jets. The jets are rotated by small air, electric, or hydraulic motors, or they can be rotated by slightly inclined orifices in a multiple-orifice nozzle.



Figure 5.13: Typical Waterjetting Tips

Waterjets are produced by orifices or tips that come in different forms. Round jets are most commonly used, but other shapes are available. A reliable round jet can be produced at 240 MPa (35,000 psig). Tips can be designed to produce multiple jets of water that normally are rotated to achieve higher removal rates.

The round jets are *cutters*, and fan jets are *scrapers* and/or *pushers*. Interchangeable nozzle tips normally are used to produce the desired streams. A typical water flow rate is 4 to 53 L/min (1 to 14 gal/min).



Figure 5.14: Waterjetting Fan Tip in Operation

Machines send a concentrated stream of water through a hose and nozzle at pressures of 70 to 414 MPa (10,000 to 60,000 psig); however, with current technology, the most practical pressures are 70 to 240 MPa (10,000 to 35,000 psig). In some cases, lower pressures may be used. Generally, using ultrahigh pressure with reduced water volume will produce less thrust and less operator fatigue.

Results from the use of HP WJ and UHP WJ are not necessarily similar. For example, surface oil and grease may not be removed by HP WJ at 70 MPa (10,000 psig), but will be removed completely by UHP WJ at 210 MPa (30,000 psig).

The angle of the nozzle and distance from the surface to be cleaned is determined by the type of matter to be removed and the type of equipment (HP WJ or UHP WJ) to be used. Although the waterjet nozzle distance from the surface can vary from 0.6 to 1 m (2 to 3 ft), typically the nozzle should be held 5 to 25 cm (2 to 10 in.) from the surface. In some instances with UHP WJ, the nozzle distance from the surface may be only 6 to 13 mm (0.25 to 0.5 in.).

When removing heavy rust scale or old coatings, the nozzle should be held 5 cm (2 in.) from the surface, virtually perpendicular (90°) to the surface. For best

results when removing mastics, the nozzle should be held at 45° to the surface.

Personnel for the Waterjetting Team

Generally at working pressures of 28 MPa (4,000 psig) or higher, the waterjetting team consists of:

- The nozzle operator
- The pump operator
- Additional operators or workers

The nozzle operator controls the operation while waterjetting is taking place. He/she holds the gun and lance or delivery hose and controls the motion and direction of the jet(s).

The pump operator monitors and controls the pressurizing pump during the jetting operation. He/she watches the nozzle operator at all times to be able to react if any difficulty arises, or if the operator begins to show signs of fatigue. The pump operator also monitors the working area and its surroundings in case anyone tries to enter the area, or in case a potentially hazardous condition occurs.

In either circumstance, or as otherwise necessary, the pump operator may reduce the pressure in the supply hose until a situation is handled. The operator should use caution in rapidly reducing the system pressure; otherwise the nozzle operator may lose his/her footing.

Depending upon the size and scope of the project, other operators or workers may be required to assist in handling a jetting gun if it is fitted with more than one jetting extension or if the hose must be fed to the work piece.

If the pump is located at some distance and out of sight of the nozzle operator, a team member may be required to

monitor the jetting operation and to communicate with the nozzle operator and pump operator.

One element of operator fatigue, mentioned earlier, is the back thrust from the high-pressure water. The operator should not be required to withstand a back thrust of more than one-third of his/her body weight for an extended period of time. For example, an operator working with a jet flowing at 70 MPa (10,000 psig) and 38 Lpm (10 gpm) will experience a back-thrust force of 23 kg (52 lbs). In this case, the operator should weigh at least 70 kg (156 lbs) to operate the nozzle. Newer units operate with less back thrust than some of the earlier units.

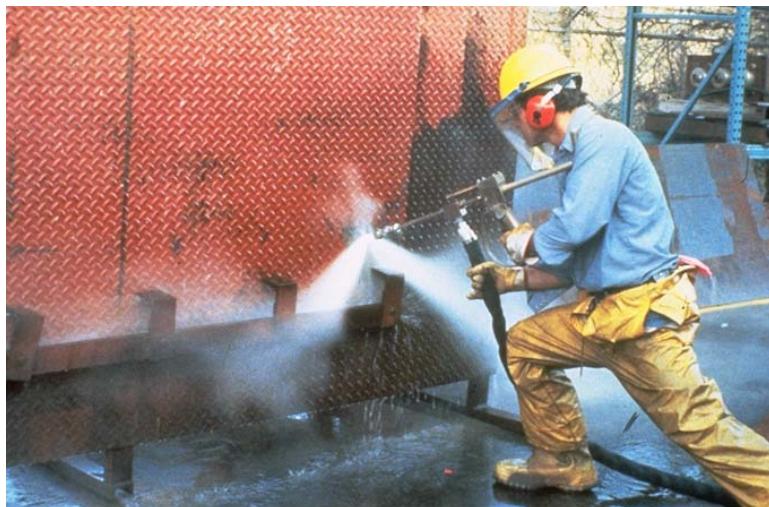


Figure 5.15: Operator Bracing Against Back Thrust

To minimize operator fatigue and to ensure a safe operation, the nozzle operator alternates positions with another operator at designated intervals, depending upon the equipment and pressures being utilized.

Pre-Service Operations

Before commencing the job, the waterjet team should ensure that:

- The work area is properly barricaded and appropriate warning signs are installed.

- Electrical equipment is properly covered and protected from the water.
- Electrical connections are not allowed to sit in water.
- All fittings and hoses are in good condition (not worn or damaged) and are properly pressure rated for the working pressure to be used.
- Nozzles are open and free of obstructions.
- The complete hook-up is flushed clean and air removed from the system before installing the nozzle.
- The dump system and all control systems are operational.
- All relevant moving equipment, such as conveyors, mixers, etc., is mechanically or electrically disabled, with appropriate lock-out provisions including the determination of Confined Space Entry Requirements.

Efficiency of Operation

Based on studies in the early 1980s, the following illustrates the overall efficiency of the HP WJ and UHP WJ.

- At pressures lower than 70 MPa (10,000 psig), loose rust, debris, and material in depressions and pits are removed, but the black iron oxide Fe_3O_4 (magnetite) remains. A matte finish is not achieved.
- At pressures of 70 MPa (10,000 psig), a uniform matte finish is obtained that quickly turns to a golden hue unless an inhibitor is added or dehumidification is used. The black oxide is removed, but at a rate too slow to be considered practical.
- At pressures of 140 MPa (20,000 psig), a uniform matte finish is obtained that quickly turns to a golden hue unless an inhibitor is added or dehumidification is used. Black oxide, paint, elastomeric coatings, enamel, red oxide, and polypropylene sheet lining are

removed. Chemical contaminants will be removed, but with varying degrees of effectiveness.

- At pressures of 234 to 248 MPa (34,000 to 36,000 psig), uniform matte finish is obtained that quickly turns to a golden hue unless an inhibitor is added or dehumidification is used. Surface materials, including most mill scale, are removed. Generally, more time is required in localized jetting to remove extremely well-bonded mill scale.

Inspection

The coating inspector may be required to monitor the waterjetting operation and to evaluate surface cleanliness in accordance with the descriptions set forth in this joint standard.

Unlike the joint NACE/SSPC standards for abrasive blast cleaning which are complete and which clearly define the surface conditions to be achieved, this joint standard on waterjetting describes surface cleanliness in terms of:

- Visual contaminants such as mill scale, rust, old coatings.
- Nonvisual contaminants such as water-soluble chlorides, iron-soluble salts, and sulfates.

The specifier generally must work closely with the contractor to determine the method of waterjetting and the test procedures for determining the amount of nonvisible contaminants. The coating manufacturer must be consulted to determine the tolerance of the candidate coating(s) to the surface conditions after waterjetting, commensurate with the in-service conditions.

These issues would best be determined in a pre-job conference, and it is essential that the coating inspector be involved in this deliberation process in order to evaluate the surface condition attained in accordance with the requirements established.

The inspector may also be required:

- To perform specified tests for the determination of the amount of nonvisible contaminants
- To monitor clean-up of the waterjetting area
- To ensure that the water run-off from the jetting operation is collected, treated, and/or disposed of according to applicable regulations
- To carefully document (with photographs, if necessary) each phase of the waterjetting operation

Safety

The joint NACE No. 5/SSPC-SP 12 standard states that "all work shall be conducted in compliance with all applicable health and safety rules and environmental regulations."

As a practical matter all personnel involved with the waterjetting, washing, and cleaning operation should obtain, study, and be familiar with, all regulations and safety procedures that apply.

The waterjetting unit shall have a pressure-control relief valve (deadman valve), which immediately interrupts the flow of water when the operator releases the trigger. (Note: This is similar to the deadman valve on a typical abrasive blasting hose.) The operator may use a shrouded foot valve to control the flow of water to the gun.

Safety considerations require the use of a well-trained operator for the waterjetting equipment.

When operating the equipment, the operator shall wear ear plugs, a face shield, a rain suit, and gloves and must have firm footing. The platform must be stabilized when using swinging scaffolds, bosun chairs, and similar riggings.

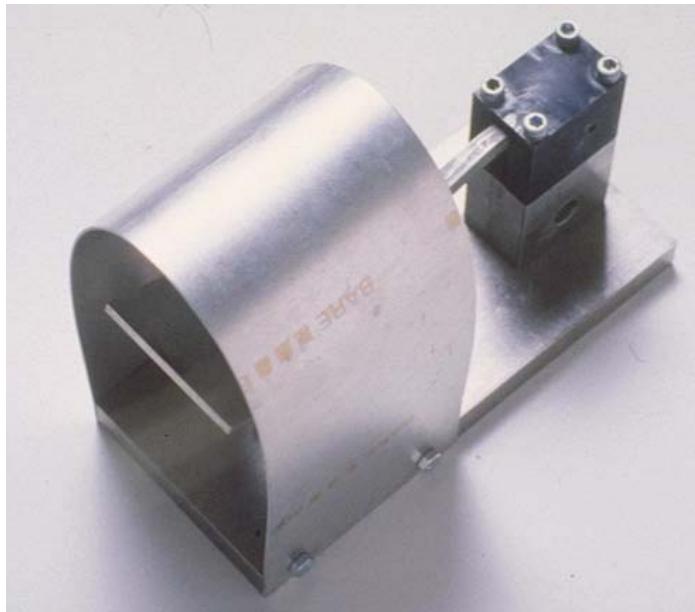


Figure 5.16: Shrouded Foot Valve for Safety



Figure 5.17: Operator Wearing Protective Clothing

All personnel should wear:

- Head protection with full-face shield
- Eye protection, such as goggles, with side shields
- Hearing protection—ear plugs, ear muffs, etc.
- Body protection, such as waterproof or chemically resistant suit (if required)
- Hand protection such as plastic-coated gloves, rubber gloves, or metal-mesh reinforced gloves
- Foot protection such as steel-toed boots and metatarsal guards
- Respirators as required, including full-face shield with supplied air

Attendant on Duty

An attendant shall be present to monitor safety and functional conditions when the waterjetting unit is in operation.

Medical Alert Card

Injuries caused by waterjetting or water-cleaning equipment can be life-threatening. Every operator should carry a medical alert card to present to medical personnel prior to any treatment. The card should have the following information on it:

“This person has been waterjetting at pressures up to 414 MPa (60,000 psig) and/or a waterjet velocity up to 870 m/s (2,850 ft/s). People injured by direct contact with high- or ultrahigh-pressure water typically experience unusual infections with microaerophilic organisms. There may be gram-negative pathogens, such as those found in sewage. Before administering treatment, the attending physician should immediately contact a local poison control center for appropriate information.”



Waterjetting—The Future

In industrial areas such as chemical plants where dry abrasive blasting is prohibited, waterjetting has found wide acceptance as a viable means of surface preparation.

Experimental UHP waterjetting is under way in the marine industry. Ships entering dry dock are being cleaned free of animal and vegetable fouling in the routine way, and then, after inspection and necessary repairs, UHP waterjetting is used with hot (82°C [180°F]) de-ionized water to remove old coatings. The ship hull is repainted and topcoated with an antifouling paint.

This procedure results in a surface virtually free of all nonvisible contaminants, but develops a very light coat of rust. Almost immediately after cleaning, the ship's hull can be painted without further treatment to remove the light rust.

The standard for the surface preparation of concrete is NACE No. 6/SSPC-SP 13 in which waterjetting is discussed as a viable method for preparing concrete for coatings. Concrete represents a large segment of the surfaces in industrial environments to be protected, especially with the current focus on secondary containment. Waterjetting is being widely used to clean and prepare these concrete surfaces for coating.

Waterjetting, used to clean and prepare steel and concrete for coating, is also used to cut and trim steel in certain environments.



Figure 5.18: Beveling End of Pipe with Waterjetting Unit

Waterjetting can be a complex process; however, the future for waterjetting is very promising, particularly in the industrial plant. The modern-day coating inspector, accustomed to working with the standards and procedures for abrasive blast cleaning of steel, should avail of the current information on the waterjetting processes for surface preparation (and cleaning). At some point, the inspector may be called upon to monitor part or all of a waterjetting operation.



Item No. 21076

Joint Surface Preparation Standard

NACE No. 5/SSPC-SP 12 Surface Preparation and Cleaning of Metals by Waterjetting Prior to Recoating

This NACE International (NACE)/SSPC: The Society for Protective Coatings standard represents a consensus of those individual members who have reviewed this document, its scope, and provisions. It is intended to aid the manufacturer, the consumer, and the general public. Its acceptance does not in any respect preclude anyone, whether he has adopted the standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not addressed in this standard. Nothing contained in this NACE/SSPC standard is to be construed as granting any right, by implication or otherwise, to manufacture, sell, or use in connection with any method, apparatus, or product covered by Letters Patent, or as indemnifying or protecting anyone against liability for infringement of Letters Patent. This standard represents current technology and should in no way be interpreted as a restriction on the use of better procedures or materials. Neither is this standard intended to apply in all cases relating to the subject. Unpredictable circumstances may negate the usefulness of this standard in specific instances. NACE and SSPC assume no responsibility for the interpretation or use of this standard by other parties and accept responsibility for only those official interpretations issued by NACE or SSPC in accordance with their governing procedures and policies which preclude the issuance of interpretations by individual volunteers.

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Foreword

This joint standard describes the surface preparation technique known as waterjetting. This technique provides an alternative method of removing coating systems or other materials from metal surfaces, including lead-based paint systems, prior to the application of a protective coating or lining system. This standard is intended for use by coating or lining specifiers, applicators, inspectors, or others whose responsibility it may be to define a standard degree of surface cleanliness. Since publication of NACE Standard RP0172,¹ surface preparation using waterjetting equipment has found acceptance as a viable method.

Waterjetting can be effective in removing water-soluble surface contaminants that may not be removed by dry abrasive blasting alone, specifically, those contaminants found at the bottom of pits of severely corroded metallic substrates. Waterjetting also helps to remove surface grease and oil, rust, shot-creting spatter, and existing coatings and linings. Waterjetting is also used in areas where abrasive blasting is not a feasible method of surface preparation.

The use of a high-pressure water stream to strip existing coatings and clean the surface has advantages over open dry abrasive blasting with respect to worker respiratory exposure and work area air quality. Respiratory requirements for waterjetting may be less stringent than for other methods of surface preparation.

Waterjetting does not provide the primary anchor pattern on steel known to the coatings industry as "profile." The coatings industry uses waterjetting primarily for recoating or relining projects in which there is an adequate preexisting profile. Waterjetting has application in a broad spectrum of industries. It is used when high-performance coatings require extensive surface preparation and/or surface decontamination.

This standard was originally prepared by NACE/SSPC Joint Task Group TGD. It was technically revised in 2002 by Task Group 001 on Surface Preparation by High-Pressure Waterjetting. This Task Group is administered by Specific Technology Group (STG) 04 on Protective Coatings and Linings—Surface Preparation, and is sponsored by STG 02 on Protective Coatings and Linings—Atmospheric, and STG 03 on Protective Coatings and Linings—Immersion/Buried. This standard is issued by NACE International under the auspices of STG 04, and by SSPC Group Committee C.2 on Surface Preparation.

Joint Surface Preparation Standard

NACE No. 5/SSPC-SP 12 Surface Preparation and Cleaning of Metals by Waterjetting Prior to Recoating

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Section 1: General

1.1 This standard describes the use of waterjetting to achieve a defined degree of cleaning of surfaces prior to the application of a protective coating or lining system. These requirements include the end condition of the surface plus materials and procedures necessary to verify the end condition. This standard is limited in scope to the use of water only.

1.2 This standard is written primarily for applications in which the substrate is carbon steel. However, waterjetting can be used on nonferrous substrates such as bronze, aluminum, and other metals such as stainless steel. This

standard does not address the cleaning of concrete. Cleaning of concrete is discussed in NACE No. 6/SSPC SP-13.²

1.3 Appendices A, B, and C give additional information on waterjetting equipment, production rates, procedures, and principles.

1.4 Visual Reference Photographs: NACE VIS 7/SSPC-VIS 4, "Guide and Reference Photographs for Steel Surfaces Prepared by Waterjetting,"³ provides color photographs for the various grades of surface preparation as a function of the initial condition of the steel. The latest issue of the reference photographs should be used.

Section 2: Definitions

2.1 This section provides basic waterjetting definitions. Additional definitions relevant to waterjetting are contained in the WaterJet Technology Association's⁽¹⁾ "Recommended Practices for the Use of Manually Operated High-Pressure Waterjetting Equipment."⁴

2.1.1 Waterjetting (WJ): Use of standard jetting water discharged from a nozzle at pressures of 70 MPa (10,000 psig) or greater to prepare a surface for coating or inspection. Waterjetting uses a pressurized stream of water with a velocity that is greater than 340 m/s (1,100 ft/s) when exiting the orifice. Waterjetting does not produce an etch or profile of the magnitude currently recognized by the coatings industry. Rather, it exposes the original abrasive-blasted surface profile if one exists.

2.1.2 Water Cleaning (WC): Use of pressurized water discharged from a nozzle to remove unwanted matter from a surface.

2.1.3 Standard Jetting Water: Water of sufficient purity and quality that it does not impose additional contaminants on the surface being cleaned and does not contain sediments or other impurities that are destructive to the proper functioning of waterjetting equipment.

2.1.4 Low-Pressure Water Cleaning (LP WC): Water cleaning performed at pressures less than 34 MPa (5,000 psig). This is also called "power washing" or "pressure washing."

2.1.5 High-Pressure Water Cleaning (HP WC): Water cleaning performed at pressures from 34 to 70 MPa (5,000 to 10,000 psig).

2.1.6 High-Pressure Waterjetting (HP WJ): Waterjetting performed at pressures from 70 to 210 MPa (10,000 to 30,000 psig).

2.1.7 Ultrahigh-Pressure Waterjetting (UHP WJ): Waterjetting performed at pressures above 210 MPa (30,000 psig).

2.1.8 Nonvisible Contamination (NV): Nonvisible contamination is the presence of organic matter, such as very thin films of oil and grease, and/or soluble ionic materials such as chlorides, ferrous salts, and sulfates that remain on the substrate after cleaning.

2.1.9 Visible Surface Cleanliness (VC): Visible surface cleanliness is the visible condition of the substrate, when viewed without magnification, after cleaning.

Section 3: Surface Cleanliness Requirements

3.1 Table 1 lists four definitions of surface cleanliness in terms of visible contaminants. A surface shall be prepared to one of these four visual conditions prior to recoating.

3.1.1 As part of the surface preparation, deposits of oil, grease, and foreign matter must be removed by waterjetting, by water cleaning, by steam cleaning, by methods in accordance with SSPC-SP 1,⁵ or by

⁽¹⁾ WaterJet Technology Association, 917 Locust Street, Suite 1100, St. Louis, MO 63101-1419.

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another method agreed upon by the contracting parties.

3.1.2 NOTE: Direct correlation to existing dry media blasting standards is inaccurate or inappropriate when describing the capabilities of water cleaning and the visible results achieved by water cleaning.

3.1.3 The entire surface to be prepared for coating shall be subjected to the cleaning method.

3.1.4 For WJ-4 (see Table 1) any remaining mill scale, rust, coating, or foreign materials shall be tightly adherent. All of the underlying metal need not be exposed.

3.1.5 Photographs may be specified to supplement the written definition. In any dispute, the written standards shall take precedence over visual reference photographs or visual standards such as NACE VIS 7/SSPC-VIS 4.³

3.2 Table 2 lists definitions of flash rusted surfaces (See Section 4). When deemed necessary, a surface should be

prepared to one of these flash rusted surface conditions prior to recoating.

3.3 The specifier shall use one of the visual surface preparation definitions (WJ-1 to WJ-4 in Table 1) and, when deemed necessary, one of the flash rust definitions.

3.3.1 The following is an example of a specification statement:

"All surfaces to be recoated shall be cleaned to NACE No. 5/SSPC-SP 12, WJ-2/L, Very Thorough or Substantial Cleaning, Light Flash Rusting."

3.4 Appendix A contains information on nonvisible surface contaminants. In addition to the requirements given in Paragraph 3.1, the specifier should consider whether a surface should be prepared not to exceed the maximum level of nonvisible surface contamination prior to recoating. A suggested specification statement for nonvisible contaminants is given in Appendix A.

Table 1: Visual Surface Preparation Definitions

Term	Description of Surface
WJ-1	Clean to Bare Substrate: A WJ-1 surface shall be cleaned to a finish which, when viewed without magnification, is free of all visible rust, dirt, previous coatings, mill scale, and foreign matter. Discoloration of the surface may be present. ^(A, B, C)
WJ-2	Very Thorough or Substantial Cleaning: A WJ-2 surface shall be cleaned to a matte (dull, mottled) finish which, when viewed without magnification, is free of all visible oil, grease, dirt, and rust except for randomly dispersed stains of rust, tightly adherent thin coatings, and other tightly adherent foreign matter. The staining or tightly adherent matter is limited to a maximum of 5% of the surface. ^(A, B, C)
WJ-3	Thorough Cleaning: A WJ-3 surface shall be cleaned to a matte (dull, mottled) finish which, when viewed without magnification, is free of all visible oil, grease, dirt, and rust except for randomly dispersed stains of rust, tightly adherent thin coatings, and other tightly adherent foreign matter. The staining or tightly adherent matter is limited to a maximum of 33% of the surface. ^(A, B, C)
WJ-4	Light Cleaning: A WJ-4 surface shall be cleaned to a finish which, when viewed without magnification, is free of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose coating. Any residual material shall be tightly adherent. ^(C)

^(A) Surfaces cleaned by LP WC, HP WC, HP WJ, or UHP WJ do not exhibit the hue of a dry abrasive blasted steel surface. After waterjetting, the matte finish color of clean steel surface immediately turns to a golden hue unless an inhibitor is used or environmental controls are employed.⁶ On older steel surfaces that have areas of coating and areas that are coating-free, the matte finish color varies even though all visible surface material has been removed. Color variations in steel can range from light gray to dark brown/black.

Steel surfaces show variations in texture, shade, color, tone, pitting, flaking, and mill scale that should be considered during the cleaning process. Acceptable variations in appearance that do not affect surface cleanliness include variations caused by type of steel or other metals, original surface condition, thickness of the steel, weld metal, mill fabrication marks, heat treating, heat-affected zones, and differences in the initial abrasive blast cleaning or in the waterjet cleaning pattern.

The gray or brown-to-black discoloration seen on corroded and pitted steel after waterjetting cannot be removed by further waterjetting. A brown-black discoloration of ferric oxide may remain as a tightly adherent thin film on corroded and pitted steel and is not considered part of the percentage staining.

^(B) Waterjetting at pressures in excess of 240 MPa (35,000 psig) is capable of removing tightly adherent mill scale, but production rates are not always cost effective.

^(C) Mill scale, rust, and coating are considered tightly adherent if they cannot be removed by lifting with a dull putty knife. (See NACE No. 4/SSPC-SP 7⁷).

Section 4: Flash Rusted Surface Requirements

4.1 Table 2 lists four definitions of flash rusted surface requirements. *Flash rust* or *water bloom* is a light oxidation of the steel that occurs as waterjetted carbon steel dries. With the exception of stainless steel surfaces, any steel surface may show flash rust within 0.5 to 2 hours, or longer depending on environmental conditions, after cleaning by water. Flash rust quickly changes the appearance. Flash rust may be reduced or eliminated by physical or chemical methods. The color of the flash rust may vary depending on the age and composition of the steel and the time-of-wetness of the substrate prior to drying. With time, the flash rust changes from a yellow-brown, well adherent, light rust to a red-brown, loosely adherent, heavy rust.

4.2 It is a common practice to remove heavy flash rust by low-pressure water cleaning. The visual appearance of steel that has heavily flash rusted after initial cleaning and is

then recleaned by low-pressure water cleaning (up to 34 MPa [5,000 psig]) has a different appearance than the original light flash rusted steel depicted in NACE VIS 7/SSPC-VIS 4.

4.3 The coating manufacturer should be consulted to ascertain the tolerance of the candidate coatings to visual cleanliness, nonvisible contaminants, and the amount of flash rust commensurate with the in-service application. These conditions should be present at the time of recoating.

4.4 The following is an example of a specification statement concerning flash rust:

"At the time of the recoating, the amount of flash rust shall be no greater than moderate (M) as defined in NACE No. 5/SSPC-SP 12."

Table 2: Flash Rusted Surface Definitions

Term	Description of Surface
No Flash Rust	A steel surface which, when viewed without magnification, exhibits no visible flash rust.
Light (L)	A surface which, when viewed without magnification, exhibits small quantities of a yellow-brown rust layer through which the steel substrate may be observed. The rust or discoloration may be evenly distributed or present in patches, but it is tightly adherent and not easily removed by lightly wiping with a cloth.
Moderate (M)	A surface which, when viewed without magnification, exhibits a layer of yellow-brown rust that obscures the original steel surface. The rust layer may be evenly distributed or present in patches, but it is reasonably well adherent and leaves light marks on a cloth that is lightly wiped over the surface.
Heavy (H)	A surface which, when viewed without magnification, exhibits a layer of heavy red-brown rust that hides the initial surface condition completely. The rust may be evenly distributed or present in patches, but the rust is loosely adherent, easily comes off, and leaves significant marks on a cloth that is lightly wiped over the surface.

Section 5: Occupational and Environmental Requirements

5.1 Because waterjet cleaning is a hazardous operation, all work shall be conducted in compliance with all applicable

occupational health and safety rules and environmental regulations.

Section 6: Cautionary Notes

6.1 Waterjetting can be destructive to nonmetallic surfaces. Soft wood, insulation, electric installations, and instrumentation must be protected from direct and indirect water streams.

6.2 Water used in waterjetting units must be clean and free of erosive silts or other contaminants that damage pump valves and/or leave deposits on the surface being cleaned.

The cleaner the water, the longer the service life of the waterjetting equipment.

6.3 Any detergents or other types of cleaners used in conjunction with waterjetting shall be removed from surfaces prior to applying a coating.

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6.4 Compatibility of the detergents with the special seals and high-alloy metals of the waterjetting equipment must be carefully investigated to ensure that WJ machines are not damaged.

6.5 If inhibitors are to be used with the standard jetting water, the manufacturer of the waterjetting equipment shall be consulted to ensure compatibility of inhibitors with the equipment.

6.6 The coatings manufacturer shall be consulted to ensure the compatibility of inhibitors with the coatings.

6.7 If effluent jetting water is captured for reuse in the jetting method, caution should be used to avoid introducing any removed contaminants back to the cleaned substrate. The effluent water should be treated to remove suspended particulate, hydrocarbons, chlorides, hazardous materials, or other by-products of the surface preparation procedures. The water should be placed in a clean water holding tank and tested to determine the content of possible contamination prior to reintroduction into the jetting stream. If detergents or degreasers are used prior to surface preparation, these waste streams should be segregated from the effluent jetting water to avoid contamination and possible equipment damage.

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14. ASTM⁽⁴⁾ D 516-02 (latest revision), "Standard Test Method for Sulfate Ion in Water" (West Conshohocken, PA: ASTM).
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⁽²⁾ International Organization for Standardization (ISO), 1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland.

⁽³⁾ Federal Highway Administration (FHWA), 400 7th St. SW, Washington, DC 20590.

⁽⁴⁾ ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

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NOTE: Appendices A, B, and C provide explanatory notes. They provide additional information on waterjetting.

Appendix A: Surface Cleanliness Conditions of Nonvisible Contaminants and Procedures for Extracting and Analyzing Soluble Salts

A1.1 For the purpose of this appendix, the list of non-visible contaminants is limited to water-soluble chlorides, iron-soluble salts, and sulfates. The contracting parties should be aware that other nonvisible contaminants may have an effect on the coating performance.⁸ The specifier should determine whether, and to what condition, nonvisible chemical contaminants should be specified. Section 3 contains additional information on surface cleanliness conditions.

A1.2 The level of nonvisible contaminants that may remain on the surface is usually expressed as mass per unit area, for example, $\mu\text{g}/\text{cm}^2$ (grains/in.²) or mg/m^2 (grains/yd²) ($1 \mu\text{g}/\text{cm}^2 = 10 \text{ mg}/\text{m}^2 = 0.0001 \text{ grains}/\text{in.}^2 = 0.13 \text{ grains}/\text{yd}^2$).

A1.3 Coatings manufacturers should be consulted for recommendations of maximum surface contamination allowed. The specification should read as follows:

“Immediately prior to the application of the coating, the surface shall not contain more than xx $\mu\text{g}/\text{cm}^2$ (grains/in.²) of the specific contaminant (e.g., chloride) when tested with a specified method as agreed upon by contracting parties.”

A1.4 The contracting parties shall agree on the test method or procedure to be used for determining the level of nonvisible contaminants.

Note: NACE and ISO committees are currently (2002) developing recommendations for the level of nonvisible contaminants that may be tolerated by different types of coatings in various services.

Table A1: Description of Nonvisible Surface Cleanliness Definitions^(A) (NV)

Term	Description of Surface
NV-1	An NV-1 surface shall be free of detectable levels of soluble contaminants, as verified by field or laboratory analysis using reliable, reproducible test methods.
NV-2	An NV-2 surface shall have less than 7 $\mu\text{g}/\text{cm}^2$ (0.0007 grains/in. ²) of chloride contaminants, less than 10 $\mu\text{g}/\text{cm}^2$ (0.001 grains/in. ²) of soluble ferrous ion levels, or less than 17 $\mu\text{g}/\text{cm}^2$ (0.0017 grains/in. ²) of sulfate contaminants as verified by field or laboratory analysis using reliable, reproducible test methods.
NV-3	An NV-3 surface shall have less than 50 $\mu\text{g}/\text{cm}^2$ (0.005 grains/in. ²) of chloride or sulfate contaminants as verified by field or laboratory analysis using reliable, reproducible test methods.

^(A) Additional information on suitable procedures for extracting and analyzing soluble salts is available in NACE Publication 6G186,⁸ and SSPC-TU 4.⁹

A2.1 Procedure for Extracting Soluble Salts by Swabbing

The following procedures may be used to extract the soluble salts from the surface:

- (a) SSPC Swabbing Method⁹
- (b) Procedure described in ISO 8502-5, Section 5.1, “Washing of the Test Area”¹⁰
- (c) Any suitable controlled washing procedures available and agreed to by the contracting parties. During the washing procedure, clean plastic or rubber gloves should be worn to ensure that the wash water is not accidentally contaminated.

A2.2 Procedure for Extracting Soluble Salts by Surface Cells

- (a) Limpet Cell Method¹¹
- (b) Surface Conductivity Cell Method^{9,11}
- (c) Nonrigid Extraction Cell Method^{9,11, 12}

A2.3 Procedure for Field Analysis of Chloride Ions

The extract retrieved using the procedures in Paragraphs A2.1 and A2.2 may be analyzed using one of the following methods:

- (a) Chloride Chemical Test Strips⁹
- (b) Chloride Chemical Titration Kit⁹
- (c) Ion Detection Tube Method^{9,10}

The following laboratory method is available as a referee method:

- (a) Specific Chloride Ion Electrode^{9,11,13}

A2.4 Procedure for Field Analysis of Sulfate Ions

The extract retrieved using the procedures in Paragraphs A2.1 and A2.2 may be analyzed using one of the following methods:

- (a) Turbidity Field Comparator Methods^{9,11}
- (b) Turbidity Method^{9,11}
- (c) Standard Test Method for Sulfate Ion in Water¹⁴

A2.5 Procedure for Field Analysis of Soluble Iron Salts

The extract retrieved using the procedures in Paragraph A2.1 or A2.2 may be analyzed using one of the following methods:

- (a) Ferrous Chemical Test Strips^{9,11}
- (b) Semiquantitative Test for Ferrous Ions⁸
- (c) Field Colorimetric Comparator Methods

A2.5.1 Papers treated with potassium ferricyanide may be used for the qualitative field detection of ferrous ions.^{8,9}

Appendix B: Waterjetting Equipment

B1.1 The commercial waterjet unit can be mounted on a skid, trailer, or truck; can be equipped with various prime movers (diesel, electric motor, etc.); and usually consists of a pump, hoses, and various tools. The tools can be handheld or mounted on a robot (or traversing mechanism). Water is propelled through a single jet, a fan jet, or multiple rotating jets. Rotation is provided by small electric, air, or hydraulic motors, or by slightly inclined orifices in a multiple-orifice nozzle.

B1.2 The units operate at pressures up to 240 to 290 MPa (35,000 to 42,000 psig), using a hydraulic hose with a minimum bursting strength of 2.5 times the capability of its maximum-rated operating strength.

B1.3 A water flow rate of 4 to 53 L/min (1 to 14 gal/min) is typical.

B1.4 Pressure loss is a function of the flow rate of the water through the hose and the inside diameter of the hose. The

manufacturer should be consulted for specific information on potential pressure loss for each type of equipment.

B1.5 Waterjets are produced by orifices, or tips, that can have different forms. The higher the pressure, the more limited is the choice of forms. Round jets are most commonly used, but orifices of other shapes are available. Tips can be designed to produce multiple jets of water that are normally rotated to achieve higher material removal rates. Interchangeable nozzle tips should be used to produce the desired streams. The manufacturer shall be consulted for specific recommendations.

B1.6 The distance from the nozzle to the work piece substrate (standoff distance) is critical for effective cleaning with any of the water methods. Excessive standoff does not produce the desired cleaning.

Appendix C: Principles of Waterjetting

NACE No. 5/SSPC-SP 12 is a performance specification, not a process specification. Appendix C is not intended to be used as an equipment specification.

C1 Commentary on Production Rates

C1.1 Operator skill and the condition of the steel surface affect waterjetting production rates.^{15,16,17} Regardless of the surface conditions, production rates usually improve when:

- (a) The operator gains additional experience with high- and ultrahigh-pressure waterjetting; or
- (b) Mechanized, automated waterjetting equipment is used.

C1.1.1 New metal with tightly adhering mill scale requires the highest level of operator skill and concentration to produce a clean surface by waterjetting. Older, more corroded, or previously coated surfaces require an average level of skill and concentration to achieve desired results. This is the opposite of abrasive blasting, when poor surface conditions require the highest levels of operator skill and concentration.

C1.2 As a general rule, production and ease of removal increase as the waterjetting pressure increases.

C1.3 Cleanup time to remove waste material should be considered when determining the overall production rate.

C2 Commentary on Waterjetting Parameters

C2.1 The specifier should describe the final condition of the substrate. Depending on the initial condition of the area and materials to be cleaned, the method to achieve Visible Conditions WJ-1, WJ-2, WJ-3, or WJ-4 may be LP WC, HP WC, HP WJ, or UHP WJ. The method of water cleaning or waterjetting ultimately is based on the capabilities of the equipment and its components. Dwell time, transverse rate, pressure, flow, stand-off distances, the number of nozzles, and rotation speed all interact in determining what material will remain and what will be removed.

C2.2 There are two thoughts on increasing production rates during the removal of materials by pressurized water. First, determine the threshold pressure at which the material will just be removed. The user can then either increase the flow to achieve adequate production rates or increase the pressure by a factor no greater

than three over the threshold pressure. These two methods do not necessarily yield the same result.¹⁸

C2.3 Details of the calculations in Table C1 are standard to the waterjetting industry and are beyond the scope of this standard.¹⁹

C2.4 Removal of degraded coating is coupled to thorough stressing of the remaining coating. The jet energy is the work done when the jet stream vertically impacts the coating surface. Energy is normally measured in kilojoules. The shear stress is developed against the vertical pit walls and larger fractures created on the eroded coating surface. This can, in gross terms, be thought of as a hydraulic load.

C2.5 Flexure stressing is induced by repetitive loading and unloading of the coatings systems by the jet streams as they pass over the surface. The rapid loading and unloading is vital to finding areas of low adherence and nonvisible adherence defects in the coating system.¹⁹

C2.6 Characteristics of typical pressurized water systems are included in Table C1.

Table C1: Typical Pressurized Water Systems

Pressure at Nozzle	70 MPa (10,000 psig)	140 MPa (20,000 psig)	280 MPa (40,000 psig)
Number of Tips	2	2	5
Diameter	1.0 mm (0.040 in.)	0.69 mm (0.027 in.)	0.28 mm (0.011 in.)
Flow	12.9 L/min (3.42 gpm)	8.3 L/min (2.2 gpm)	2.0 L/min (0.52 gpm)
Cross-Sectional Area	0.81 mm ² (0.0013 in. ²)	0.37 mm ² (0.00060 in. ²)	0.065 mm ² (0.00010 in. ²)
Jet Velocity	360 m/s (1,180 ft/s)	520 m/s (1,700 ft/s)	730 m/s (2,400 ft/s)
Impact Force (per tip)	8.1 kg (18 lb)	7.7 kg (17 lb)	2.4 kg (5.3 lb)
Jet Energy	141 kJ (134 BTU)	189 kJ (179 BTU)	89 kJ (81 BTU)
Energy Intensity (energy/cross-sectional area)	175 kJ/mm ² (107,000 BTU/in. ²)	513 kJ/mm ² (314,000 BTU/in. ²)	1,401 kJ/mm ² (857,000 BTU/in. ²)

C2.7 In field terms, the 70-MPa (10,000-psig) jets may not significantly erode the coatings. Therefore, they are typically used for partial removal or for cleaning loose detrital material. The 140-MPa (20,000-psig) jets erode the coatings fairly rapidly and are typically used for partial removal. The 280-MPa (40,000-psig) jets erode and destroy coatings very fast and are typically used when most or all of the coating is to be removed (WJ-1 or WJ-2).

C2.8 Application judgment is employed by operators or users who make the decisions concerning which type of jetting water to use:

(a) HP WC (the water's flow rate is the predominant energy characteristic);

(b) HP WJ (pressure [i.e., the velocity of the water] and flow rate are equally important); or

(c) UHP WJ (the pressure [i.e., the velocity of the water] is the dominant energy characteristic).

C2.9 As water passes through the orifice, potential energy (pressure) is converted to kinetic energy. The energy increases linearly with the mass flow, but increases with the square of the velocity, as shown in Equation (C1).

$$\text{Kinetic Energy} = \frac{1}{2}mv^2 \quad (\text{C1})$$

where

m = mass (derived from water volume)
 v = velocity (derived from pressure)

In order to calculate the kinetic energy from flow rates and velocity, a time period must be selected. A time period of 10 milliseconds is used for Equation (C1).

C2.10 The threshold pressure⁽⁵⁾ of a coating must also be determined. In general, the tougher or harder the coating (i.e., the more resistant to testing by a pocket knife), the higher the threshold pressure; the softer and more jelly-like the coating, the lower the threshold pressure.

C2.10.1 Once the threshold pressure is achieved or exceeded, the production rate increases dramatically. Therefore, waterjetting production rates are affected by two conditions:

- (a) Erosion at pressures lower than the threshold pressure, and
- (b) Waterjet cutting and erosion at pressures greater than the threshold pressure.

⁽⁵⁾ Threshold pressure is defined as the minimum pressure required to penetrate the material.²⁰



Level 2

Chapter 6

Self-Study Questions

Chapter 1—Introduction

1. Upon successful completion of CIP Level 2, the inspector trainee should be able to _____ all _____ listed in Level 1.
2. Only after _____ completion of CIP _____ and _____, and the _____ can the participant attain _____ _____ _____ recognition.
3. Level 3 Certification _____ must be completed every ____ years.
4. You will be responsible for:
 - a. Your own _____
 - b. _____ your own _____
5. The coating specification is based on the following elements:
 - a. _____ of work
 - b. _____ selection
 - c. _____ preparation
 - d. _____
 - e. _____
 - f. _____
6. Scope may include the _____ of the project
7. Materials selection may include the approved _____ systems and _____.
8. Surface preparation may include the _____ standards and _____ requirements
9. Application may include a section on _____, the _____ methods, workmanship and _____ limitations and the work schedule
10. Inspection (_____ _____) may include the _____ standards and _____.

11. The inspector should not leave the pre-job conference without a _____ of:
 - a. The _____
 - b. Their _____ on the _____
 - c. Their _____ on the _____
12. The anchor pattern or _____ is largely dependent upon the coating selected.
13. Dew point temperature generally is determined by using a _____ and _____ charts.

Chapter 3—Dehumidification

1. Dehumidification is defined as the removal of _____ from the air to _____ the _____ temperature.
2. Humidity and temperature impact _____ and _____.
3. _____ can absorb moisture from the air and _____ it on the surface in a microscopic layer of _____.
4. _____ air can contain or _____ more moisture than can _____ air.
5. _____ the air does not change its _____ content, which is a quantity of _____, but it does _____ its ability to _____ moisture vapor; and thus it _____ its relative humidity.
6. _____ the air _____ its ability to _____ moisture vapor and, thus, _____ its relative humidity.
7. Most coatings _____ be _____ when the _____ is higher than ____%.
8. The air _____ to the steel is called the _____.

9. There are two ways to _____ the relative humidity of the boundary layer:
 - a. Increase the _____
 - b. Reduce _____ content by _____.
10. Frequently, _____ is used in _____ with _____ and _____ dehumidifiers.
11. _____ are substances that naturally have a _____ for water.
12. Most desiccants are _____ in their _____ state, though there are some _____ desiccants, such as common _____.
13. Desiccants in _____ are called _____ desiccants.
14. For the contractor, benefits of dehumidification are
 - a. Crews can start _____ in the day and work _____.
 - b. _____ of _____ by the blasting operation can be _____.
 - c. Extended _____ intervals can be _____.
15. Typical solvents used in coatings are _____ than ___, and they tend to _____ to the _____ of a structure, tank, etc.

Chapter 4—Centrifugal Blast Cleaning

1. Some basic elements of the blast system are:
 - a. Abrasive _____ system
 - b. The blast _____
 - c. The abrasive _____.
2. A _____ blast machine cleans _____ when there is a _____ of _____.
3. One advantage of centrifugal blast cleaning is the abrasive is _____
4. Most wheel units are designed to run at full-_____.

5. The _____ area of blast is called the *hot spot*.
6. _____ on the _____ and _____ affects the _____ and _____ of the _____.
7. Steel _____ may be the best _____, _____, or _____ abrasive available.
8. Steel _____ is best for _____, i.e., creating a _____, prior to _____ or _____.
9. Portable wheel blast equipment permits _____ wheel blast cleaning during _____ and _____ of _____, _____, and _____ surfaces, which include:
 - a. Ship decks, _____, and _____
 - b. Storage _____
 - c. Concrete _____
 - d. Highways and _____
10. In general, centrifugal blast cleaning is more _____ compared with _____ or _____ blast cleaning.
11. With the blast wheel, as little as _____ misalignment of the pattern _____ can _____ cleaning _____ by _____ or more.
12. The _____ of the blast wheel depends upon many factors including:
 - a. Abrasive _____ mix.
 - b. _____ of the abrasive.
 - c. _____ of the abrasive coming _____ the _____.
 - d. _____ and _____ of the _____ abrasive.
 - e. Condition of the _____ parts.

Chapter 5—Waterjetting

1. The NACE No. 5/SSPC-SP 12 joint standard is for _____ and _____ of _____ by _____ prior to _____.
2. The standard NACE VIS 7/SSPC-VIS 4 provides _____ for the various grades of _____ as a function of the _____ of the steel.
3. Waterjetting is the use of a _____ water stream to strip off _____ and to _____.
4. Waterjetting uses _____, without the addition of _____, such as _____ or _____, in the _____.
5. Low-pressure water cleaning is performed at pressures lower than _____ (34 MPa).
6. Ultrahigh-pressure waterjetting is performed at pressures higher than _____ (210 MPa).
7. Surface cleanliness conditions after waterjetting are defined as:
 - a. WJ-1 to WJ-4 _____ contaminants
 - b. NV-1 to NV-3 _____ contaminants
8. The specification must use one visual definition (WJ-1 to WJ-4) and one nonvisual definition (NV-1 to NV-3) to _____ degree of surface matter to be _____.
9. The (high-pressure) _____, hose _____, and all other equipment, including the _____, _____, _____, and _____, should have a _____ of _____ times the capability of its _____ rated _____.
10. The high-pressure hose is fitted with a _____ device known as a _____.
11. The section of hose next to the gun is fitted with a _____.
12. The _____ and _____ must agree on the _____ to be used for determining the amount of _____ contaminants present on the surface.

13. After waterjetting, the _____ of a clean steel surface immediately turns to a _____ unless an _____ is used, or _____ are employed.
14. A WJ-1 surface shall be cleaned to a finish which, when viewed _____, is free of _____ visible _____, previous _____, _____, and _____. _____ of the surface _____ be present.
15. An NV-1 surface shall be free of _____ levels of _____, as verified by _____ or _____ analysis using reliable, _____ test methods.
16. A surface that, when viewed without _____, exhibits a layer of _____ rust that _____ the _____ steel surface is defined as _____.
17. A typical water _____ is _____ to _____/min (_____ to _____/min).
18. When removing heavy _____ or _____, the nozzle should be held _____ (_____ cm) from the surface, virtually _____ (_____ to _____) to the _____.
19. When operating the equipment, the operator shall wear _____, a _____, a _____, and _____, and must have _____.
20. Every _____ should carry a _____.



Level 2

Chapter 7

Personal Profile System

Job Factor Analysis

Before beginning the discussion of Personal Profile students should complete Pages 1 and 2 of the Job Factor Analysis on the following pages.

Following the instructions on the form, assess each factor and its relevance to the job of a coating inspector. After all 24 boxes have been filled, total the numbers for each symbol (hearts, clubs, diamonds and spades), and enter those total numbers in the four boxes provided at the foot of page 7.3.

Please do not turn past page 7.3 until the instructor requests that you do so.

Remember that the questions asked relate to the job of a coating inspector.

The Coating Inspector's Job

Use your judgment to rate the importance of each of the following "job factors" for the coating inspector. Choose a number from 1 to 5 using the following scale:

1=not important, 2=low importance, 3=fairly important, 4=very important, 5=essential. Circle the appropriate number, then enter the number in the box at the right side of the page.

The Coating Inspector should:

♥	1. Have the ability to make unpopular decisions in performing job responsibilities.	1 2 3 4 5	<input type="text"/>
♦	2. When necessary, "stick" to one work station.	1 2 3 4 5	<input type="text"/>
♠	3. Be diplomatic and tactful.	1 2 3 4 5	<input type="text"/>
♥	4. Have the ingenuity to create and use new ideas.	1 2 3 4 5	<input type="text"/>
♠	5. Use a systematic approach to resolve situations or perform activities.	1 2 3 4 5	<input type="text"/>
♠	6. Concentrate on key details of the job.	1 2 3 4 5	<input type="text"/>
♣	7. Exercise caution in calculating risks.	1 2 3 4 5	<input type="text"/>
♥	8. Have the vision to plan ahead.	1 2 3 4 5	<input type="text"/>
♦	9. Try to develop a harmonious working environment.	1 2 3 4 5	<input type="text"/>
♥	10. Be decisive when required to act without precedent.	1 2 3 4 5	<input type="text"/>
♣	11. Be able to organize various types of people.	1 2 3 4 5	<input type="text"/>

◆	12. Be able to develop a workable, repeatable routine.	1 2 3 4 5	
◆	13. Have the persistence to perform steadily at repetitive work.	1 2 3 4 5	
♣	14. Have the skill to persuade others to his/her own point of view.	1 2 3 4 5	
♠	15. Have the capacity to complete work to perfection.	1 2 3 4 5	
♣	16. Be able to create an environment where people motivate themselves.	1 2 3 4 5	
♣	17. Have the ability to solve human problems through discussion.	1 2 3 4 5	
♠	18. Consider alternatives before taking action.	1 2 3 4 5	
♣	19. Be skilled in the use of language, and poised when expressing oneself.	1 2 3 4 5	
♥	20. Be able to overcome objections.	1 2 3 4 5	
◆	21. Have patience to follow step-by-step instructions.	1 2 3 4 5	
♥	22. Be able to take command of the work situation.	1 2 3 4 5	
♠	23. Have capacity to cope with interruptions and changes.	1 2 3 4 5	
◆	24. Possess steadiness to follow an established work pattern.	1 2 3 4 5	

Total Scores:

♥ = ♣ = ◆ = ♠ =



Personal Profile System

Overview

It's probably safe to say that most of us feel we can probably do a better job getting along with each other than we do. We know that by cooperating and working together as a team we become more productive as an organization.

All right. Now, first off, let me ask if there are any people here who feel they get along terrifically with every one of their co-workers?

Coating inspectors must also recognize the importance of cooperation and teamwork. This course will provide some guidelines to help identify methods to improve working relationships on the job.

Explain Personal Profile System

The purpose of this session is to help you learn ways to increase your effectiveness in working with other people so that everyone benefits—you, your colleagues, and your organization.

The core of our session is a self-report instrument called the Personal Profile System, which helps people identify their own behavioral styles, as well as the styles of others. Over 15 million Profiles have been used. The Personal Profile System is one of the most popular and successful personal and professional development instruments in the world.

Our Personal Profile System session today has four goals. It will help you:

- Understand your work behavioral tendencies and develop a beginning understanding of how these styles may affect others.

- Understand, respect, appreciate, and value individual differences.
- Develop strategies for working together to increase productivity.
- Enhance your effectiveness in accomplishing tasks by improving your relationships with others.

In this next section, we'll discuss the workshop structure, including:

- Completing the Personal Profile System
- Interpreting and discussing the results
- Video segments!

Facilitator's Role

The facilitator's role is not to teach so much as to serve as a guide throughout this session.

Participant's Role

The participant's role is to:

- Participate as actively as possible.
- Be nonjudgmental of others in the group.
- Maintain confidentiality.
- Be willing to learn.

We're now going to focus on some basic concepts about human behavior that you might want to keep in mind before you take the Personal Profile System.

Behavioral Basics

Johari Window

How many of you feel you're pretty open with people, that you disclose a lot about yourself to your fellow workers and that they, in turn, would say that they know you pretty well?

Some people, for a variety of reasons, do not disclose a lot about themselves to their co-workers. They may, for example, simply feel it's not necessary or appropriate to let their co-workers know them very well.

How many of you generally do not disclose a lot of information about yourselves to your co-workers?

Well, since much of this seminar is about self-awareness and style-awareness, I think it's important for us to realize that some of us may not feel as comfortable as others in the group talking about ourselves and our personalities.

Two sociologists named Joseph Luft and Harry Ingam developed a simple model called the Johari Window that depicts basic levels of self-awareness and awareness of others.

As you can see, the Window is divided into four sections, which appear on this slide to be the same size. In reality, this is rarely the case.

The upper left section is called the *Arena*. It represents the things I know about myself that you also know about me. This common knowledge that you and I know about ourselves and each other enables us to build a relationship and work together more effectively.

The lower left section is called the *Facade* or *Mask*. It represents things I know about myself that you do not know about me. I may be consciously concealing this information or I simply may not have disclosed it yet. If our interactions are to become more meaningful, I'll need to disclose more and more information about myself.

Doing this will increase the size of the Arena, which is where trust is developed and relationships deepen.

Many people, including some of us in this group, find it difficult to disclose personal information. We may, for example, be shy, reserved, or concerned about losing control of a situation. But regardless of our reasons, when we finally take the initiative and begin to disclose information about ourselves, others feel safe to disclose as well. This is how relationships continue to grow and develop.

The upper right section is called the *Blind Spot*. It represents the things you know about me, primarily from observation, that I am not aware you know. These may be things I really am aware of at a deeper level but have chosen to block out of my consciousness, or simply things about me that I really haven't noticed. In any case, I need to discover what you know about me if we are to develop a relationship of mutual trust.

The trick to finding out what others know about you is to encourage them to provide you with feedback. How do you do this?

Well, the best way I know is to be receptive to feedback. A lot of people with Blind Spots tend to be so busy doing and talking that they are unaware of the effect they have on others. By taking a risk and asking questions designed to elicit feedback about the way others see you, you can find out information about yourself that others know. At the same time, your willingness to accept personal feedback may in turn make others more willing to accept feedback from you.

Finally, the lower right section is called *Potential* and simply represents the situation that exists when neither you nor I know each other very well. In order to work and interact effectively with each other, we need to be able to disclose information, and receive feedback, about ourselves. We need to decrease the Potential section and increase the Arena section in this model.

As we saw earlier, much of this session deals with self-awareness and disclosure. From the Johari Window here, you can see that self-disclosure also involves receiving and soliciting feedback from others. By completing the Personal Profile System, you are, in fact, soliciting feedback from yourself. Your responses are used to provide more complete, organized information about your natural behavioral style. This experience will start you on the path to enlarging your Arena and enhancing your relationships with others.

You have a copy of the Johari Window in your slide handout pages.

Motivating Principles

We've talked about the different levels of awareness we have about ourselves and others, and how disclosing more about ourselves can cause others to do the same. Part of learning about ourselves and others is discovering what motivates us to develop certain styles of behavior in the first place.

There are six principles of motivation.

We'll look at each one in turn.

The first principle is "**You cannot motivate other people.**" What we have to realize here is that we can give people incentives to perform better and encourage and support their efforts, but the basic motivation for their behavior must come from within. People motivate themselves.

Now look at the second principle: "**All people are motivated.**" How many of you know people that you feel just aren't motivated at all?

Actually, though, research indicates that all people are motivated, no matter how they're behaving. Say, for example, Joan is working at a slow pace. Her manager may assume Joan is lazy or "unmotivated." But she actually may be motivated by a desire to achieve perfection. If the task requires speed instead of



perfection, Joan's manager needs to coach her to help her adapt her behaviors.

Let's say Tom is another employee who works at a slow pace, but for a completely different reason. What other reason or motive could he have for being a slow worker?

All of these examples support the third motivating principle as well: **"People do things for their reasons, not your reasons."** This may seem selfish, but let's face it: self-interest is a question of survival.

What we need to realize is that even if we can't directly motivate others, we can create an environment that will encourage them to motivate themselves in ways that are desirable.

Let's look at the fourth motivating principle now:

"A person's strength, overused, may become a limitation." Who can give me an example of when that might be the case?

What about the fifth principle: **"If I know more about you than you know about me, I can control the communication"**? This brings us right back to our Johari Window, and the Mask or Facade that people erect to avoid letting people know them.

Knowledge is power, and understanding others is the key to good communication and successful and productive work relationships.

Finally, let's look at the last principle of motivation: **"If I know more about you than you know about yourself, I can control you"**.

Many of us think we know ourselves pretty well, and yet we still are surprised by the way people react at times to the things we do or say. Our challenge is to recognize both our strengths and our limitations so that we remain in control of situations, particularly in those situations where we find ourselves typically uncomfortable or ineffective.

What questions or comments do you have now about these motivating principles, or about anything we've covered so far?



Getting Started with the Personal Profile System

Introducing the Personal Profile System

We've talked so far about being aware of how we behave, and why we behave the way we do. All of us think, feel, and act certain ways because we've developed a pattern of behavior over time. In fact, this pattern is so ingrained in most of us that we can call it a "style."

What we're now going to discover is how we behave—in other words, our "behavioral style"—in a work environment. The Personal Profile System is a simple, self-scoring instrument that will help us not only understand ourselves and others, but learn about how to work productively and harmoniously with those in our organization whose behavioral styles are different from ours.

The Personal Profile System isn't a test that you can pass or fail. There's no one style or pattern that's most effective or productive in our organization, or anywhere else for that matter. Remember: diversity in society is not only inevitable, it's essential. We need the different temperaments and talents of both artists and engineers, actors and entrepreneurs, poets and politicians. Imagine how boring it would be if we all reacted the same way to everything!

The Personal Profile System clues us in on the different ways we behave in work situations. Once we've identified our behavioral style, we can:

- Create a motivational environment most conducive to success.
- Increase our appreciation of the different work styles of others.
- Minimize potential conflicts with others.

At this time, take the Booklet called the **Personal Profile System**, and please write your name and today's date on the bottom of the Profile's front cover. After "Response Focus," write "**Me at Work.**"

Now open the Profile to page 2. The 28 boxes on this page each contain four words that describe behaviors.

What you need to do here is select from each box the one word that most describes your behavior in your work environment, and the one word that least describes your behavior in your work environment. So, in other words, you'll have one **MOST** and one **LEAST** word selection in each response box. You'll be using a coin or metal object to make your selection.

For example, in the first box you see the words "enthusiastic," "daring," "diplomatic," and "satisfied." If I see myself as **MOST** enthusiastic, I'll use the coin to rub on the oval next to "enthusiastic" under the **MOST** column.

If I see myself as **LEAST** daring, I'll use the coin to rub on the oval next to "daring" in the **LEAST** column.

To remind yourself that you need to respond according to how you see yourself in your work environment, write on the top of page 2, on the Focus line.

Be sure not to rub the oval too hard or you'll rub right through the paper and never see the symbol.

When the symbols appear, you'll see Zs, Squares, Triangles, Stars, and Ns. We'll discuss what they mean a little later.

Please respond as quickly as possible. You'll have 7 to 10 minutes to complete the 28 word groups. Keep in mind that your first answer is generally the one that is most correct for you. If you decide to change your mind after rubbing on an oval, simply cross it out with a pencil or pen and rub on the oval that more accurately describes your behavior.

In some cases, you'll think that all the terms describe your behavior. Please select the one most and the one least descriptive of you. In other cases, you may think that none of the terms describes you. Still, force yourself to make the selections that are most and least descriptive of you in your work environment. Then move to the next box.

When you've finished responding, close the Profile. We'll come back to it and work through it together.

Are you ready? I'll let you know when half the time has elapsed. Okay, begin.



Scoring and Tallying

The Tally Box

All right. Now, please open your Profile to page 3. In the lower right-hand corner of the page, there's a section labeled "Tally Box." Please tear along the perforated line to reveal the actual Tally Box on page 5.

As you can see, there are three columns in this Tally Box, labeled "Most," "Least," and "Difference."

What I'd like you to do now is total up the number of Zs found in all four of the MOST columns and record that number with a pen or pencil in the Z block of the MOST column. Follow exactly the same procedure for the Squares, Triangles, Stars, and Ns.

When you've finished recording the symbols in the MOST columns, add the numbers to make sure the sum is 28. Since you had 28 possible selections, you should also have a total of 28 in each column of your Tally Box.

All right, you can begin.

Now please follow the same procedure for the LEAST column. Again, make sure the Tally Box Conduct activity column totals 28. When you've finished recording these numbers, just put your pen down.

The third column of the Tally Box is the difference between your MOST and LEAST columns. For example, subtract the total Zs found in your LEAST column from those in your MOST column. If the Z count in your LEAST column is larger than the Z count in your MOST column, record a negative number in your DIFFERENCE column.

Look at the example above the tally box.

Please fill in the DIFFERENCE column at this time.

Now open your Profile so that all of page 5 is revealed. What you're going to do is transfer the Tally Box numbers into the graphs at the top of page 5.

The graphs correspond to the MOST, LEAST, and DIFFERENCE columns. This means that you will take the numbers found in your MOST Tally Box column to create Graph I.

Do you see the small letters in the upper left corner of each of the Tally Box numbers?

To create your graphs, you need to know that the Z response is plotted in the D column; the Square response is plotted in the i graph column; the Triangle response goes into the S column, and the Star response is plotted on the C column. Simply find your actual number along the scale from 0 to 28 in the columns corresponding to each symbol. Use your pen or pencil to plot and connect your points.

Be sure to pay attention to the positive and negative numbers you may find in your Tally Box DIFFERENCE column. As you can see, Graph III contains positive and negative numbers in the D, i, S, and C scales.

All right. You may now begin.

Note High Points

You probably know by now that the D, i, S, and C columns represent different behaviors. Before we talk about these behavioral styles, let's look at the three graphs you just plotted.

Graph III provides a description of your self-perception. It is a summary graph in that it combines two different ways of looking at yourself. Some people find that they are more comfortable in describing themselves by MOST choices rather than LEAST choices. Others may feel that they described themselves more accurately in their LEAST choices. And still others may feel equally comfortable in either choice process. The combination of your responses to both choices provides the most comprehensive picture of how you see yourself.

I'd like you to do one more thing now. Look at Graph III and see the columns in which you circled high points-D, i, S, and/or C.

Then turn to page 7 of your Profile.

This is the beginning of the interpretation process. You'll notice the page is divided into four boxes: D, i, S, and C. Circle the box or boxes corresponding to the letter representing the high points in your Graph III. For example, if you have high points in the S column in Graph III, circle the S box on page 7.

We're now going to take a 15-minute break. When you return, we'll find out more about what all these boxes, categories, and behavioral styles mean.

Defining Our Personal Styles DISC Style Description

Now let's find out more about these four behavioral styles described on page 7 of your Profile.

As you can see, the four styles stand for:

- Dominance
- Influence
- Steadiness
- Conscientiousness

Take a few minutes now to read the section you circled as representing your high points on Graph III.

Underline those behaviors that you agree are natural for you. In other words, if you circled C as your highest plot point on page 7, underline all the behavioral descriptions of C behavior that you believe apply to you. Also underline the environmental descriptors that you prefer. This is your primary behavioral style.

When you've finished personalizing the high-point section, follow the same procedure for your second highest plot point. This is your secondary behavioral style. If you have a third high plot point on the graph, underline the appropriate behaviors and environmental descriptors for that behavior as well.

D Behavioral Tendencies

Let's look at these styles in more detail now, starting with D, or Dominance, behavior.

People who display Dominance behavior shape the environment by overcoming opposition to accomplish results. They tend to get immediate results, cause action, accept challenges, make quick decisions, question the status quo, take control, manage trouble, and solve problems.

People who use D behavior tend to be motivated in an environment that includes prestige, challenge, power and authority, straight talk and direct answers, opportunities for advancement and individual accomplishments, freedom from direct control and supervision, new and varied activities, and a wide scope of operations.

Now turn to your handout titled "High D-Dominance." When we describe people as having a "High" style, we mean people who have plot points in segments 5, 6, or 7 or that style on their Profile Graph m.

Let's review what we just learned about the D behavioral style. Please fill in items #1 through #5 on your handout.

All right. What is the basic orientation of a person with High D tendencies? In other words, what is a person who uses High D behaviors primarily interested in?

The answer is Goals or Results: And a person who is goal-oriented will move people to action and not have much patience for small talk. People with High D tendencies desire change and variety and will cause change to occur in their environments.

Now since people with D behavior like to have control of the environment and the people in it, they like to take authority and use it directly.

Remember, this is an internal motivation. It's what compels people with D tendencies to behave the way they

do. I'm sure you know people like this; you may even have a High D style yourself. D's like the challenge of getting the job done, no muss, no fuss, no chit-chat.

Fear can also motivate people with D tendencies, as it can motivate people with the other three behavioral tendencies. What we observe is behavior that is designed to avoid this fear. What do you think a person with the High D style would fear the most?

Finally, remember earlier when we discussed the motivating principle, "A person's strength, overused, may become a limitation"? Think about the D style. Also think of people you know who have High D tendencies. What are some of their strong characteristics that, when overused, can prove to be limitations. In other words, what are some of the less positive aspects of their behavior?

i Style Tendencies

Now let's look at people with i tendencies.

Like people with D behaviors, people who display i behaviors also enjoy shaping the environment. They don't do this by direction; however, they do it by bringing others into alliance through persuasion. In other words, people with High i tendencies are people-oriented. They contact people, make favorable impressions, are articulate, create motivational environments, generate enthusiasm, entertain people, and desire to help others and participate in groups.

What kind of environment do you think people with i behavior would tend to prefer?

People who display i behavior prefer environments that emphasize popularity, social recognition, public recognition of ability, group activities, democratic relationships, freedom of expression, and freedom from control and detail.

i Style Tendencies

Now turn to your handout titled “High i-Influence.”

Let's review what we just learned about the i behavioral style. Please fill in this handout, just as you did the last one.

What would you say is the most observable characteristic of the i style?

Discuss i style's orientation

Good. Now, what is the basic orientation of people with the High i style? Remember: the High D style was goal-oriented. What is the High i style oriented toward?

People who display High i behavior are socially oriented; they're often emotionally charged and love to entertain. This is because the positive motivator for High i behavior is social recognition. They need companionship, to be with people and to be approved of by people.

If social recognition is the positive motivation behind much i behavior, what do they fear? Remember, fear is also a motivator in the sense that people behave certain ways to avoid the things they fear.

I'm sure you know people who take criticism of their social interactions and of their personally felt adeptness as a personal rejection of them. In their minds, they're exhibiting i behavior. This doesn't mean their behavioral style is necessarily i; it just means that in this circumstance they display an i behavior.

All right. Now think of people you know, maybe even your co-workers, who have High i tendencies, who are real “people persons.” What are some of their strengths that may prove to be limitations? In other words, what are some of the less positive aspects of their behavior?

Keep in mind that, like the person with D tendencies, the highly motivated person with i tendencies is also interested in power. Except, the kind of power the person

with i tendencies wants is social power and influence. What questions are there about the Dominance or Influence styles we've just discussed?

S Style Tendencies

Next, let's look at S tendencies.

S, of course, stands for Steadiness, and people who display S behaviors are extremely predictable and reliable. They're particularly comfortable cooperating with others in carrying out tasks. People with S behavior demonstrate patience, show loyalty, are good listeners, and calm excited people.

Like people with D tendencies, but on a different level, they're interested in consistently accomplishing tasks; because of this, they tend to concentrate on jobs, develop specialized skills, and perform accepted work patterns.

You can see right away the differences between the styles we've discussed so far, can't you?

What kind of environment do people with S behavior tend to prefer? Well, they're motivated in safe and secure environments where:

- The status quo is the rule.
- Changes are the exception.
- Work does not continually infringe on home life.
- Credit is given for work accomplished.
- Territory is limited.
- Sincere appreciation for work is provided.
- The individual can identify with the group.
- Traditional procedures are observed.

Now turn to your handout titled "High S-Steadiness."

Now let's review what we just learned about the S behavioral style. Fill in this handout just as you did with the others.

What would you say is the most observable characteristic of the S style?

Now we've already mentioned that individuals with S tendencies are oriented toward tasks, but they're even more greatly interested in achieving results through team effort.

People who display the S style like structured, tranquil environments with calm interactions. They're particularly uncomfortable with the unknown. They like stable settings in which proven practices are followed. A common S style response is likely to be: "If it works, why change it?"

What do you think is the basic fear of individuals with S tendencies?

Now think again of people you know who have High S tendencies. What are some of their characteristics that prove to be limitations?

Like many of the fears we've discussed so far, possessiveness is just an over extension of an individual need, in this case, the person with S style's need for stability.

C Style Tendencies

Finally, let's look at C tendencies.

C stands for Conscientiousness. People with C tendencies emphasize working within existing circumstances to ensure quality and accuracy. They tend to:

- Pay attention to key directives and standards.
- Concentrate on details.
- Think analytically.
- Be diplomatic with people.
- Check for accuracy.
- Use subtle or indirect approaches to conflict.
- Analyze performance critically.

As we might expect, individuals with C tendencies prefer sheltered environments, those in which:

- Performance expectations are clearly defined.
- Quality and accuracy are valued.
- Atmosphere is reserved and business-like.

Now turn to your handout titled High "C" Conscientiousness.

Let's review what we just learned about the C behavioral style. Fill in this handout just as you've done before.

What would you say is the most observable characteristic of the High C style?

A person with a High C style may be a natural quality-control person who tends to be precise and prize information. Rather than being oriented toward people, High C individuals are more task-focused.

Because of their precise, careful approach to things, people with High C tendencies are cautious with people and relationships and much more comfortable with tasks. People are often too disorderly for people with a High C style. They're highly disciplined, organized people, who are motivated by doing things the correct or proper way.

What do you think the basic fear is of people with High C tendencies?

People with High C tendencies like to analyze the pros, cons, alternatives, and outcomes of things and thus remain in control of the task, process, situation.

Now think of people you know who have High C tendencies. What are some of their characteristics that prove to be limitations?

Keep in mind that even though we're calling these characteristics "limitations" for each style, they can also be seen as opportunities for change and improvement. Limitations or overuses are characteristics or behavioral tendencies that each of us may have, given our particular style, and they can be turned into strengths if we learn how to modify them.

Wrap-Up

Summary

As you know, we've covered a lot of information today about our behavioral styles, tendencies, and patterns. The Personal Profile System has helped us:

- Understand our work behavioral tendencies and develop a beginning understanding of how these styles may affect others.
- Understand, respect, appreciate, and value individual differences.
- Understand how to enhance our effectiveness in accomplishing tasks by improving our relationships with others.

Now, even more than we've done before, we're going to focus on our final goal for the seminar, which is to:

- Develop strategies for working together to increase productivity.
- Develop a working plan of action to increase your effectiveness in working with people with different styles.

Intensity Index

Do you see the blue bar of 28 numbers on the left side of each graph on page 5?

Since Graph III provides the most comprehensive picture of your self-perception, I'd like you to go to Graph III and draw a horizontal line from your D plot point straight across to the number on the blue bar. Then circle that number. Next, draw a similar horizontal line from your i plot point to the number on the blue bar. Repeat this step for the S and C plot points. We will use these numbers on the blue bar to complete our Job Factor Analysis.

Job Factor Analysis

Finally, we're going to return to the Job Factor Analysis questionnaire that we completed at the beginning of the session. Turn back to page 7.3, and record the scores that you calculated for ♥, ♣, ♦, and ♠. Enter the numbers in the first column (column A) of Table 7.1 on the next page.

Make the calculations, and follow the instructions associated with Table 7.1

Table 7.1: The Coating Inspector's Job Analysis

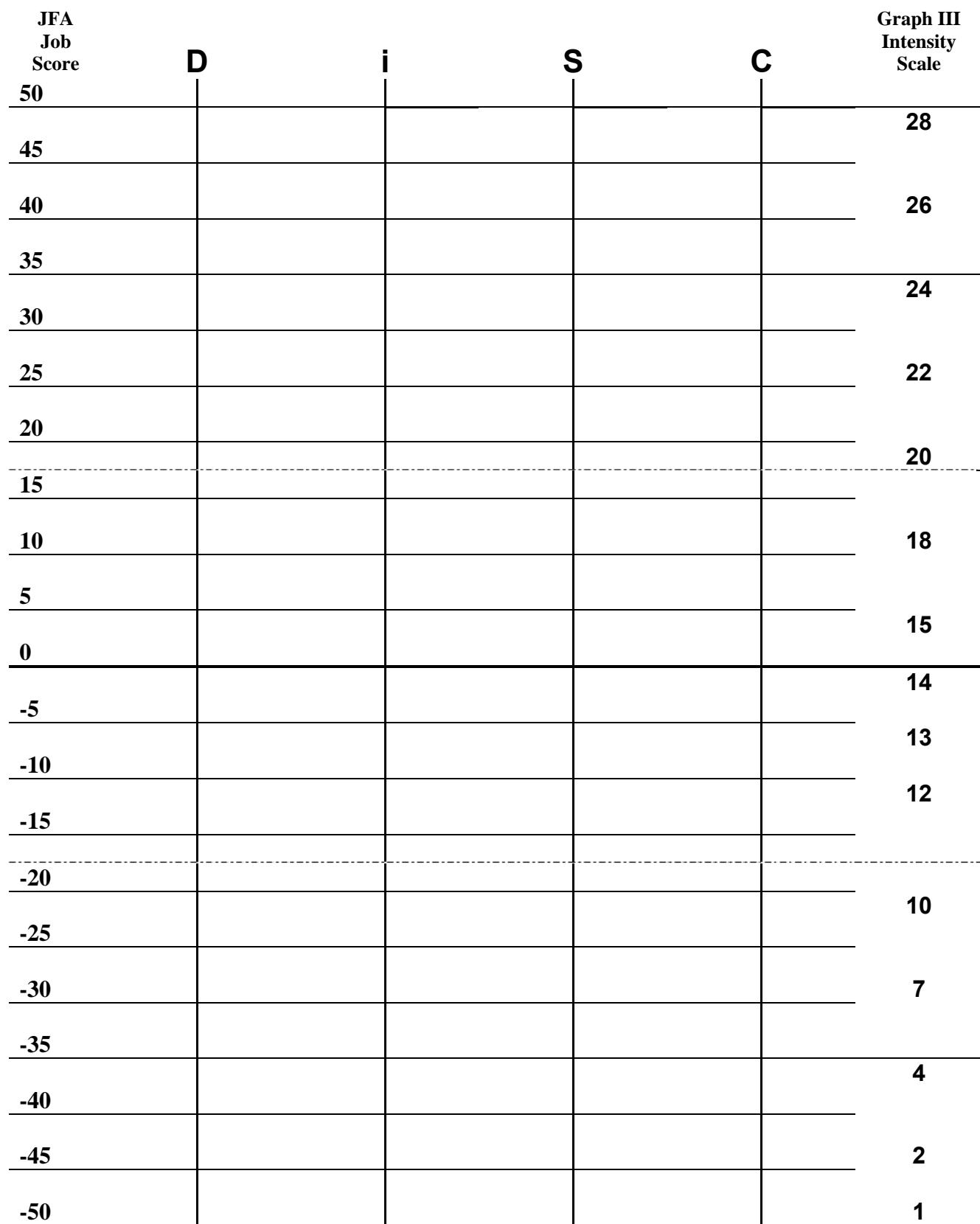
	A	B	C	F	D	
	Score (A)	Average Score (B = T ÷ 4)	Difference (C = A-B)	Multiplication Factor	Job Score (D=C x F)	Personality Type
	♥					D
	♣					i
	♦					S
	♠					C
Total (T)						

1. Collect the total scores for ♥ ♣ ♦ ♠ from page 7.3 and write in appropriate box of column A.
2. Total the scores in column A, and write into Total (T) box.
3. Divide Total scores (T) by 4, and write into each box of column B.
4. Subtract number in column B from number in column A, and write in column C. Keep positive or negative indicators (i.e. if column B is more than column A, number C is negative, if number in column B is less than number in column A, number is positive.)
5. Find Factor (F), based on Average score (column B) from table below.

Job Factor Calculator (F)			
When the average score (B) is:			
12 through 13	F = 8	13.5 through 15	F = 7
15.5 through 17.5	F = 6	18 through 18.5	F = 5.5
19 through 21.5	F = 5	22 through 23	F = 4.5
23.3 through 26.5	F = 4	27 through 28	F = 3.5

6. Multiply number in column C by Factor (F), and place resulting number in column D.
7. Transfer numbers in column D to appropriate position on Job Analysis Graph (next page), and draw the graph. (Example: D=27, circle +27 on D line, I=-5, circle -5 on I line, etc.)
8. Note: if score in any category is >50 or <-50, use "50" or "-50" on appropriate scale.

The Coating Inspector's Job Analysis Graph



On the same graph (previous page) plot the PPS graph III. Use the Intensity Index numbers from graph III to help you make the plot. Use either a different color pen for the second graph line, or make it a series of dashes to differentiate the two lines.

The two plots represent:

- Your own ideas of an ideal profile for a coating inspector.
- Your own personality at work, as defined by you for your current working situation.

Are the two lines identical? If not, there may be some conflict between your ideas regarding yourself in the work environment and the 'ideal' coating inspector. Examine the differences on the vertical lines (DiSC). Identify whether your own working personality needs to be stronger (i.e., moved up the scale), or weaker (i.e., moved down the scale) to match the profile you decided is appropriate for a coating inspector.

You can use the Interpretations of the PPS system (page 7) to identify personality traits that might be modified or adjusted in the work environment to more closely meet your own expectations.

=====

Remember that there are no "correct" personality types, just different people. The purpose of this exercise is to help you to identify different personality traits, and find ways to improve relationships by knowing more about the people that we work with.

As coating inspectors we can become better team players if we use the information we have learned today.

=====

Word	Alternate words	Definition (person who)
accommodating	helpful	is willing to adjust or change when requested, or to be helpful
accurate	factual, correct	wants to be correct, checks all the facts
active	energetic, dynamic	rarely rests
adaptable	versatile, adjustable	can accept change
adeptness	competence, proficiency	possesses many skills
admirable	commendable, praiseworthy	is admired by colleagues
adventurous (adventuresome)	enterprising, questioning	willing to try new experiences, perhaps take risks
affable	friendly, easy-going, amiable	is a good companion
aggressive	assertive, pushy, determined	invites conflict
agreeable	amiable, friendly, nice	is co-operative, willing to agree
alert	attentive, vigilant, watchful	is wide awake and is wary
aloof	detached, distant	difficult to communicate with
amiable	friendly, pleasant, likeable	good company
analytical	logical, rational, systematic	considers the facts and seeks a solution
animated	active, energized, lively	is demonstrative, has lively body-language
antagonism	conflict, hostility, discord	actively causes contention
appealing	attractive, pleasant	likeable
arbitrary	impulsive, subjective, erratic	is not open to ideas other than own
argumentative	quarrelsome, combative	cannot see others viewpoint
assertive	forceful, confident, domineering, outspoken	pushes his or her own ideas forward
attractive	appealing, pleasant, enjoyable	attracts others
belligerent	contentious, truculent, aggressive	usually engages in conflict or aggressive behavior
bold	brave, daring, fearless	willing to take risks, make decisions
brave	unafraid, fearless, courageous	is willing to take chances
calculated risk taker	balanced activist, logical, analytical adventurer	willing to take risks, but studies options before making decisions
calm	tranquil, not agitated	is impassive, serene
captivating	charming, influential, charismatic	able to command attention
careful	cautious, takes care	attentive to detail, avoids mistakes
cautious	wary, careful	does not wish to take risks
change-oriented	likes change, seeks new experience	does not want to be in a rut and likes challenge of new things
charming	delightful, fascinating	pleasing to others
cheerful	happy, lighthearted, optimistic	sees each day as a new beginning
cognitive	aware, alert, recognizes issues	can know or perceive action from emotion
collaboration	cooperation, united effort	is willing to work with others for the common good
companionable	friendly,	enjoys company, likes fellowship with associates
competitive	aggressive, ambitious,	compares actions and achievements with other people and wants to win
complacent	indifferent, apathetic, nonchalant	is satisfied with own ideas, is not willing to make an effort
compliant	yielding, agreeable	complies with demands or requests
condescending	disdainful, patronizing	feels others are beneath them, but will tolerate them
confident	assured, secure, certain	is there own person in thinking and acting.
conscientious	painstaking, fastidious, meticulous, detailed	takes care in every detail
conservative	traditional, orthodox, moderate	likes the existing order of things

Word	Alternate words	Definition (person who)
considerate	kind, thoughtful, polite	thinks of other people, is aware of other's needs
contented	satisfied, comfortable	is satisfied with things as they are
controlled	reserved, regulated, managed, suppresses emotions	can regulate and direct
conventional	regular, standard, prefers customary approach	lacks originality or spontaneity
convincing	persuasive, reassuring, can cause others to agree or believe	has credibility
co-operative	agreeable, willing	willing to work together with others
cordial	friendly, congenial	has sincerity of feeling and warmth
courteous	polite, refined, gracious	has considerate regard for others
critical	crucial, important, momentous	gives careful precise evaluations
cultured	learned, cultivated	is refined in morals, mind, and taste
daring	bold, brave, fearless, courageous	willing to take risks, try new ideas
decisive	conclusive, definite	makes decisions readily
defiant	bold, insolent, rebellious	disregards authority and opposition
deliberate	calculated, considered, studied	thinks and considers carefully
demanding	insistent, exacting	asks boldly and authoritatively
demeanor	behavior, conduct	acts in a proper and suitable manner
dependent	helpless, reliant, vulnerable	is subject to outside control
determined	resolved, unwavering	has a fixed purpose
devout	dedicated, religious	is heartfelt and sincere
diligent	hard-working, industrious	shows perseverance in actions
diplomatic	tactful, suave	is skillful in dealing with people
direct	blunt, candid, frank, plain	to the point
discontented	dissatisfied, unhappy	is restless, uneasy in mind
discriminating	discerning, fastidious	can draw clear distinctions
dispassionate	calmly, objective	will be impartial and unbiased
dissension	difference of opinion	might be dissatisfied or angry
dominant	commanding, controlling	has power
domineering	taking control	demands control, uses power
eager	impatient, anxious, ready for action	shows enthusiasm or interest
easy-going	relaxed, care-free	does not get upset easily, is easy to please
easily led	no strong ideas	can be manipulated
egocentric	self-centered	has strong personality drive
emotional	impulsive	reacts with strong feelings
empathy	sympathetic	can understand without experiencing
enthusiastic	strongly attached to a cause, excited	has keen, animated interest in something particular
evasive	not direct or frank	avoids ready perception or understanding
even-tempered	calm	not excitable, slow to become angry
expressive	demonstrative, animated, flamboyant	shares ideas and thoughts freely
extroverted	out going, socializer	likes attention, likes to be seen
fact-finder	reality check	collects information correctly
factual	literal, exact	accepts only truth
fault-finding	critical, carping	is dissatisfied and finds fault
fearful	apprehensive, afraid	is filled with uneasiness
fidgety	nervous, restless	cannot sit or stand still for long

Word	Alternate words	Definition (person who)
firm	strong, unyielding	takes a strong view, willing to be strong
force of character	mentally strong	imposes ones opinion on someone
forceful	powerful, commanding	demands attention
friendly	showing interest and goodwill, open, cheerful	well disposed, not antagonistic is also helpful
frustrated by status quo	impatient, upset	cannot easily accept established order
fussy	finicky, particular, hard to please	wants all the details to be correct, everything to be neat and tidy
generous	unselfish, charitable	willing to share
gentle	tender, kind	refined, not harsh or rough
good-mixer	congenial, sociable	likes to be with other people
good-natured	amiable, having a pleasant, friendly disposition	others like to be associated with
gregarious	sociable	enjoys the company of others
harmonious	compatible, complimentary	shows agreement in views, feelings
helpful	kind	willing to help
high standards	yardsticks	expects others to live by own actions
high-spirited	energetic	full of energy, possibly nervous
humble	modest, unassuming	not proud
impartial	neutral, not biased	does not show any preference
impatient	lacking patience, overactive	will not wait, acts quickly
impetuous	reckless, headlong	acts on sudden impulse without forethought
impulsive	spontaneous, acts suddenly, unpredictable	acts on impulse, will make a decision and act on it very quickly and perhaps unpredictably
inactive	idle, indolent	has no desire for action
independent	self-reliant	willing to act alone, may prefer to act alone
individualistic	independent	can be self interested, no regard for others
influential	powerful, effective	wields a greater control
inquisitive	curious, searching	asks questions, wants to know the issues and facts
insistent	firm, determined	persists, will not be deflected
inspiring	encouraging, motivating	influences others
insightful	intuitive	able to see into a situation
intimidation	scare, make timid	makes others fearful by whatever means
introspective	reflective, thinker	looks inward, thinks deeply
introverted	inward looking	focuses on themselves, possibly shy
irrational	absurd, senseless	acts contrary to reason
jovial	genial, playful, humorous	makes many jokes, has good humor
joyful	happy, carefree, full of joy	has contentment and satisfaction
kind	sympathetic, nice, helpful	friendly, particularly when sympathy is needed
lenient	merciful,	is not harsh or severe when judging others
light-hearted	care-free, cheerful	not too serious
logical	wise, rational, sound	conforms to the laws of logic
loyal	dependable, reliable	faithful to friends or to the company, can be relied on
magnetic	charismatic	has ability to attract others
manipulative	skillful	can handle ideas and people shrewdly
mature	fully developed	is highly developed intellect
mild	amiable-kind	gentle and moderate in actions
mobile	movable-free flowing	can move easily from one thing to another
moderate	not extreme	avoids extremes, takes middle road

Word	Alternate words	Definition (person who)
modest	self-effacing, not pretentious	not boastful, plays down their own achievements
neighborly	friendly, sociable	easily makes friends
nervy	brash-impudent	is insolently assured
non-demonstrative	reserved	can not show inner feelings
nonchalant	casually indifferent	does not show interest or excitement
obedient	willing to follow orders	will obey orders or instructions
obliging	helpful	ready to help or respond
observant	watchful	sees details
observing	looking at, watching	spectator
obstinate	unyielding, stubborn	is fixed in ones purpose or opinion
open-minded	reasonable, receptive	is free from prejudiced conclusions
opinionated	close minded	obstinately attached to ones own views
optimistic	positive, bright outlook	sees the good side of any situation
original	creative, inventive	has new ideas
outgoing	friendly, sociable, open	joins in with the crowd, shares themselves
outspoken	speaks out, expresses opinion freely, bold speaker	can be very candid, gives opinions frankly
own person	confident	does not need ego satisfaction
passive	quiet, inactive	submits without resistance
patient	persevering, tolerant	has patience, can wait for results
peaceful	undisturbed	can act without hostile actions
perceptive	observant, aware	can see and recognize more detail
perfectionist	idealistic, flawless	sets high goals for self and others
persistent	unrelenting	keeps trying, will not give in
persuasive	convincing	has the ability to make you believe or agree
pessimistic	gloomy, cynical	takes a dark view of anything
pioneering	original, adventurous	willing to try something new, test new ideas
playful	frisky	likes to play or make a joke
poised	confident, polished, gracious	acts with superior confidence
polished	slick, practiced	has great style
popular	likeable	liked by many people
positive	out-going, not negative	always looks on the bright side of life
possessive	selfish	wants to dominate physically or emotionally
precise	accurate, specific	likes to have exact descriptions and definitions
predictable	consistent, unchangeable	actions can be anticipated because they rarely change
prerogatives	rights, automatic choices	demands rights hereditary or official
private	reserved, guarded	does not easily share personal thoughts or opinions
quarrelsome	argumentative,	disagrees often, picks fights
quick	sharp, intelligent	has readiness of movement or action
quiet	serene, calm	is modest, not showy
realistic	practical, down to earth	likes factual not theoretical ideas
rebellious	resentful	resists allocated duties, fights against the status quo
receptive	open minded, amenable, flexible, perceptive	is willing to listen, responds well to suggestions or new ideas
refined	cultured	behaves well, has good manners
reflective	thoughtful	gives careful consideration and thought
relaxed	at ease-unperturbed	is less formal or strict
reserved	restrained	hides or does not share emotions
resigned	submissive	reconciles oneself to the inevitable

Word	Alternate words	Definition (person who)
respectful	deferential	shows respect to others
responsive	reactive, supportive	quick to provide answers, act in support
restless	uneasy, not relaxed	does not rest, seeks change, needs activity
restrained	cautious	is able to hold back from quick action
reticent	silent, reserved	reluctant to speak out,
retiring	humble, unassuming	does not need social activity
ridicule	taunt – deride	makes fun at actions of another
rigid	fixed, unbending	does not easily accept change or new ideas
risk-taker (see also calculated risk-taker)	gambler	takes risks
sarcastic	mocking – scornful	uses words to conceal own failings
satisfied	contented, pleased, have wishes fulfilled	is free from doubt of anxiety, well pleased with lot in life
self-reliant	self-contained, confident	able to trust their own judgement, not dependant on others
self-assured	confident	sure of themselves
self-conscious	shy, self-aware	not confident
self-critical	harsh, judgmental (to self)	finds fault with own achievements
self-disclosure	expose ones actions	can tell of ones faults without worry
self-effacing	modest	own achievements
self-promoting	ambitious	wants to work in behalf of oneself
self-reliant	resourceful	does not need others judgements
self-righteous	formality, hypocrisy	feels morally right in own actions
sensitive	touchy	easily offended
serene	calm, regal, peaceful	not troubled, able to live without worry
sociable	gregarious, companionable	enjoys the company of others, likes to be part of a crowd
soft-spoken	mild, quiet	speaks softly
spontaneous	unrestrained	acts on own impulse
stable	steadfast	is not easily moved, shaken, overthrown
stimulating	exciting, encouraging	provides new ideas, promotes enthusiasm and new thinking
strong-willed	determined	has confidence in their own ideas and abilities, willing to push forward with projects
stubborn	unyielding, strong-willed	will not change their mind
submissive	yielding	does not resist, gives in
sulky	ill-humored – cross	is dismal and gloomy
suspicious	distrustful – skeptical	imagines something wrong without proof
sweet	agreeable, pleasant	Is gentle, pleasing and kind
sympathetic	understanding, in agreement with	is responsive to others' moods or opinions
systematic	logical, organized	follows a logical sequence in their work activities
tactful	diplomatic, discreet, inoffensive, polite	careful with words
tactless	not possessing tact, indiscrete	not careful with words
talkative	talks often, likes to talk	likes to share ones own thoughts
team-person	colleague	feels secure working with others
tenacity	constancy, persistent	holds strong opinions and rights
thorough	carry to completion, detailed	remembers all the details, misses nothing
Timid	shy, hesitant	lacking in self-confidence, may be frightened
tolerant	lenient, liberal	is willing to accept beliefs and views even if

Word	Alternate words	Definition (person who)
		different
trusting	confidence	relies on integrity of others
unassuming	modest, reserved	is not demanding, does not proclaim own achievements
unconquerable	proud, unyielding	is resistant to criticism
unobtrusive	modest, shy, timid	will not force opinions others without request
unsure	doubtful, uncertain	cannot be definite on some ideas
verbalize	use words	expresses oneself with words
vigorous	forceful, powerful	is energetic
weighs pros and cons	open minded sees both sides	does not take action before all avenues are considered
well-disciplined	controlled, behaves well	will comply with rules and regulations
will power	self-control	controls purpose over impulse
willing	ready to act, open	ready to contribute or help, open to suggestion
withdrawn	reserved, retiring	is unsociable, mentally detached
worrisome	irksome, annoying	sees the negative in a situation



Level 2

Chapter 8

Case Study B

"It's rained every day this week," Butch Gofer thought as he drove to work that Friday, August 15. "This paint contract job with Loverboy Painting sure isn't turning out like I thought it would; I've worked every weekend since the beginning of summer and there's still no end in sight. I should get a plaque for all this extra work," he thought.

When he arrived at work at Blue Chip Fabricators, Butch was greeted by Malcolm Bodger, the shop foreman. "Looks like a great day for painting," Malcolm said cheerfully as he met Butch in the parking lot. "It will be great if that pencil-neck inspector doesn't show up with his stack of nonconformance reports," said Butch.

"Too late for that," said Malcolm, "There he is now."

Simon Peabody had worked for Impeccable Inspections Inc. for almost five years and had developed a reputation for thoroughness and attention to detail. Impeccable Inspections Inc. had been hired by Skinflint Pipeline, Ltd. to oversee quality control for a pipeline, which was being installed in Alaska and was due for completion by the end of September. The 26-in.-diameter steel pipeline was being coated with 25 mils of 100%-solids polyurethane by Loverboy Painting, Inc. at Blue Chip Fabricators' yard in Seattle.

"Perhaps you could give me an update on what work has been performed since my last inspection," Simon said to Butch as he approached. "All we've managed to do is patch the stuff you rejected last time," said Butch. "With all this rain, I haven't been able to coat a stick of pipe and Blue Chip's yard is getting so crowded that I can't even turn around."

"Well, it's got to be right before it gets on that boat or there will be hell to pay in Alaska," Simon said.

When they got to the work site, Simon began inspecting pipe and making notes in a leather-bound journal. After a few minutes he approached Butch who was preparing his crew for the day's work. "I'm going to have to write an NCR (Nonconformance Report) on those patches you've



made," Simon said. "What for?" asked Butch. "Well, the specification says under the workmanship clause that the surface of the paint shall be free of any runs, sags, or overspray. There is overspray around each one of those patches you made. In addition, the previous coat has been sanded beyond the area of the patch making the overall appearance unsightly, which also is not allowed by the spec," Simon said.

Butch inhaled deeply and began to turn bright crimson as Simon described his NCR and finally exploded, "What am I supposed to do about that Simon? The specification dictates that I sand the previous coat and that I spray apply all patches. If you think that I am going to mask around each patch, you're out of your *-&#@ mind."

"It's not my job to show you how to conform with the specification, Mr. Gofer. All I know is that it does not conform and is not acceptable," Simon said. "Well, I'm going to go see Malcolm about this," Butch said, storming off, "because I've had it up to here!"

As Simon and Butch entered the job site office, Malcolm was chatting amiably to Sally, one of the secretaries, over a cup of coffee. Just then the phone rang. "Bert Stoud on line one," Sally said. "I can guess what this is about," said Malcolm as he picked up the phone. "Where is my pipe?" Bert shouted. "You promised me a shipment last week and I understand that it still hasn't gone out." "That's true, Mr. Stoud," Malcolm said. "Tell you what, the painting contractor and the inspector just walked in my office, let me put them on the speaker phone."

After listening for a couple of minutes, Bert had enough. "I don't want to hear about weather problems and nonconformance reports, all I care about is getting pipe on the jobsite. If I get shut down due to lack of pipe, both Blue Chip and Loverboy are going to pay through the nose in back charges. Get me some acceptable pipe by the end of next week or else," Bert said and hung up.

They all sat looking at each other for a few minutes when Malcolm finally asked, "O.K. you guys, how can we work out these differences and get some pipe shipped?"



SUMMARY TEAM EXERCISE:

1. Identify the styles represented by the individuals involved and explain why you have made those evaluations. Use class notes.
2. Describe what it is about the people/materials/process that make this a difficult situation.
3. Describe how the problem could be handled more effectively or made less difficult.
4. Develop a plan of four to six action steps to use on the job to work more effectively with the other three styles represented.
5. Prepare to make a 5- to 10-minute presentation of items 1 through 4 to the rest of the class.





Level 2

Chapter 9

Practical Math

Let's Think Metric

Introduction

Gradually, the United States is converting from its system of measuring inches and pounds to the metric system. Perhaps within the next *generation or two*, the metric system will be adopted in the United States, and the inch ruler will be replaced by the centimeter ruler.

About 20 years ago, attempts were made to change to metric, but the efforts failed from lack of support by business and industry.

To help things along, in 1991 Congress passed a law that made it mandatory, after 1992, for the United States Government to buy only those goods produced in metric units. The law did not say we had to change to metric, it merely said the government wouldn't buy anything unless it was produced in metric units.

Europe and the United Kingdom have similar rules and regulations, so if you want to do business with the governments in Europe and the United States you must start to think metric. If you do any inspection work in Europe or most other parts of the world, you will need to know the metric system and be able to work with it.

Some major United States industries, such as the liquor, pharmaceutical, and automotive industries, already produce goods in metric units. Others, such as the food industry, list both United States and metric units on their product labels. United States automobiles have the speedometer in both miles per hour and kilometers per hour.

The metric system tends to put most Americans on edge, generally because they think it will be too difficult. Actually, the metric system, like our dollar, is based on the decimal system so in many ways it is easier to use than our system of inches, pounds, and degrees Fahrenheit.

To learn the metric system, we need to learn to *think* in that system—to *conceptualize* not just *visualize* the quantity of the physical dimension being measured by the metric unit. We can visualize distance, but we cannot visualize temperature, nor can we visualize mass (weight). We need to know what it feels like to lift a mass of a certain size, and if it is too heavy to lift, we need another reference and must be able to visualize something we already know is heavy.

Objectives

In this exercise, we want to try to get a better *feel* for the metric system. We want to:

- Look at some metric units of measurement and their symbols
- Identify prefixes to be used with metric units
- Identify a few body reference sizes for small distances
- List comparative measurements of many of the common objects around us
- Explore some simple ways to make quick conversion from one system to the other to obtain approximate values
- Complete some simple exercises using various metric units

Simplified Metric System

The metric system is based on the simplified system called SI (Système International d'Unités), which was adopted about 1960 by most of the important international scientific organizations for scientific use throughout the world. In 1972, this international agreement was reaffirmed and signed by the major industrial nations, including the United States.

Metric Units and SI Symbols

The table below gives the most commonly used metric units and SI symbols (not abbreviations)

TABLE 9.1

Physical Quantity	Unit	SI Symbol
length	meter (metre)	M
volume	liter (litre)	L
weight (mass)	gram (gramme)	G
temperature	degrees Celsius	°C

Prefixes

The metric system has a root for each physical quantity and a prefix for each significant size. These prefixes tell how many times larger or smaller a unit is and they also make things comfortably sized, so that with them, no SI unit is *too small* or *too large*.

Each prefix is some multiple of 10, and can be used with each root. The prefix *kilo* means a thousand times. Kilo added to the root *gram* produces 1,000 grams which is a kilogram. Kilo added to *meter* makes kilometer a measure of distance equal to 1,000 meters.

The table below gives the most common prefixes and their symbols. Most prefixes that end in *i* make the root *smaller* and the ones that end in *o* or *a* make things *larger*.

TABLE 9.2

Prefixes(makes smaller)	Meaning	Symbol
deci	0.1 (one tenth of)	d
centi	0.01 (one hundredth of)	c
milli	0.001 (one thousandth of)	m
micro	0.000 001 (one millionth of)	μ
Makes larger		
hecto	a hundred times (100)	h
kilo	a thousand times (1,000)	k
mega	a million times (1,000,000)	M

Common Units for Small Distances

In the metric system, the distances between a tenth of an inch and a few yards normally are expressed in three ways:

- In millimeters (mm)
- In centimeters (cm)
- As decimal parts of a meter (m)

Definitions

- Meter

In the eighteenth century, the meter was defined as 1/10,000,000 of the distance between the Equator and the North Pole. Now it is defined more precisely as 1,650,763.73 wavelengths of orange-red line of the isotope krypton-86 (or 39.37 in.).

- Units of Mass (Weight):

There are four major units of mass (weight):

- The milligram (mg) (about the weight of a grain of salt.)
- The gram (g), (which is the weight of 1 ml of water)
- The kilogram (kg)
- The megagram (Mg)

- Units of Volume:

In the United States, units like the dry quart and the liquid quart are very nearly, but not exactly, the same. Metric measures for volume are much simpler, because one set of units is for both liquid and dry measures. The metric system uses three main units to measure volume:

- Liter (L)
- Milliliter (mL)
- Cubic meter (m^3)

The most common unit for volume is the liter because it is so near the quart (actually 5% more than a quart). By definition, 1 liter is 1 cubic decimeter (1 dm^3). A cube with each side equal to 1 decimeter (10 cm) will hold 1 liter

- Units of Temperature

Temperature is based on the Celsius scale formerly known as the Centigrade scale.

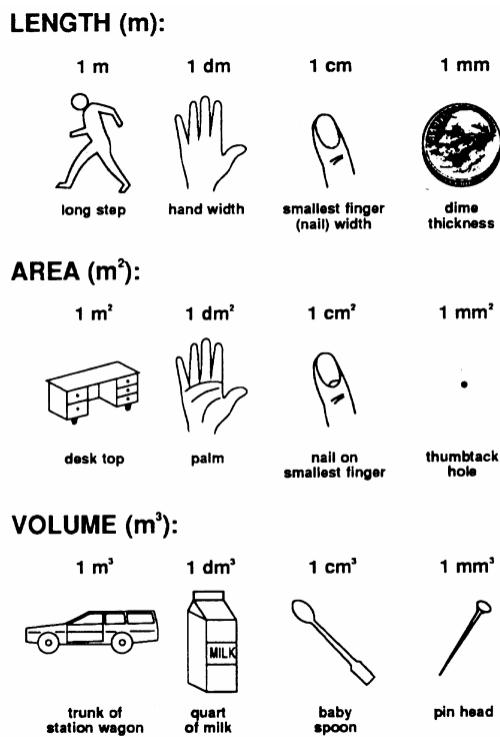
The spread is 100° between the point at which water boils (100°C) and freezes at 0°C . With the Fahrenheit scale, this spread is 180° .

Distances

We can identify certain body reference sizes that could be used to estimate small distances. The following are some average body reference measurements:

- Width of the nail on the smallest finger 10 mm
- Tips of 4 fingers pressed together 50 mm
- Width of hand from thumb knuckle to side 100 mm
- Left shoulder to longest right finger tip 1 m
- From elbow to longest finger tip 500 mm
- Length of hand from wrist to the longest finger tip 200 mm

Figure 9.1 shows how m, m^2 , and m^3 , and their submultiples relate to parts of the human body and to some common objects.



The size represented by dm^3 (10 cm x 10 cm x 10 cm) is commonly referred to as the liter (litre). The symbol cm^3 is often denoted by the mL and sometimes, incorrectly in the United States, also by the cc. In engineering, and in all technical writing, only the SI symbols (m^3 , dm^3 , cm^3 , mm^3 , km^3 , etc.) should be used.

In engineering drafting, dimensions are shown in mm only. Engineers generally shun the prefixes centi and deci except with volume. These prefixes, centi and deci, shown in Table 9.3, could be replaced with the prefix m or no prefix at all. In this case, the measurements would become:

- The long step (pace) would be 1 m or 1,000 mm
- The hand width would change from 1 dm to 100 mm
- The smallest fingernail width changes from 1 cm to 10 mm
- The thickness of the dime would remain at 1 mm
- The area of the smallest fingernail changes from 1 cm^2 to 100 mm^2

Measurements of Some Common Objects

- Distance—Think Meters (Metres)

- Diameter of a quarter 25 mm
- Diameter of a penny 18 mm
- Diameter of a cola can 50 mm
- Diameter of a pencil 8 mm
- Diameter of a needle 1 mm
- Diameter of thread 0.3 mm
- Diameter of large tree 1 m
- Diameter of an aspirin 10 mm
- Height of cola can 120 mm
- Height of average woman 1.65 m
- Height of average man 1.80 m
- Height of basketball player 2.13 m
- Height of jockey 1.5 m
- Height of Sears Tower 442 m

- Height of Empire State Building 381 m
- Furlong 200 m
- Home plate to left-field wall 100 m
- Pitchers mound to home plate 19 m
- Football field 90 m
- Olympic high jump 2.25 m
- Olympic pole vault 5.60 m
- Eleven football fields 1 km
- Area—Think Square Meters (Metres)
 - Office desktop 1 m^2

In metric, land is measured in are(s) (pronounced air). One are is equal to 100 m^2 .

($10 \text{ m} \times 10 \text{ m}$). A hectare (hecto = 100) is $10,000 \text{ m}^2$ or 1 km^2 . This is equal to 2.5 acres or the equivalent of a typical baseball field.

- Volume—Think Liters (Litres)

- Box to hold large refrigerator, or the trunk space of average-size station wagon 1 m^3
- Quart of milk 1 dm^3 (1 liter)
- Baby spoon 1 cm^3 (1 mL)
- 1 Teaspoon 5 mL
- 1 Tablespoon 15 mL
- 1 Cup 250 mL
- 1 U.S. gallon of milk 3.8 L (liters)
- A cube $10 \text{ cm} \times 10 \text{ cm} \times 10 \text{ cm}$ 1 dm^3 or 1 L
- A cube $1 \text{ cm} \times 1 \text{ cm} \times 1 \text{ cm}$ 1 cm^3 or 1 mL

- Weight—Think Grams (Grammes)

– A box 1 m x 1 m x 1m equals 1 m ³ and will hold	1,000 kg of water
– 1 metric ton (tonne)	1,000 kg
– A large man	100 kg
– An average man	80 kg
– A small woman	50 kg
– An average woman	60 kg
– Heavy wrestler	125 kg
– Jockey	45 kg
– 1 large apple	100 g
– 1 fresh pineapple	1 kg
– Large can of soup	500 g
– Telephone receiver	300 g
– D-cell battery	100 g
– 1 nickel	5 g
– 1 carpet tack	1 g
– Heavy suitcase	25 kg
– Christmas turkey	9 kg

- Temperature—Think Celsius

<u>Degrees</u>	<u>°F</u>	<u>°C</u>
– Water freezes	32	0
– Water boils	212	100
– Room temperature	70	20
– Bitter cold day	-22	-30
– Coldest day in N. Dakota	-40	-40
– Scorching day in Arizona	113	45

Body temperatures

– Normal body temperature	98.6	37
– Slight cold	99.5	37.5
– Low-grade fever	100.5	38
– Flu (influenza)	102	39
– Quite ill	104	40
– Alarming	105	40.5
– Convulsions	106	41

Miscellaneous temperatures: (approx.)

– Iron melts	4,500	3,000
– Gold melts	1,800	1,000
– Broiling steaks	480	250
– Baking potato	390	200
– Baking cake	375	190

- Pressure—Think Pascal

Pressure is defined as the action of a force spread over an area. The SI unit is N/m^2 and this unit was named *pascal* in honor of the French scientist. The symbol of the unit is metric Pa.

The pascal replaces all other pressure units including the unit called bar, though frequently this term is still used by some engineers.

In SI, the distinction between absolute pressure, gauge pressure, and vacuum pressure must be stated in words because there are no symbols for these. For example:

- Absolute pressure of 150 kPa
- Gauge pressure of 80 kPa; 85 above ambient
- 85 below ambient (the term *vacuum* is usually avoided)

The unit of pressure is one of those units where a difference between a scale and an increment may cause an error in conversion; for example, it is often not apparent what is meant by atmosphere. The scale conversion is complicated by the existence of two standardized reference air pressures—the *international* (101.325 kPa) and the *technical* (99.067 kPa).

The reference ambient (atmospheric, barometric) pressure level is *expected* to be *established* for *engineering* work at 100 kPa, with the increment being the pascal.

Some common equivalent values of pressure include:

- 1 psi is a little less than 7 kPa (actual 6.895 kPa)
- 1 standard atmosphere is exactly 100 kPa
- 1 MPa is 10 times the atmosphere
- 1 bar (when used) is exactly 100 kPa
- 1 in. Mercury (Hg) is about 3.5 kPa
- Speed—Think Kilometers per Hour

In metric, speed is measured in kilometers per hour (km/h), and for scientific work it is measured in meters per second (m/s). One kilometer is about six-tenths of a mile, so 100 km/h is equal to about 60 miles per hour; 1 mile is equal to 1.609 km; therefore 100 miles per hour is equal to 161 km/h.

References for speed (approximate):

- Walking at a moderate pace 5 km/h
- Jogging 10 km/h
- Driving in a school zone 32 km/h
- City driving 55 km/h
- Freeway (turnpike) driving 113 km/h
- Driving the Indianapolis Speedway 320 km/h
- Traveling on a jet plane 965 km/h

Short Cuts

- Distance

For approximate values, some simple conversions may be used, but for precise scientific or engineering work, exact conversion factors *must* be used. Rule-of-thumb conversions are easy to memorize. Two of these should be remembered.

- When converting from a *larger* unit to a *smaller* unit, you get a *larger* number.

For example, when you want to convert 5 in. to cm, multiply the 5 by 2.5, which yields 12.5.

Larger Unit	Smaller Unit
5 in.	12.5 cm

The reverse is true:

- When converting from a *smaller* unit to a *larger* unit, you will get a *smaller* number.

Smaller unit	Larger Unit
50 cm	0.05 m

The conversion factor from in. to cm is 2.54 or 2.5. You can multiply in. by 2.5, or, for approximate values, you can double the in. and add half.

For instance:

To convert 20 in. to cm, double 20 and add half, or $20 \times 2 = 40 + 10$, which equals 50 cm.

When converting miles to km, you may multiply miles by the conversion factor of 1.609 (km) per mile or simply add 60%. For example, 100 miles per hour is equivalent to 100 mph + 60 % of 100 mph or 160 km/h.

- Temperature

The conversion from $^{\circ}\text{F}$ to $^{\circ}\text{C}$ is based on the formula:

$$^{\circ}\text{C} = \frac{5}{9} ({}^{\circ}\text{F} - 32)$$

For *approximate* values of $^{\circ}\text{C}$, take half the temperature in $^{\circ}\text{F}$ and subtract 15, as follows

$$^{\circ}\text{C} = \frac{1}{2} ({}^{\circ}\text{F}) - 15$$

$$^{\circ}\text{C} = ({}^{\circ}\text{F} - 32) \times \frac{5}{9}$$

$$^{\circ}\text{C} = (90 - 32) \times \frac{5}{9} = 32.2^{\circ}\text{C}$$

- Weight (Mass)

When converting from lbs to kg, remember a pound is smaller than a kilogram (1 lb = 0.45 kg). To make a quick conversion, take half and then some, say 10%, of what is left.

For example, using 90 lbs

$$1/2 (90) = 45$$

10% of 45 is 4.5 (say 5), so $45 - 5 = 40$ kg. The actual value is 40.5 kg.

- Volume

When working with liters, remember a liter is larger than a quart (1 L = 1.057 quarts). If you treat a quart as though it were a liter the error is only about 5 %.

Exercises with Metrics

1. Write the name of the prefix and corresponding symbol that is used to express each of the following:

- a. 0.01 _____ _____
- b. 1,000,000 times _____ _____
- c. 1,000 times _____ _____
- d. 0.1 _____ _____
- e. 0.000001 _____ _____
- f. 100 times _____ _____
- g. 0.001 _____ _____

2. Change each of the following quantities to its equivalent in the root size, and list the corresponding symbol:

- a. 1 milligram _____ gram _____
- b. 1 kilometer _____ meters _____
- c. 1 microgram _____ gram _____
- d. 1 centimeter _____ m _____
- e. 1 micrometer _____ meter _____
- f. 1 millimeter _____ meter _____
- g. 1 centiliter _____ liter _____

3. Write the metric symbol for each of these units:

- a. centiliter _____
- b. kilometer _____
- c. centimeter _____
- d. milliliter _____

- e. deciliter _____
- f. micrometer _____
- g. hectogram _____
- h. millimeter _____
- i. megagram _____
- j. micron _____

4. Without looking back at heights of some objects, complete the following:

- a. Your height in millimeters is _____ mm.
- b. A jockey would be about how tall in centimeters? _____ cm.
- c. The average man is about _____ cm.
- d. A basketball player would be about _____ cm.
- e. The height of a cola can is about _____ cm.

5. Without looking back, estimate the following:

- a. How much is 5 m³ of water in kilograms? _____ kg.
- b. What do you think a 200-lb package would weigh? _____ kg
- c. What does a liter of milk weigh in grams? _____ g or _____ kg
- d. 1 m³ of water weighs how much? _____ kg
- e. A teaspoon of medicine is _____ mL.
- f. A quart of milk is about _____ liter.

6. Without looking back, estimate the following:

- a. Normal body temperature _____ °C
- b. Water boils _____ °C
- c. Winter day in N. Dakota _____ °C
- d. Room temperature _____ °C

e. 100 kilometers is about _____ miles.

f. A jet plane travels at about _____ km/h.

7. Short cuts

a. Larger units to smaller units

10 in. _____ centimeters

1 meter _____ inches

1 meter _____ centimeters

1 hectare _____ acres

1 liter _____ milliliters

1 kilometer _____ meters

b. Smaller units to larger units

100 centimeters _____ meter

1,000 centimeters _____ meters

1,000 meters _____ kilometer

1 acre _____ hectare

1,000 kilograms _____ metric ton



Level 2

Chapter 10

Nondestructive Test

Instruments and

Methods

Nondestructive Test Instruments and Methods

Introduction

In Level 1 of this program, a number of basic coating inspection test instruments used by coating inspectors worldwide were thoroughly reviewed. These instruments were used in preparing practice panels at the field lab site and again in the final practical examination.

Other types of coating inspection instruments and tests are covered in this course. These instruments are:

- More sophisticated and/or more complex and because of their nature are used less often.
- Part of a group of destructive test instruments which are used only when required by the specification or otherwise authorized by contract.

The inspection tests and instruments to be discussed include:

- Atmospheric monitoring and safety
 - Solvent vapor meter
 - Drager meter
- Surface testing
 - pH meter
 - Magnifiers
 - Blister evaluation
 - Moisture indicator
 - Water-soluble chemical salt tests

- Coating integrity: nondestructive instruments
 - Type-1 magnetic pull-off gauge
 - Type-2 electromagnetic DFT gauge
 - Eddy-current DFT gauge

Atmospheric Monitoring and Safety

Introduction

Many environments in which coating inspectors work are hazardous, either as a result of the existing environment, or because a toxic or combustible atmosphere is created by paint-related materials, primarily solvents.

Safety and atmospheric monitoring equipment is designed to ensure a safe working environment in the following work areas typically classified as “dangerous”:

- Oil and gas production or storage facilities
- Fuel storage facilities
- Sewage treatment plants/sewage pipelines
- Chemical plants
- Rail tank cars

Conditions are especially hazardous when working in confined spaces, such as in tanks, rail tank cars, pipelines, or storage vessels.

The coating inspector is responsible for his own safety, and unless required by the specification or by separate contract, the inspector generally does not *monitor*, *supervise*, or otherwise *enforce* safety rules and/or regulations.

Because of possible legal implications, the inspector should attempt to limit this responsibility, though some aspects of safety monitoring may be a requirement of employment.

The inspector has a *duty of care* and should report any safety violations or unsafe practices to his supervisor.

Solvent Vapor Meter

Several types of solvent vapor meters monitor the atmosphere for:

- Toxic gases (methane, hydrogen sulfide, etc.)
- Combustible gases (most solvents)
- Oxygen deficiency (oxygen content is normally 20%)

The instrument is capable of monitoring all three conditions, and is small and light enough to be carried as a personal monitor. Most instruments like this have up to three separate sensors that allow the device to simultaneously monitor the three conditions.



Figure 10.1: Solvent Vapor Meter (Tritector)

Typically these sensors are:

- Galvanic cells, which monitor oxygen content by producing current in proportion to the oxygen level.

When the current reaches a preset level, an alarm is sounded.

- Metallic oxide sensors, which monitor toxic and/or combustible gas levels. The metallic oxides change their electrical resistance in the presence of the gases. When the resistance of either cell reaches a preset level, an alarm is sounded.

The manufacturer's instructions must be consulted for operation and maintenance of each make and model, but some general principles of operation may include:

- Read the instructions.
- Check calibration of the device as frequently as required to ensure accurate readings.
- Ensure the batteries for the unit are fresh and adequately charged.
- Allow a warm-up/purge period when the device is first turned on so it stabilizes and provides accurate readings.

It is important that the inspector test the atmosphere in the areas where work is actually performed.

Many companies now require that their workers carry personal monitors and emergency air packs (personal LEL meter and 10-minute rescue air pack) if they will be working in and around confined spaces.



Figure 10.2: Personal Monitor with 10-Minute Air Pack

Monitoring devices occasionally must be calibrated using standardized concentrations of gas (methane, hydrogen sulfide, etc.).

The inspector should carefully study and follow the manufacturer's instructions when calibrating these instruments.

Some models of these instruments are made to monitor only one gas or vapor and it is imperative to know what might be in the environment being tested.

Drager Meter and Tubes

One example of a single atmospheric sampling instrument is the Drager meter. This device is fitted with bellows and is operated by compressing and releasing the bellows. This pumping action brings air or other gas through a glass tube which has a preset chemical indicator inside.

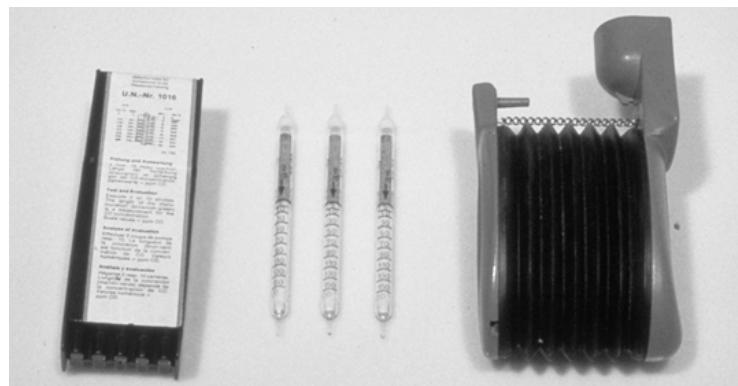


Figure 10.3: Drager Meter with Detector Tubes

Also available with the device is a set of about 250 glass tubes, each containing a separate preset chemical test reagent. Each tube is for one specific chemical vapor or gas; therefore, the inspector or tester must have an indication of which gas or vapor is suspected or is to be tested for. The tube is sealed at each end, but is designed to be broken easily to allow entry of air or vapor.

To operate, the tester selects the tube for the anticipated gas, and breaks each end of the tube. The tube is correctly

positioned in the Drager meter, and the bellows are compressed an appropriate number of times (usually 10).

As the vapor flows through the tube, a color change takes place, indicating the level of the gas being tested. Tubes are fitted with graduating marks along their length which indicate the concentration, if any, of the suspected gas in parts per million (ppm). This reading can be checked against predetermined acceptable levels.

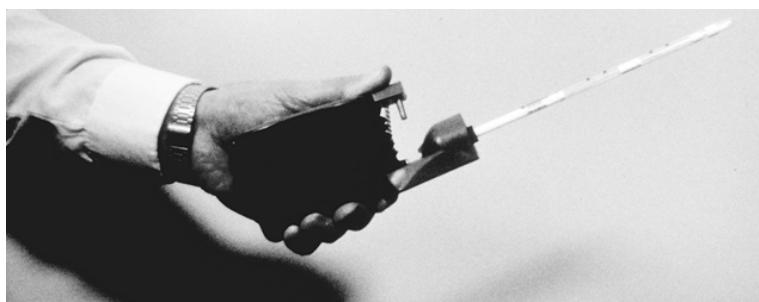


Figure 10.4: Drager Bellows with Tube Inserted

Surface Testing

Introduction

In CIP Level 1, much emphasis was placed on surface preparation, including:

- Observation or inspection of the surfaces to be coated
- Pre-cleaning, which includes inspection of design or fabrication defects and re-evaluation after specified corrections are made
- Cleaning operations
- Evaluation of the cleaned surfaces prior to application of the coating, and of the coated surface before and after each coat of material

This emphasis on surface preparation will be continued here as the following inspection tools and tests are discussed:

- pH meter
- Magnifiers
- Blister evaluation test
- Moisture indicator
- Water-soluble chemical salts



Figure 10.5: Distilled Water and pH Strips

pH Meter

The pH meter is a specific test instrument used in the laboratory and generally not found in the field.

As stated in Level 1, the pH level is an indication of how acid or how alkaline an aqueous solution is, with a pH of 7.0 being neutral. The pH range of 0.0 to 7.0 is acidic, and the range above 7.0 up to 14.0 is alkaline.

In use, the probe of the pH meter is placed in the aqueous solution to be tested. The probe contains two cells that produce an electrical voltage in the solution. The circuitry of the meter then converts this voltage to a pH reading.

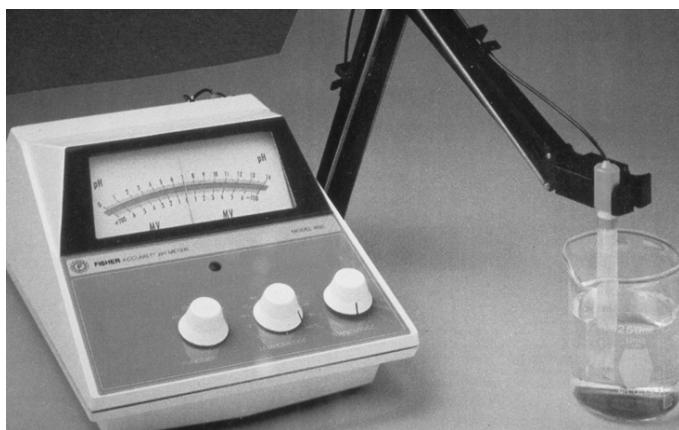


Figure 10.6: pH Meter

A pH meter is calibrated using a standard buffer solution of a known concentration at a specific temperature. A pH meter could be used in place of the pH paper described in CIP Level 1 to test the acidity or alkalinity of water from the surface to be coated, or from water used in testing abrasives for contamination.



Figure 10.7: Matching pH Indicator Strips with pH Scale

Magnifiers

In addition to the 5X surface comparator mentioned in Level 1, other types of magnifiers may sometimes be useful to the coating inspector. These devices are used for examining the surface for:

- Contamination
- Blisters
- Rust
- Mill scale
- Pinholes

A variety of pocket magnifiers that fold up and can be easily carried are available. They can be very useful to the inspector.

30X Surface Microscope

The 30X microscope is generally as high as is practical for field use for close examination of surfaces before and after preparation and after coating. The unit shown here is particularly useful because it is compact, folds for easy storage, and is self-illuminated.



Figure 10.8: 30X Surface Microscope

The magnifier consists of two tubes. One tube contains the 30X magnifier, and the other houses the batteries for the light which illuminates the surface.

Binocular Microscope

The binocular microscope, also called a *stereo microscope*, provides a three-dimensional image. These microscopes are available with magnifications up to 500X.

Blister Evaluation Test

The blister evaluation test is based on ASTM D 714, *Standard Test Method for Evaluating Degree of Blistering of Paint*. This test is used frequently to evaluate the degree of blistering which can result from testing a coating under laboratory conditions, such as in an Atlas cell test.

In the field, a surveyor also frequently uses this test method to evaluate the degree of blistering found in coatings on a structure. The standard test uses a set of glossy black-and-white print photographs taken by the surveyor to evaluate the degree of blistering by both the size and frequency of the blisters.

This test method is designed for use primarily on metal surfaces, but it may also be used for coatings on porous surfaces.

There are four sizes of blisters pictured here that range from large Blister size #2 to small Blister size #8.

The frequency of blisters ranges from dense to few, as follows:

- Dense (D)
- Medium dense (MD)
- Medium (M)
- Few (F)

This slide shows four panels which depict blister size #4.

More important than determining the size and frequency of blisters is understanding what causes them. Common causes of blisters include:

- Presence of water-soluble ferrous salts or hygroscopic chemical residues on the bare or coated substrate (osmotic blistering)

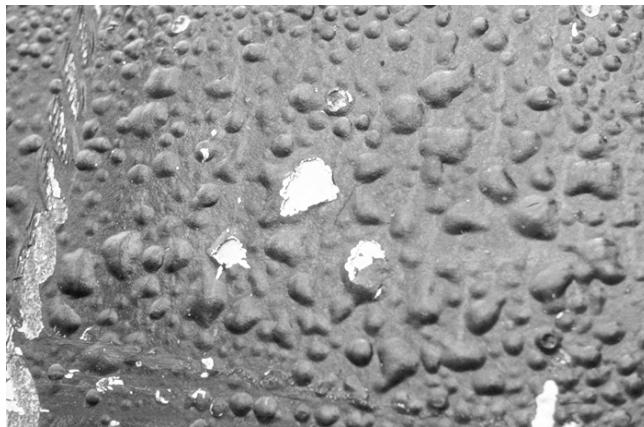


Figure 10.9: Osmotic Blistering Caused by Chemical Salts

- Solvent entrapment

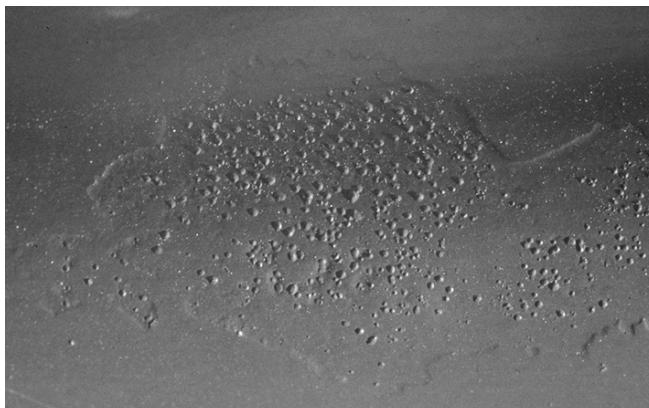


Figure 10.10: Blisters Caused by Solvent Entrapment



Figure 10.11: Broken Blisters in Tank with Underfilm Corrosion

- Temperature gradients across the film
- Incompatible coating materials
- Chemical attack
- Excessive cathodic protection voltage potential

Blister reporting should detail the following items:

- Size
 - Smaller areas are indicated in square inches or square centimeters
 - Larger areas are indicated in square feet or square meters
- Pattern of distribution (spotty, local, or general)
- Shape of blisters

Some causes of blistering particular to porous substrates are:

- Moisture in the substrate
- Entrapped air in the substrate
- The air and/or moisture expanding due to changes in temperature and/or barometric pressure
- The presence of hydroscopic salts beneath the coating film

Detection of Moisture—Indicators and Tests

Moisture in wood and plaster can be measured with a moisture meter, which indicates moisture level related to paint on the substrate.

A moisture meter also can be used as a qualitative indicator of the moisture content in concrete.

Moisture Indicators for Wood, Plaster, and Concrete

One moisture meter is an electronic battery-operated nondestructive instrument used to determine the moisture levels in plaster and gypsum walls, brick, concrete, and wall and roof insulation through qualitative comparative readings. It can be used on wood for which it reads wood moisture content directly as a percentage of dry weight.



Figure 10.12: Moisture Meter

The meter features two scales, one marked “wood” and the other marked “plaster-concrete” with 0 to 100 markings to be used as a reference scale. When testing wood, the readings are made on the “WOOD” scale and they indicate *percent moisture content*.

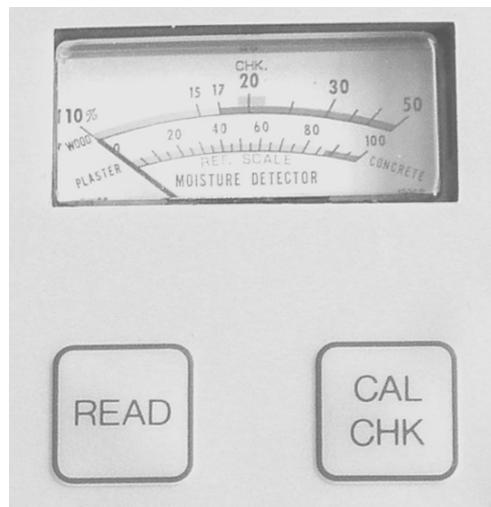


Figure 10.13: Moisture Meter—Close-Up of Meter Face

When testing concrete, plaster, or brick, the readings are taken on the “plaster-concrete” reference scale. These readings are to be considered a **qualitative indication** of the moisture level. Readings at the low end of the scale indicate a “drier” condition, which becomes progressively more “wet” as readings show toward the upper end of the scale.

It is suggested that tests be made on “dry” acceptable samples of materials, and to use such readings as standards, or reference points, against which subsequent readings are compared.

Because the tester operates on the principle of electrical conductivity, the user should establish that no readings (or only very low ones) are obtained on “dry” samples. A material that, even when dry, causes the unit to read high is in itself conductive and makes the instrument ineffective.

Test Procedures

First, check calibration by pushing “Cal Check.” The needle pointer should move to “20” on the scale. If it does not or if it pegs to the left, replace the battery and check calibration again. Connect the electrode to the instrument. Drive electrode pins into the material to be tested.

Wood: Read the wood scale. Drive or push electrode pins into the wood and read percentage moisture directly off the scale.

Plaster: Insert electrode pins into the plaster. Take readings on the plaster scale. A “dry” reading indicates that the plaster is dry enough for safe application of paints or adhesives.

A “wet” reading indicates excessive moisture unsafe for any paint. A borderline condition is indicated by a reading in the small yellow section between the “dry” and “wet” section of the dial.

As a guideline, when testing plaster and dry wall, readings in the green section indicate the moisture level is less than 4 to 5%, while readings in the red section indicate moisture is greater than 6%.

Concrete: Read the plaster/concrete scale. Results are qualitative only.

Special Considerations for Concrete

Moisture detectors, such as the Delmhorst BD type, utilize the relationship between electrical resistance and moisture content in hygroscopic materials. In some cases, this relationship is reliable to the point that a specific calibration curve can be developed such that the meter reads the moisture in terms of percentage.

In the case of concrete, bricks, and insulation, calibration of this type of instrument in terms of percent moisture is difficult and unreliable. This is due to many variables often hard to identify.

Concrete has a high level of electrical conductivity, even when it contains a minimum amount of moisture. For example, 3 to 4% moisture in wood, which resistance-type moisture meters cannot detect, causes a significant needle deflection in the meter. For this reason, instruments used to test moisture in plaster and concrete are less sensitive than those used for wood.

When testing concrete slabs, especially on grade or sub-grade, the moisture content should be tested not only on the surface but also in the body of the slab to determine if there is continuous moisture migration toward the surface.

When such a condition exists, the moisture movement may be slow to the point that as the moisture reaches the surface, it evaporates, causing a "dry" reading when the surface is tested. A similar test in the unexposed portion of the slab usually results in a high meter reading, indicating the presence of moisture and potential problems.

If the slab is coated and the upward movement of moisture continues, such movement will build pressure under the "non-breathing" portion, usually causing delamination of the coating.

Concrete Test Procedure

Drive two hardened concrete nails about 18 mm (0.75 in.) apart and 3 mm (0.125 in.) deep. Touch the electrode to the nails. Press the "Read" button and read the meter. If the meter reads "wet," the concrete is not satisfactory for painting. If the meter reads "dry," it shows the surface is dry.

To make a subsurface test, drill two holes 6 mm (0.25 in.) in diameter, 18 mm (0.75 in.) apart, to a depth of 12 mm (0.5 in.) to 18 mm (0.75 in.). Drive two concrete nails into the bottom of the holes without touching the sides of the holes, and make the test as described above. If the meter reads "dry," it is ready for coating.

It should be noted that even readings in the "red" zone of the dial indicate a relatively low moisture content in concrete. For example, a reading in the 80 to 90 range of the scale indicates a range of moisture of 2 to 4%.

Checking Meter Operation

Can the moisture meters be calibrated? Yes. Press the button marked "Cal-Check." The needle pointer should move to "20" on the scale. If it does not or if it "pegs" to the left, replace the battery. It is normal for the instrument to "peg" left when the electrodes are not in contact with any material.

How do you know when it is not working properly? If unit is calibrated to 20 and it does not register when the electrode is in contact with a wet surface, then the unit is not working properly. Also, if a new battery does not restore the unit to calibration, then it is not working properly.

Advantages

Portable
Easy to use
Results immediate

Disadvantages

Cannot be used on metals
When used for concrete,
results are qualitative only

Safety Issues

Unit is not intrinsically safe

Other Moisture Tests for Concrete

Other tests for the presence of moisture in concrete include:

- ASTM D 4263, Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method
- ASTM F 1869, Calcium Chloride Test

Test Procedure for Plastic Sheet Method

A segment of a 1.0 mm (4.0 mil) thick, clear polyethylene sheet approximately 457 x 457 mm (18 x 18 in.) is taped over the concrete to be tested so that the concrete is tightly sealed from the atmosphere and sunlight. The test patch is allowed to remain a minimum of 16 hours.

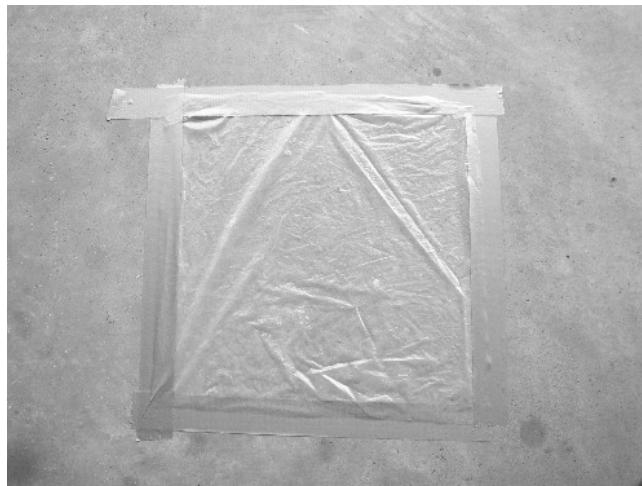


Figure 10.14: Plastic Sheet Test on Concrete Floor

After the allowed time has elapsed, the plastic sheet is removed and the underside of the sheet and the concrete surface at the patch are inspected for the presence of moisture.

Samples for floors, walls, and ceilings require one test area per 46 m^2 (50 ft^2), or portion thereof, of surface area, unless otherwise specified.

The recommended practice is a minimum of one test for each 3 m (10 ft) of vertical rise in all elevations starting within 300 mm (12 in.) of the floor.

Calcium Chloride Test Procedure—ASTM F 1869

A weighed amount of calcium chloride, which is very hygroscopic, is applied to a measured area of the concrete surface and allowed to remain for an agreed period of time. At the end of this period, the calcium chloride is removed and weighed again. A rating scale may be developed from the differences in weight of the wet and dry calcium chloride. This rating scale may be used to evaluate the condition of the concrete surface before painting.



Figure 10.15: Calcium Chloride Moisture Vapor Emission Test on Concrete Floor

This is a test often used by flooring contractors to develop a “disclaimer” in their warranties if the moisture vapor emission level in the concrete was considered to be too high for painting or sealing.

The failure of coatings applied to floors can be a result of the slab containing too much liquid water or from the passage of water vapor through the slab. It is important to check for both before applying coatings to concrete floors.

Tests for Water-Soluble Chemical Salts

Water-soluble chemical salts, in the form of soluble ferrous ions, and chloride, sulfate, carbonate, or other ions can be present on an uncoated steel surface.

Sulfur dioxide in the atmosphere may react with moisture on the steel to form sulfurous and sulfuric acids that react with steel to form the ferrous sulfate, water-soluble iron.

Chloride ions may be deposited on steel surfaces near marine atmospheres or chemical facilities.

Any water-soluble salts, if allowed to remain on the bare substrate after surface preparation, may absorb moisture

from the atmosphere and form a corrosion cell. Such a cell can remain active on the substrate after a coating has been applied and could lead to premature coating failure.

This situation can be more critical when the steel is severely pitted. In such a case, a combination of wet abrasive blasting and high-pressure waterjetting, followed by dry abrasive blasting, may be required to reduce the amount of contamination to a desirable minimum.

The effect of soluble salts as contaminants in the coating scheme has long been recognized. Unfortunately, the industry has not yet arrived at a consensus on acceptable minimum levels of contamination.

Nor has industry developed a standard procedure for the detection and evaluation of these soluble salts. Currently NACE, jointly with SSPC and ISO, is working to develop such a standard test method. It is expected that as part of this joint effort, some acceptable minimum level of soluble salts contamination will be recommended.

Qualitative Test for Water-Soluble Ferrous Salts

The qualitative test for water-soluble ferrous salts (ions) is designed only to detect the presence of this substance on a steel substrate. It is not designed to measure the quantity of these ions.

Ferrous Ions Test Procedure

Qualitative test for water-soluble ferrous salts include:

- Use of prepared indication paper
- Misting surface with distilled water
- Applying test paper
 - Dark blue color indicates presence of soluble salts

Filter paper is saturated with 5% potassium ferricyanide and allowed to dry. This indicator paper is available commercially, but can be prepared by the inspector, provided he has a supply of potassium ferricyanide.

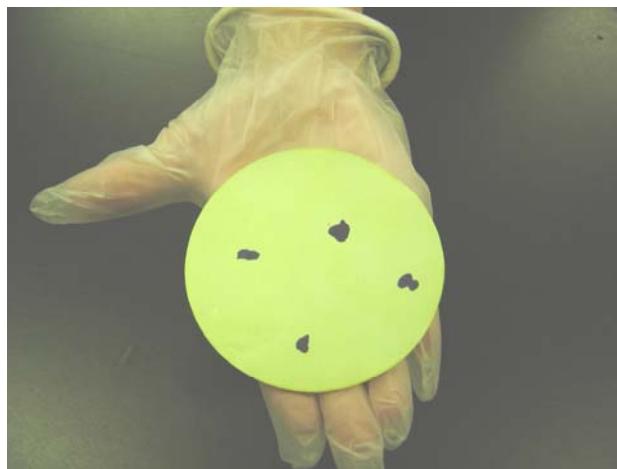


Figure 10.16: Potassium Ferricyanide Paper Indicating the Presence of Soluble Ferrous Salts

To conduct the test, spray mist a small amount of distilled water onto the steel surface and allow the water to stand for 30 seconds. Press the indicator paper onto the wetted surface and hold for about five seconds.

Any soluble ferrous salts present will be drawn into the test paper and will produce blue dots on the paper corresponding to the contaminated areas of the steel surface.

This is a sensitive test and even minute amounts of soluble iron can be detected. If the indicator paper displays a large amount of blue color, the user may make further tests to attempt to quantify the iron.

The test paper is photosensitive and moisture-sensitive and should be stored in a dry, dark place away from light until needed. Potassium ferricyanide also dissipates with time, so the test paper should be fresh (shelf life is approximately three months) to minimize false readings.

Semi-Quantitative Test for Water-Soluble Ferrous Ions

Efforts have been made to introduce a realistic quantitative test for ferrous ions that could be conducted in the field. However, these efforts have not been totally successful. The test method described below is classified as *semi-quantitative*, and its accuracy depends largely on operator technique.

Test Procedure

- Mark off a 15 x 15 cm (6 x 6 in.) area of the bare substrate to be tested.



Figure 10.17: Semi-Quantitative Test for Water-Soluble Salts—Mark Off a 15 x 15 cm (6 x 6 in.) Area

- Add two or three drops of vinegar (dilute acetic acid) to a 100-mL graduated cylinder, and fill the cylinder with distilled or deionized water up to the 22.5-mL mark.
- Pour this solution into a 100 to 150 mL beaker.
- Select a ball (also called *wool*) of medical cotton about the size of a golf ball, and immerse it into the solution.
- Use the wetted cotton ball to wash the surface of the test area, being cautious to keep the water within the inscribed area.



Figure 10.18: Semi-Quantitative Test for Water-Soluble Salts—Measuring Water in Graduated Cylinder



Figure 10.19: Semi-Quantitative Test for Water-Soluble Salts—Swabbing Surface with Medical Cotton

- Return the cotton ball to the beaker containing the wash solution.
- Use a new, dry cotton ball to dry up the test area.
- Return the second ball to the beaker containing the test solution, and repeat the drying process with new cotton balls until the surface is dry.
- Stir the contents of the beaker (which contains all cotton balls used) for 20 seconds.



Figure 10.20: Semi-Quantitative Test for Water-Soluble Salts—Stir Contents in Beaker for 20 Seconds

- Remove one or two test strips from the container, using caution not to touch the test paper zone. Briefly immerse (1 to 2 seconds) a test strip in the solution.



Figure 10.21: Semi-Quantitative Test for Water-Soluble Salts—Immerse Test Strip in Solution for 1 to 2 Seconds

- Within 20 seconds, compare the test paper zone with the color scale on the side of the test strip container.

The color chart indicates the concentration in mg/L (parts per million). The concentration is read in mg, but is reported in mg/m². This procedure provides a semi-quantitative indication of water-soluble ferrous ions.

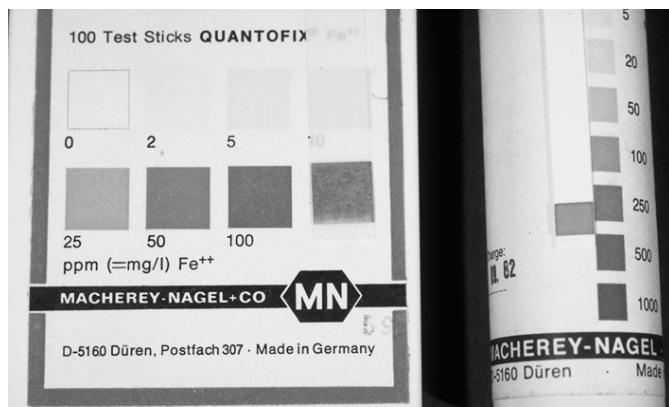


Figure 10.22: Semi-Quantitative Test for Water-Soluble Salts—Within 20 Seconds Compare Test Strip with Color Scale

Storage

Avoid exposing the sticks to sunlight and moisture. Store the kit in a dry place at a temperature below 30°C (90°F).

Indicator papers are available for a wide variety of substances. Of particular interest are those used for the detection of:

- Water-soluble ferrous salts
- Halides, specifically chlorides, usually in the form of sodium chloride

Shown in this slide, from left to right, are:

- Qualitative paper for water-soluble ferrous salts
- Semi-quantitative paper for soluble iron
- Semi-quantitative paper for chlorides

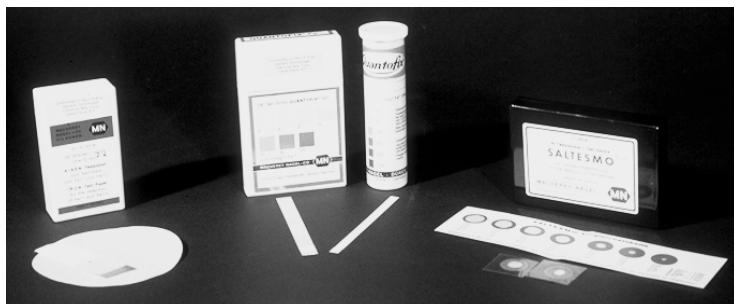


Figure 10.23: Indicator Papers

Tests for Chloride Ions

It is possible to test for chlorides with the same test solution used to determine soluble ferrous salts, but different test sticks are used.

In one particular procedure, titrator test sticks capable of detecting chloride in the range of 30 to 600 ppm (0.005% to 0.1% as sodium chloride) are used.

These chloride titrators consist of a thin, chemically inert plastic sheath. Laminated within the sheath is a strip impregnated with silver dichromate. When a titrator strip is placed in an aqueous solution, fluid will rise up the strip by capillary action.

The reaction of the silver dichromate with chloride produces a white column of silver chloride in the strip. When a strip is completely saturated, a moisture-sensitive signal string across the top of the strip turns blue. The length of the white column in the strip is proportional to chloride ion concentration.

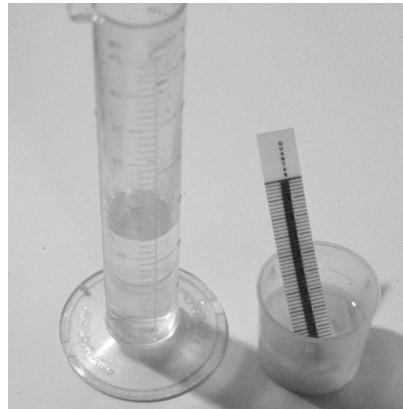


Figure 10.24: Chloride Titrator in Solution

The test is performed as follows.

- Place the lower end of the titrator in the solution to be tested. (Immersion of the entire strip will trigger a false completion color change.)
- Allow sample fluid to completely saturate strip.

- Determine the height of the white column in measured units between 2 and 30 minutes after the signal string begins to turn blue.

There will be a cone-shaped bleached area on the strip. The number closest to the peak of the bleached-out portion is recorded.

This number is then compared to the chart accompanying the test kit. It is important to use only matching lot numbers for the chart and the strip to avoid erroneous readings.

The concentration of chlorides is given in parts per million (mg/L).

Other methods of testing for soluble salts are:

Cell Retrieval Method (BresleTM) ISO 8502-6

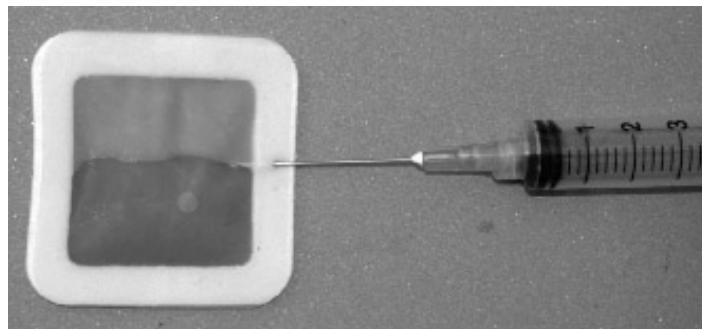


Figure 10.25: BresleTM Patch

The following procedure is used with the BresleTM Cell:

Remove the backing and the foam circle from the test cell and adhere the cell tightly to the area to be tested.

Insert the 5-mL syringe needle into the cell through the spongy foam perimeter. Remove the air from the test area by pulling back the plunger.

Inject all of the reagent water (3 mL) into the cell being careful to keep air bubbles out. Make sure there is no leakage.

Remove the syringe needle from the center of the cell, but leave it in the spongy perimeter and gently massage the top of the cell for 10 to 15 seconds. Withdraw and reinject the water a minimum of three times. Then retrieve as much of the water as possible with the syringe and place it in a clean vial or other container.

This solution can then be tested using kitigawa tubes, quantab method, titrators, or conductivity to determine the concentration of soluble salts.

Sleeve method. A pre-measured amount of solution is poured into a sleeve provided in the test kit. The sleeve is adhered to the surface by its adhesive edges. The sleeve is lifted and held up to force the solution onto the surface being tested. The operator massages the test solution against the surface through the test sleeve for 2 minutes. The sleeve is then removed from the surface and placed in a hole provided in the lid of the test kit box. Both ends of the titrator tube are snapped off with a metal snapper provided. The titrator tube is inserted into the sleeve with the smaller numbers and arrow at the bottom. Wait approximately 1.5 minutes or until the solution has wicked-up to the top of the titrator tube. Cotton at the top of the titrator tube will change color to amber when fully saturated. Immediately remove and read the number on the titrator tube at the interface of the color change. Pink is normal, white is the chloride level. This number is $\mu\text{g}/\text{cm}^2$ or parts per million.



Figure 10.26: Sleeve Test Kit—Solution, Sleeve, and Titrator Tube

The Chlor*Test™ “CSN Salts” kit has components to test for chlorides, sulfates, and nitrates. This test corresponds to:

ISO 8502-5, NACE Publication 6G186, and SSPC-Guide 15.



Figure 10.27: CSN Salts Test Kit

This is a field test kit and will be used in this class.

Chloride Test by Conductivity

This is a method of measuring the conductivity of a solution that contains chloride. The test is run by using a conductivity meter to measure a blank solution (no chloride) and then measuring a solution known to contain chlorides. The increase in conductivity provides an indication of the chloride content of the solution.

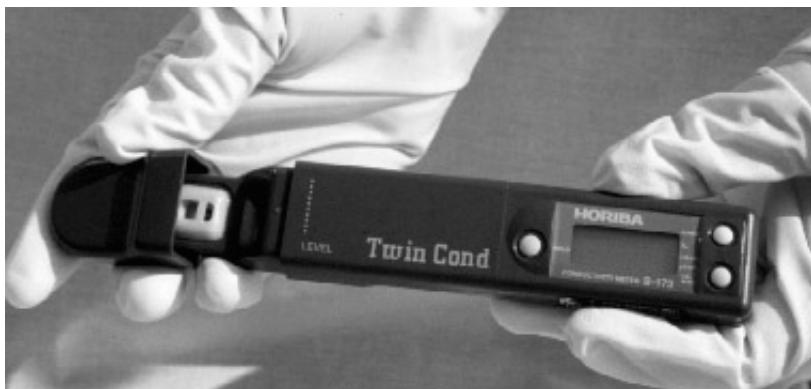


Figure 10.28: Conductivity Tester

Other tests may be conducted in the laboratory under controlled conditions.

Note that these are not official NACE International recommendations.

NACE currently has no standard recommended practices regarding these tests, and these data are presented for information only.

All of the above tests have advantages and disadvantages. The major limitation is that the retrieval efficiency will vary with the test method and the operator. Clarification and agreement should be reached by all parties involved before conducting these tests.

Testing Coating Integrity by Dry-Film Measurements

Introduction

In Level 1, each student was able to review in detail SSPC-PA 2, *Measurement of Dry Paint Thickness with Magnetic Gauges*, which describes the use of the two basic types of magnetic gauges:

- Type 1, Magnetic Pull-Off Gauges
- Type 2, Fixed-Probe Electromagnetic Gauges

Both Types 1 and 2 are used to determine the DFT of nonmagnetic coatings over a magnetic (usually ferrous) substrate.

Frequently nonmagnetic and/or nonconductive coatings are applied over conductive, but nonferrous, substrates, such as aluminum, zinc, copper, brass, and some stainless steels. Test instruments using the eddy-current principle are used to determine the DFT of nonconductive coatings over these surfaces.

Type 1 Magnetic Pull-Off Gauges

As described in Level 1, the Type 1, magnetic pull-off gauge uses a spring to lift a small permanent magnet from the surface of the paint. The gauge translates into coating thickness the force required to lift the magnet off the surface. The force holding the magnet to the surface varies with the distance between the magnet and the steel surface (i.e., the thickness of the paint).

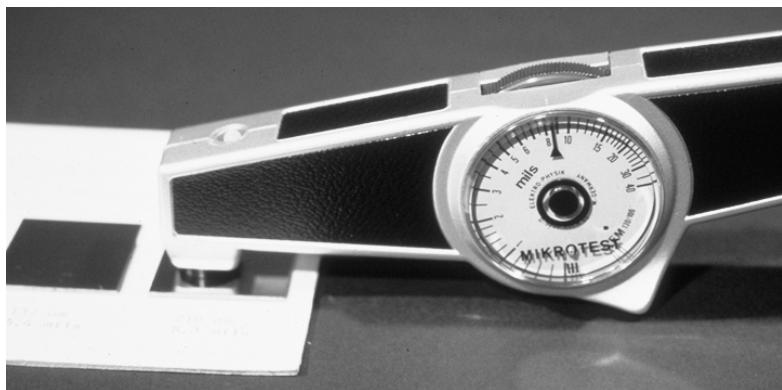


Figure 10.29: Type 1 Dial-Type DFT Gauge

The Type-1 gauge should be calibrated according to the manufacturer's instructions or the specification. It may be calibrated according to the calibration procedure described in SSPC-PA 2 which is explained here. PA 2 is intended to supplement the manufacturer's instructions, not to replace them.

Calibration Verification and Measurements— Type 1 Pull-Off Gauges:

For Type-1 gauges, use test blocks bearing calibrated nonmagnetic coatings that are traceable to a suitable national standard (see Section 8.15). The standards must be large enough to exceed the critical mass of steel needed to satisfy the magnetic field of the Type-1 (pull-off) magnets. Shims of plastic or of nonmagnetic metals which are acceptable for calibration of Type-2 (constant pressure probe) gauges should not be used for calibration of the Type-1 gauges (see Section 8.1.1). If the manufacturer's instructions are in conflict with this standard by allowing the use of plastic or other nonmagnetic shims for the calibration of a Type-1 gauge, the contracting parties must both be notified of this fact and agree on a method of calibration.

If proprietary thickness standards are to be used, agreement between contracting parties should be reached prior to starting the job.

Using the Type-1 (pull-off) gauge, measure the thickness of a series of calibration standards covering the expected

range of coating thickness. To guard against measuring with an inaccurate gauge, recheck the gauge at the beginning and the end of each work shift with one or more of the standards. During the work shift, if the gauge is dropped or suspected of giving erroneous readings, its calibration should be rechecked. If deemed appropriate by the contracting parties, initial agreement can be reached on the details and frequency of verification or calibration. Record the calibration data and the method used to verify the calibration. If the gauge is found to be out of calibration at the end of the work shift, all measurements made since the last calibration are suspect.

When the gauge no longer agrees with the standard, check the probe for cleanliness. If dirty, clean as described in Section 8.5.1. If the gauge still does not agree with the standard, the gauge is in need of repair or replacement. Some gauges can be adjusted to read accurately in a given range. Adjust the gauge to read correctly on a given standard. Then check the gauge on standards of higher and lower thicknesses to establish the range over which the gauge is accurate. All Type-1 gauges have nonlinear scales and any adjusting feature is linear in nature. Therefore, only a given segment of the scale can be accurate after adjustment.

Measure the bare substrate at a number of spots to obtain a representative average value. This average value is the base metal reading (BMR). Note: the gauge is not to be calibrated on the bare substrate.

Measure the dry coating at the number of spots specified in Section 5.

Subtract the BMR from the gauge reading to obtain the thickness of the coating.

Note: If the gauge is of the type that cannot be adjusted, then the accuracy of the gauge must be determined before measurements are taken on the dry coating. To determine the accuracy of the gauge, measure a series of calibration blocks closest to the expected thickness of the coating to

be measured and get an average. If the gauge is reading high, then this error factor must be subtracted, along with the BMR, from the measurements on the dry coating film. If the gauge is reading low, then this error factor must be added to the measurements on the dry coating film. The BMR is always subtracted. This process must be repeated each time a different range of film thicknesses is to be measured.

Type 2 Electromagnetic DFT Gauges

Type 2 fixed-probe electromagnetic gauges use direct current to induce a magnetic field, which then interacts with the ferrous metal of the substrate in exactly the same manner as the permanent magnet of the pull-off gauge.



Figure 10.30: Type 2 Fixed-Probe Electromagnetic Gauge

The fixed probe of the Type-2 gauge must remain in contact with the paint film during measurement. When the digital read out stabilizes, it can be read off the digital indicator.



Figure 10.31: Type 2 Fixed-Probe Electromagnetic Gauge with Shims

Calibration, Verification, and Measurement: Type 2 Constant-Pressure Probe Gauges

Different manufacturers of Type 2 (constant-pressure probe) gauges follow different methods of calibration or adjustment. Calibrate the gauge according to manufacturer's instructions.

A common method, and one that we will use in this course, is to calibrate the gauge on plastic or nonmagnetic shims of known thickness. A shim should be selected according to the thickness of the coating film we expect to be measuring. The thickness of the shim should be verified with a micrometer. The shim is placed on the cleaned magnetic surface which must be at least 76 x 76 x 3 mm (3 x 3 x 0.125 in.). The gauge is calibrated to the shim thickness. The gauge should be held firmly against the shim. Excessive pressure should be avoided: it may indent plastic, or on a blasted substrate, may impress the peaks into the plastic shim.

With a properly calibrated gauge, measure the dry coating as specified.

Electromagnetic vs. Eddy-Current DFT Gauges

Electrically operated gauges are used frequently instead of the magnetic types to measure DFT. Advantages of using this type of gauge include (claimed) better accuracy, the ability to make many measurements in a relatively short period of time, and the capability to use computer technology such as print-outs of measurements and statistical analysis.

The first generation of electronic gauges was generally larger than today's models, but in common with most electronic technology, newer gauges are smaller, better, and cheaper.

Two types of gauges, based on the principles of either electromagnetic or eddy-current measurement are generally available. Instruments using ultrasonic sound waves are also available, and these can be used for measuring the thickness of coatings over concrete and other nonmetallic surfaces.

- Electromagnetic DFT gauges

Instruments based on the electromagnetic principle are used to measure the DFT of nonferrous coatings on ferrous substrates. The instrument probe uses an oscillator to induce a magnetic field that then interacts with the ferrous metal of the substrate, in exactly the same manner as the permanent magnet of the pull-off gauge. The strength of the substrate influence is sensed within the probe, and the resulting electrical measurement is converted to a thickness reading on the screen or dial of the instrument.

Calibration of the gauge is essential if accurate measurements are to be made, although the stability of the circuitry should ensure that calibration, once made, remains stable for long periods, sometimes weeks. It is wise, however, that the inspector checks accuracy by calibrating the instrument at least once each day, and whenever the accuracy is doubted, such as when unusual

measurements are encountered. As always, when a specification dictates a working method, it should be followed. (Note: SSPC-PA 2 requires calibration before and after use, on the same day).

Factors that affect the accuracy of electromagnetic gauges include:

- Magnetic properties of the substrate

For best accuracy, the calibration piece should be of the same metallurgical composition as the coated item being measured. Different steel alloys, and measurement of coating thickness on castings have been known to change the accuracy of the gauge, thereby requiring a recalibration.

- Substrate thickness

Depending on the specific instrument, required minimum substrate thickness will vary. Some instruments require more "magnetic bulk" or mass than others, to maintain consistent accuracy.

- Edges

Generally, measurements cannot accurately be made closer than 25 mm (1 in.) to any edge.

- Curved surfaces

When this type gauge is used to measure DFT on a curved surface, the probe should be held at right angles to the surface; calibration (if possible) should be made on a similar curved surface.

- Magnetic coatings

Measurement of DFT of partially magnetic coatings, (such as those containing micaceous iron oxide pigment) can have problems, and the manufacturer's recommendations should be sought.

- Configuration of substrate

The nature of the substrate, whether smooth or roughened by blast-cleaning, may affect measurement

accuracy. Calibration should be made on a substrate similar to that being coated, unless otherwise specified.

In every case, the specific instructions and recommendations of the instrument manufacturer should be carefully studied and complied with.

- Eddy-current DFT gauges

Instruments based on the eddy-current principle are used to measure the DFT of nonconductive films applied to conductive substrates, most often nonferrous metals such as aluminum, copper, brass, and stainless steel. The instrument may look exactly like the electromagnetic gauge, but it induces an eddy current in the substrate by way of an alternating current fed to the probe.

Although measurements can be made on any conductive metal, the shape and size of the probe and the conductivity of the metal substrate are significant. Calibration of the gauge should be made on the actual substrate or on a substrate similar to that being coated.

Instruments capable of operating under both electromagnetic *and* eddy-current principles usually use a separate probe for each principle. Some eddy-current gauges use separate probes for ferrous and nonferrous substrates.

Eddy-current probes are more specialized than electromagnetic probes, and generally can be used over a smaller range of DFT.

Most eddy current probes have been designed and calibrated for use over aluminum substrates, and their use for measurement over other substrates may provide less accurate results.

The probe design is the crucial factor. The manufacturers' opinion appears to be that a uniform response and guaranteed accuracy can be gained from eddy-current gauges only when they are used to make DFT measurements on aluminum substrates. Recalibration for

other substrates improves accuracy, but often cannot guarantee it.

Factors affecting the accuracy of eddy-current gauge measurements include:

- Magnetic and conductive properties of the substrate

For highest accuracy, the calibration piece should be of the same metallurgical composition as the coated item being measured.

- Substrate thickness

Depending on the specific instrument, required minimum substrate thickness will vary. Some instruments will work over substrates as thin as a few mils.

- Edges

Generally, measurements may not be accurate when made closer than 25 mm (1 in.) to any edge.

- Curved surfaces

If this type gauge is used to measure DFT on a curved surface, the probe should be held at right angles to the surface, and calibration (if possible) should be made on a similar curved surface.

- Conductivity of coatings

Measurements of DFT of conductive coatings (such as aluminum pigmented coatings) will almost certainly have problems, and manufacturer's recommendations should be sought.

In every case, the specific instructions and recommendations of the instrument manufacturer should be carefully studied and complied with.

- Calibration

- Once the instrument has been turned on, it should be allowed a brief warm-up period and time to stabilize.

- Plastic shims of known thickness should be used in calibrating the gauge. The shim thickness should be in the thickness range of the coating to be measured. (If allowed by the client, NIST calibration standards may be used.)
- The plastic shims should be placed over a substrate of sufficient bulk (mass) for the instrument to be used. Up to 3 mm (0.125 in.) substrate bulk may have a significant influence in the calibration scheme.
- Instruments with multiple scales should be set to the appropriate measuring scale.
- Most gauges use a calibration technique by which measurements are made at both “zero” and “high” (chosen DFT) ends of the scale, on a bare substrate and nonferrous (electromagnetic) or nonconductive (eddy current) shim respectively.

Once the calibration has been made, measurements should be reasonably accurate across the scale, that is, at intermediate points between the calibration values used.

- To achieve accurate calibration, test measurements may have to be repeated until measurements stabilize. Older instruments in particular may require a sequence of “zero/high/zero/high. . .” adjustments until consistent results are achieved.

There are a wide variety of electronic gauges available, and the manufacturers’ instructions should always be followed to ensure accurate measurements can be made.

It should be noted that if an inspector wants to measure the DFT of a material such as aluminum-pigmented mastic over a substrate like copper, he/she can not rely on results obtained using either electromagnetic or eddy-current instruments.

The inspector may estimate the DFT from the WFT of the coating as applied, or, alternatively, use a Tooke gauge.



Level 2

Chapter 11

Destructive Instruments and Tests

Destructive Instruments and Tests

Introduction

The inspection tests and instruments discussed so far have been classified as *nondestructive*; that is, the instrument or test is not designed to destroy or adversely affect the coating.

As discussed in Level 1, in some cases, the high-voltage holiday detector can damage a coating if the voltage is too high. However, this instrument is regarded as a *nondestructive* instrument, not *destructive*.

Some instruments or tests used to perform certain inspection tests or functions may deface or destroy a portion of the coating. Obviously, these tests/instruments are classified as *destructive*.

The coating inspector should not perform any destructive test or use any destructive-type instruments on coatings unless:

- The specification clearly requires specific destructive testing.
- The owner or owner's representative requires or allows such testing.
- Such tests are required in a failure analysis assignment.

Some tests, procedures, and instruments classified as *destructive* include:

- Solvent sensitivity test
- Paint inspection (Tooke) gauge

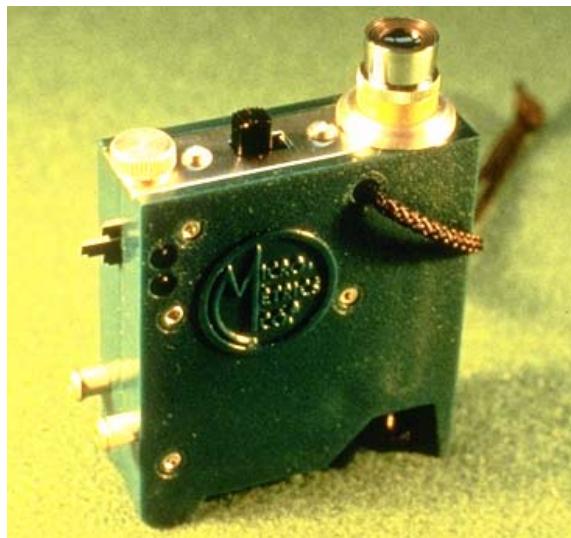


Figure 11.1: Tooke Gauge

- Adhesion
 - Knife/micrometer/microscope
 - Tape pull-off
 - Dolly pull-off
- Hardness
 - Pencil
 - Impressor (indentation)
- Cathodic disbondment



Figure 11.2: Measuring DFT of Paint Chip with Micrometer

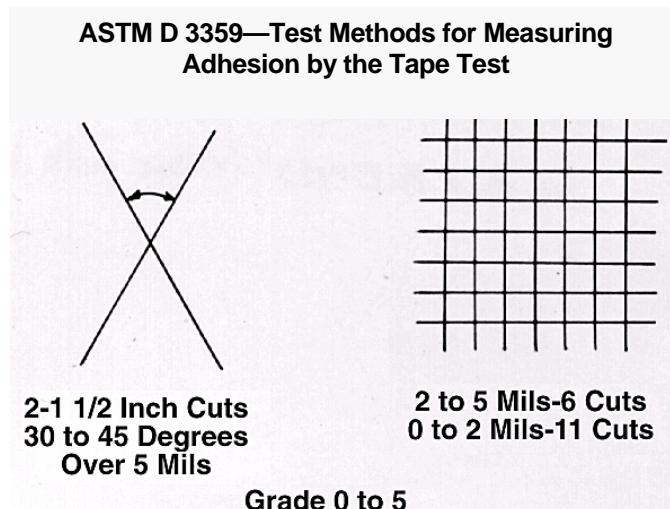


Figure 11.3: X-Cut and Cross-Hatch Cuts



Figure 11.4: Elcometer® Adhesion Test



Figure 11.5: Pencil Hardness Test



Figure 11.6: Barcol Impressor



Figure 11.7: Cathodic Disbondment Test

International Maritime Organization (IMO) Resolution MSC.216(82) Performance Testing

The new IMO standard, developed in an effort to improve coatings performance (fifteen-year minimum target life cycle), has specific requirements for performance testing of candidate coatings for ballast tank installation. They include Testing for Simulated Ballast Tank Conditions (Appendix 1) and a Condensation Chamber Test (Appendix 2). Each test has a 180-day duration. The standard notes specific performance and acceptance

criteria that must be achieved during testing for epoxy-based systems and alternate proposed systems.

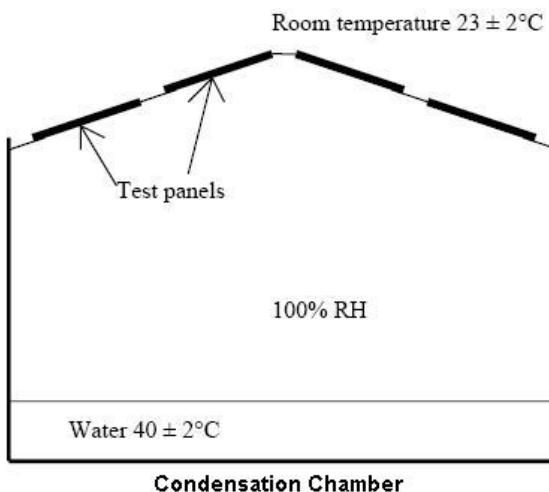


Figure 11.8 Condensation Chamber Test

Other Laboratory Tests for Determining Coating Performance

Solvent Sensitivity Testing

This discussion focuses on the solvent sensitivity test for inorganic zinc (ASTM D 4752, *Test Method for Measuring MEK Resistance of Ethyl Silicate Zinc-Rich Primers by Solvent Rub*).

This standard, which involves a rub technique, was established to assess the methyl ethyl ketone (MEK) resistance of ethyl silicate (inorganic) zinc-rich primers.

The MEK resistance of some two-component ethyl silicate zinc-rich primers correlates well with the cure of the primer as determined by diffuse differential reflectance infrared spectroscopy.

Many industry users have adopted this test, or some modification of it as an indication of the cure of polymerized (chemically induced or heat-induced)

coatings. A user may develop special criteria for the coating being tested, and an inspector involved in such testing should be aware of and understand those criteria.

Test Procedure

A modified test is generally used in industry, and the inspector may be required to perform this test as follows:

- Select areas on the coating surface at least 150 mm (6 in.) long on which to run the test.
- Clean the surface with tap water or dry cloth to remove any loose material, and measure the DFT in the selected area.
- Fold a piece of cheesecloth into a pad of double thickness.
- Saturate the cloth to a dripping condition with MEK. Do not allow more than 10 seconds to elapse before proceeding to the next steps.
- Place a properly protected index finger into the center of the pad while holding the excess cloth with the thumb and remaining fingers of the same hand.
- With the index finger at a 45° angle to the test surface, rub a rectangular area with moderate pressure, first away from the operator and then towards the operator. One forward and back motion is one double-rub and is completed in approximately one second.
- Continue rubbing the surface with the saturated MEK, holding the pad as necessary without lifting it from the surface until either the metal substrate is exposed or 50 double-rubs have been completed.
- Record the number of rubs when (if) the substrate is exposed.
- Select an adjacent area as a *control*. Repeat the above steps, except use a dry cheesecloth to establish the effect of burnishing without the influence of MEK.

Use this area as the control to visually show the appearance of *no effect*.

As stated, the owner may have developed some acceptance criteria using this procedure to determine coating cure, or using the scale of resistance published in ASTM D 4752.

Scale of Resistance Rating

Resistance Rating	Scale for Resistance Rating
5	No effect on surface; no zinc on cloth after 50 double-rubs
4	Burnished appearance in rubbed area; slight amount of zinc on cloth after 50 double-rubs
3	Some marring and apparent depression of the film after 50 double-rubs
2	Heavy marring; obvious depression in the film after 50 double-rubs
1	Heavy depression in the film, but no actual penetration to the substrate after 50 double-rubs
0	Penetration to the substrate in 50 or fewer double-rubs

ASTM D 5402, *Test Method for Measuring Solvent Resistance of Organic Coatings*, is performed the same way on organic coatings using an agreed upon solvent.

In general, a chemically induced or heat-induced polymerized coating is considered fully cured if none or only a trace of the coating comes off after 50 double-rubs.

Paint Inspection (Tooke) Gauge

The next inspection device for consideration is the paint inspection gauge. This tool is often called the Tooke gauge after its inventor, H. Tooke (ASTM D 4138, *Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means [Method A]*).

The gauge is used to measure total coating thickness and the thickness of individual layers of coatings in multi-coat films. The direct measurement is independent of substrate characteristics and, therefore, often finds application as a referee instrument.

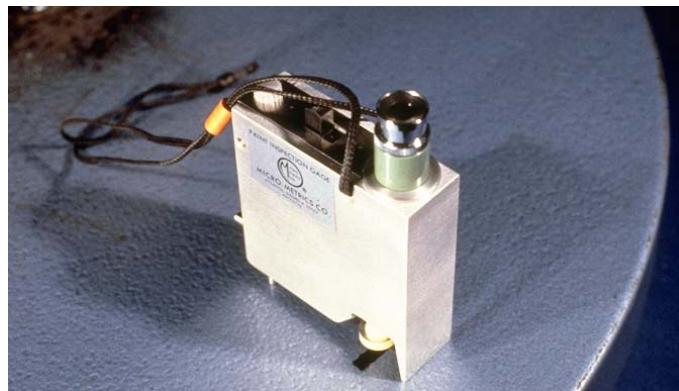


Figure 11.9: Tooke Gauge

The gauge may be used to see microscopic cracking, tendency for brittleness, blistering, or other microscopic anomalies in coatings. The surface microscope of the gauge may be used to inspect the substrate under the coating for surface contamination, mill scale, and quality of the abrasive blast. The gauge is used frequently in failure analysis.



Figure 11.10: Cylindrical Model of Tooke Gauge

The Tooke gauge is used quite commonly in coating failure analysis.

Description

A paint inspection gauge (often called *PIG*) is fitted on one side with factory-set guide studs in precise alignment with a cutting tip(s).

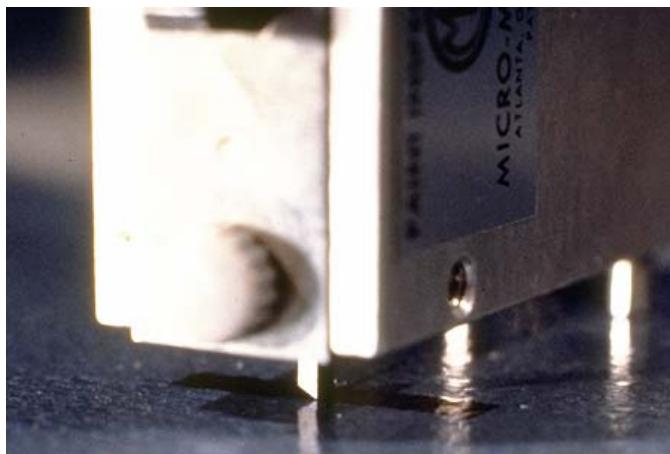


Figure 11.11: Guide Studs on Tooke Gauge

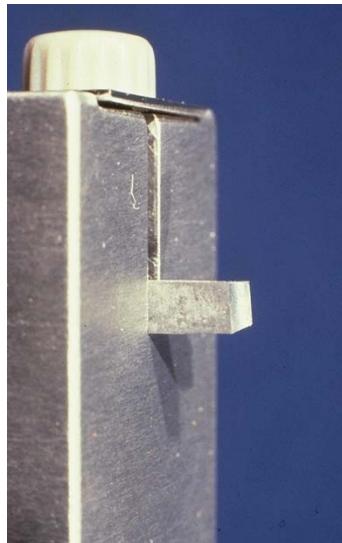


Figure 11.12: Cutting Tip on Tooke Gauge

One side of the gauge, at right angles to the side with the guide studs, is equipped with an illuminated 50X microscope. The eyepiece of the scope contains a measuring reticle, which establishes scale.

Uses

The PIG is a destructive test instrument/test method used to:

- Measure total DFT of coatings from 0.0 to 1,270 μms (0.0 to 50.0 mils).
- Measure DFT of each coat of paint of contrasting colors (It may be difficult to distinguish between multiple coats of material of the same color.).
- Assess abrasive blast cleaning work. It also can detect mill scale not removed by blasting. Also, the use of a 5% solution of copper sulfate may be helpful in distinguishing between zinc and the steel substrate.
- Measure plating and paint thickness on ceramic, metal, wood, concrete, and the protective backing on mirrors.
- Measure paint on plastics.

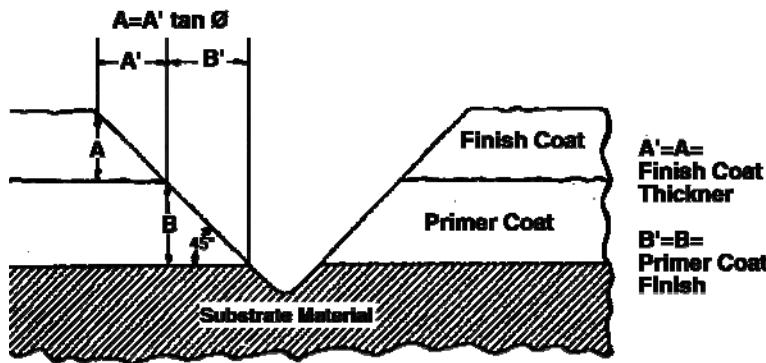


Figure 11.13: Measurement Principle of Tooke Gauge

Test Procedures

- Estimate or measure the coating thickness in the area to be tested. Select a cutting tip (called *cutter* or *tip*) according to the coating thickness:

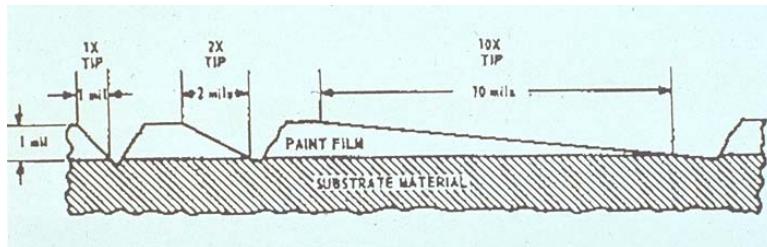


Figure 11.14: Cutting Angles of Tooke Gauge Blades

- A 1X (45° angle) tip is used for coatings 500 to 1,250 μm (20 to 50 mils) thick. When using the 1X tip, each line on the reticle scale represents 25.4 μm (1 mil).
- A 2X (26.6° angle) tip is used for coatings 50 to 500 μm (2 to 20 mils) thick. When using this tip, each line on the reticle scale represents 12.7 μm (0.5 mils).

A 10X (5.6° angle) tip is used for coatings 0 to 75 μm (0 to 3 mils) thick, and when this tip is used, each line on the reticle scale represents 2.5 μm (0.1 mil).

- Use a surface marker of contrasting color to mark a line (benchmark) on the surface about 50 cm (2 in.) long. Erasing fluid (White-OutTM) may be useful as a marker on dark surfaces.

- To incise a groove, grip the Tooke gauge firmly, with the guide studs and cutting tip forming a tripod on the coated surface with the cutting tip slightly above the mark and aligned to scribe across the mark.
- Draw the cutting tip straight across the mark (at right angles to the mark), with the guide studs leading the cutting tip. Increase pressure on the cutting tip until it barely cuts into the substrate before it crosses the benchmark.

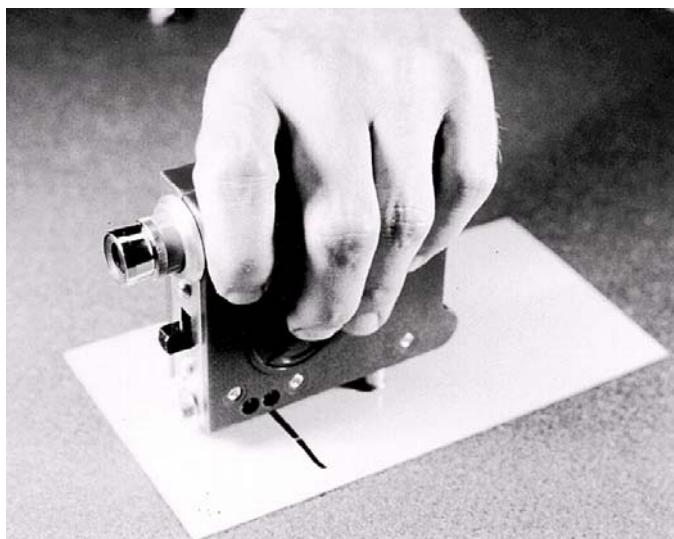


Figure 11.15: Making Cut with Tooke Gauge

- Maintain continuous three-point contact to ensure precise vertical alignment of the groove, but avoid excessive pressure on the guide studs. If the groove is not properly made through the coating to the substrate, make a new scribe at another location. Do not attempt to re-cut any previous incision
- Turn the microscope lamp on and view the incision through the 50X microscope. Use the focusing screw in the body below the microscope to adjust the image. Rotate the chrome eyepiece to focus the reticle scale image in the microscope

The coating will be visible on both sides of the exposed substrate. One side will appear to have a smoother edge at the benchmark than the other. Evaluate only the smoother

side of the coating (Note: When you pull the cutter toward you, line up the microscope, find the exposed substrate, and read LEFT).

- Align the left edge of the cut with any convenient long line of the reticle, and count inward, left to right, until the next layer of coating or the substrate is reached.

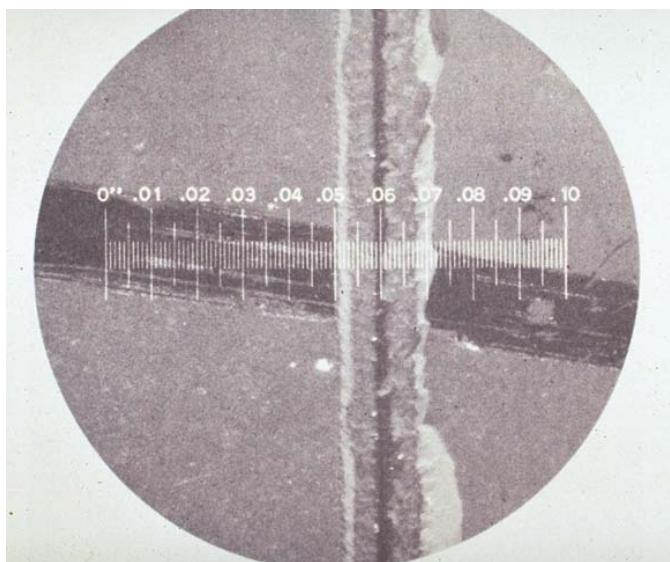


Figure 11.16: Calculating Measurement

Gauge Calibration

The Tooke gauge cannot be calibrated. Original factory calibration is done by setting the guide studs in precise alignment with the cutting tip(s). Checks can be made with precision-applied coating film standards.

For very high-precision work, the user should maintain painted panels of known thickness and check the instrument to these panels periodically.

In the field, verify the cutting tips are in good condition. If the coating tears or is difficult to cut through, the cutting tips may be worn and should be replaced.

Advantages

The Tooke gauge offers specific advantages, such as:

- Portable
- Useful in the field or in the lab
- Relatively easy to use
- Can mount camera and take pictures through the microscope
- Is a reliable *referee* instrument, in case of arbitration

Disadvantages

The Tooke gauge has certain disadvantages:

- Needs battery power
- Must destroy section(s) of coating to conduct test
- May not produce smooth cut in filled or fiber coatings
- Soft or elastic coatings may need to be cooled or frozen with dry ice to allow a good cut
- May not be intrinsically safe

Precision Groove Grinder

An auxiliary instrument often used with the Tooke (PIG) gauge is called a *precision groove grinder*. This portable, hand-held, battery-operated tool uses a precisely shaped wheel, instead of a stylus, to incise a groove in a coating for observation with the Tooke gauge.

The stylus of the Tooke gauge is not a reliable incisor on certain types of coatings such as soft, rubbery, highly filled, or glass-fiber-reinforced materials. The precision groove grinder does provide a smooth incision in these type coatings.

The incision, correctly made, resembles a narrow half-moon or crescent shape in the coating. The straight line is the correct site for observation and for thickness measurements. Once the cut is made, the Tooke gauge may be used to measure the DFT, as though the cut was made by a Tooke gauge.



Figure 11.17: Making Cut with Precision Groove Cutter



Figure 11.18: View of Cuts Made with Precision Groove Grinder

A calibration procedure for the groove grinder is outlined at the end of this chapter.

Another instrument similar to the precision groove grinder is the microgroove, which is described and pictured in ASTM D 4138.



Figure 11.19: Microgroove with Positioning Block



Figure 11.20: Making Cut with Microgroove Tool

Saberg Drill

ASTM Standard D 4138 describes Method C, which involves the use of a specific angle-tip drill bit to cut a conical cavity in the coating.

Such a tool is a Saberg drill, which can cut a hole in the coating counter-sunk to the substrate. The device is equipped with a 50X microscope and two hand wheels for holding the cutter/drill in place, and turning.



Figure 11.21: Saberg Drill

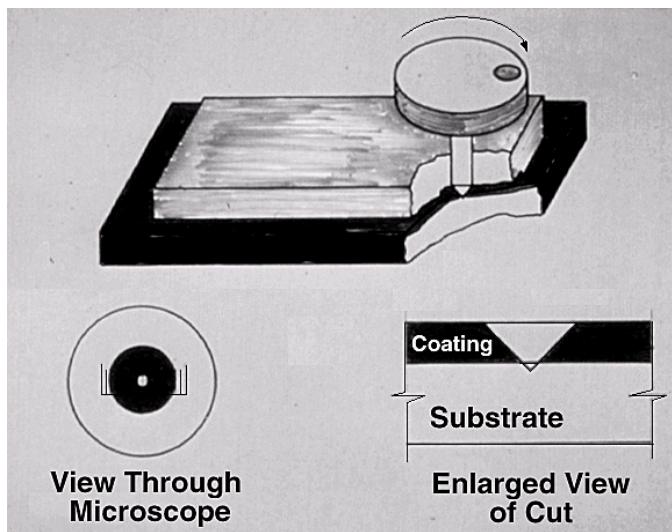


Figure 11.22: Saberg Drill Method of Measurement

The heavy wheel is for use with hard or thick coatings more than 250 μm (10 mils) in thickness, and the light wheel is for soft or thin coatings less than 250 μm (10 mils) thick.

The microscope is focused on the side of the hole, and the number of reticle divisions between the coating surface and the substrate or the individual layers of paint is noted.

To calculate the coating thickness:

- For mils, multiply the gradations by 0.79.
- For μm , multiply the gradation by 20.0.

Adhesion Tests

Most coatings properly applied to a well-prepared surface have good adhesion to the substrate. However, some users may elect to conduct some type of spot adhesion tests to determine the quality of the coating bond to the substrate, as well as between coats.

Some of these adhesion tests are:

- Knife/micrometer/microscope
- Tape pull-off (ASTM D 3359)
- Dolly pull-off (using a fixed-alignment adhesion tester Type 2, ASTM D 4541)

Adhesion tests such as these may be used to investigate coating failures.

Knife/Micrometer

A pocket knife or a very sharp putty knife or scraper may be used for a quick adhesion test. The knife is used to cut through the coating, and an attempt is made to peel the coating from the substrate.

This is a highly empirical test, and the evaluation of bond strength may be in the *eyes of the beholder*. An evaluation of the results may be subject to dispute. Obviously, if the coating is easily peeled from the surface, then it could be said that the adhesive bond to the substrate is unacceptable.

If the coating can be dislodged from the surface in minute pieces by picking with the knife, then the bond may be totally acceptable. If this test is used, then some



agreement between the parties involved must be reached as to how to evaluate the test results.

Measuring Adhesion by Tape Test

ASTM D 3359, *Standard Test Method for Measuring Adhesion by Tape Test*, describes two methods for measuring adhesion by the tape test.

The method depicted on the left in this slide is Method A, in which an X cut is made in the coating film. This method is used for coating films thicker than 127 μm (5 mils).

The method depicted on the right in this slide is Method B. In this case, a series of cuts are made at right angles to each other. For films thinner than 50 μm (2 mils), 11 cuts 1 mm apart are made in each direction. For coating films from 50 to 127 μm (2 to 5 mils) thick, six cuts are made 2 mm apart at right angles to each other.



Figure 11.23: X-Cut After Tape Removal

Method A

The ASTM descriptions for rating adhesion by the X-cut method (Method A) are:

- 5A No peeling or removal
- 4A Trace peeling or removal along incisions or at their intersections
- 3A Jagged removal along incisions up to 1.6 mm (0.0625 in.) on either side
- 2A Jagged removal along most of incisions up to 3.2 mm (0.125 in.) on either side
- 1A Removal from most of the area of the X under the tape
- 0A Removal beyond the area of the X

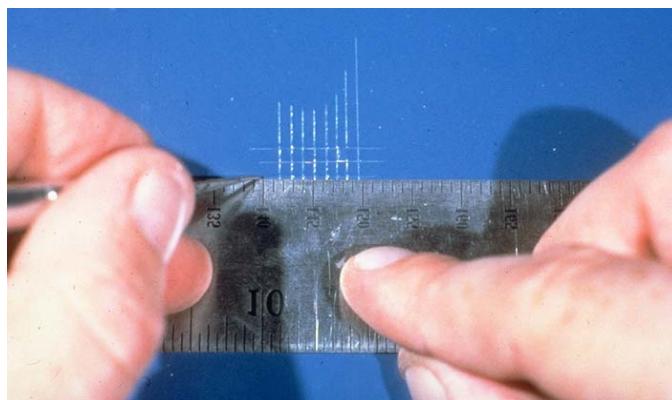


Figure 11.24: Making Cuts with X-Acto Knife for Cross-Hatch Tape Test

After the cuts have been made, brush the area lightly to remove any dislodged coating. Remove two complete laps of special tape. Place tape over the cuts, smoothing the tape firmly with an eraser to ensure good contact. Remove the tape within 90 (± 30) seconds of application by seizing the free end and rapidly pulling it off (but not jerking) at as close to an angle of 180° as possible.

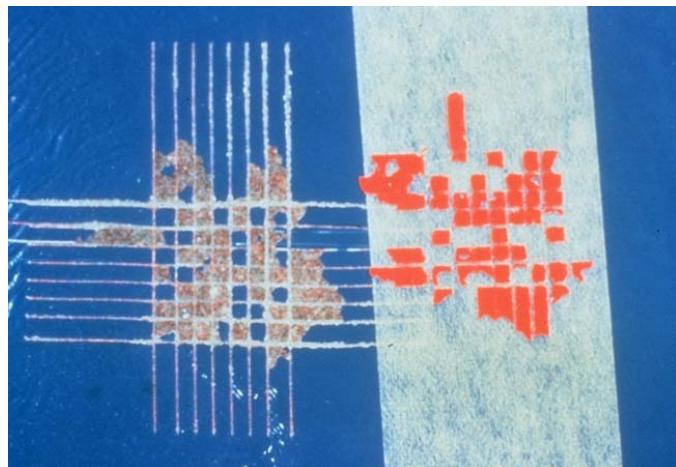


Figure 11.25: Tape After Cross-Hatch Test

Surface of Cross-Cut Area from Which Flaking has Occurred (Example for Six Parallel Cuts)	
5B	None
4B	
3B	
2B	
1B	
0B	Greater 65%

Figure 11.26: Classification of Adhesion Tape Test Results

Method B

The ASTM descriptions for rating adhesion when this test is performed are:

- 5B The edges of the cuts are completely smooth; none of the squares of the lattice are detached.
- 4B Small flakes of the coating are detached at intersections; less than 5% of the area is affected.
- 3B Small flakes of the coating are detached along the edges and at the intersections of the cuts. The area affected is 5 to 15% of the lattice.
- 2B The coating has flaked along the edges and on parts of the squares. The area affected is 15 to 35% of the lattice.
- 1B The coating has flaked along the edges of cuts in large ribbons, and whole squares have detached. The area affected is 35 to 65% of the lattice.
- 0B Flaking and detachment worse than Grade 1.

One tool is specially designed for this test. It consists of either a six-blade or an eleven-blade cutter in a holder. The edges of the cutter are pressed to the surface to be tested, and the tool is pulled once in each direction to intersect at a 90° angle.

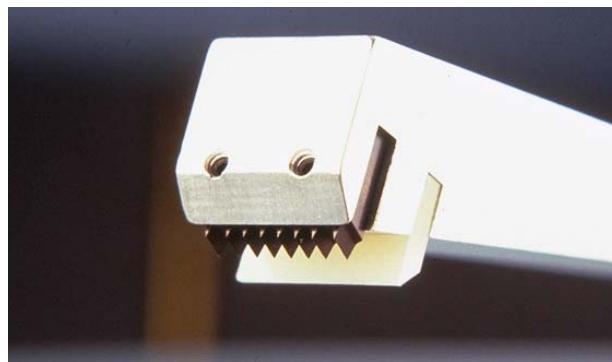


Figure 11.27: Cross-Hatch Cutter with Six Blades

It should be noted that some coatings that might give good pull-off test adhesion results do not give very good

cross-hatch adhesion test results. Coatings that are brittle tend to fracture badly when tested by this method.

Cross cuts can be made using a razor-sharp blade and an appropriate template guide with 1-, 2-, or 3-mm separation.

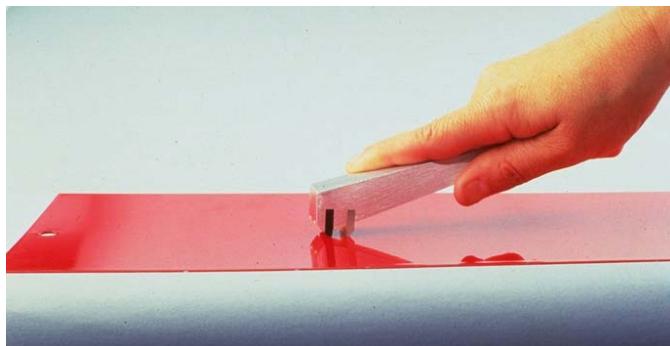


Figure 11.28: Using Cutter Tool to Make Cuts

Pull-Off Adhesion Tests Using Portable Adhesion Testers

The tape tests just described provide a rough indication of coatings adhesion to a substrate. Frequently, however, a more precise method of measuring coating adhesion, particularly in multi-coat systems, may be required.

Such a method is described in ASTM D 4541, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*, Annex A-2.

This test method covers a procedure and apparatus for evaluating pull-off strength (adhesion) of a coating by determining:

- Either the greatest perpendicular force (in tension) that a surface can bear before a plug of material is detached, *or*
- If the surface remains intact at a prescribed force (pass/fail)

Failure will occur along the weakest plane in the system, which comprises the:

- Test fixture
- Adhesive coating system
- Substrate

Failure will be exposed by the fracture surface.

This test method minimizes tensile stress compared with the shear stress applied by other such methods as scratch or knife adhesion, and the results may not be comparable.

This test method uses a portable adhesion tester that is capable of applying a concentric load and counter load to a single surface so coatings can be tested even though only one side is accessible.

Measurements are limited by the strength of the adhesion bonds between the loading fixture and the coating surface, or the cohesive strength of the substrate.

The test can be destructive and spot repairs may be necessary.

In general, the pull-off adhesion test is performed by securing with an adhesive, a loading fixture (aluminum test dolly) perpendicular to the surface of the coating. After the adhesive is cured, the portable test apparatus is attached to the test dolly and aligned to apply tension perpendicular to the test surface.

The force applied to the test dolly is increased periodically and monitored until either a plug of coating material is detached, or a specified value is reached.

When a plug of material is detached, the exposed surface represents the plane of limiting strength within the system. The nature of failure is qualified by the percent of adhesive and cohesive failures at the interfaces and layers involved. The pull-off strength (adhesion) of the coating is reported in kilograms per square centimeter (kg/cm^2) or pounds per square inch (psi).

Test Procedure

The test is performed as follows:

- The areas selected for testing should be flat surfaces large enough to accommodate the specified number of replicate tests. Usually, a minimum of three replications is required to statistically characterize the test area.

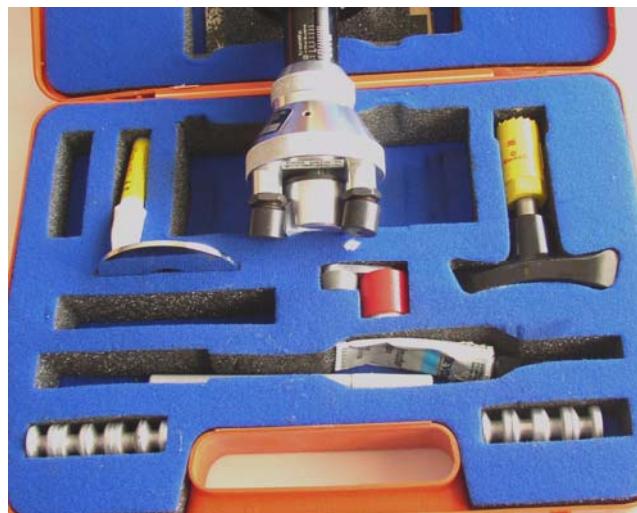


Figure 11.29: Adhesion Tester

The selected testing areas must have enough perpendicular and radial clearance to accommodate the apparatus, be flat enough to permit alignment, and be rigid enough to support the counter force.



Figure 11.30: Roughening Dolly

- Remove any oil and grease from the test dolly with a suitable solvent, such as MEK or xylol.

- Lightly abrade the bottom surface of the test dolly.
- Clean the surfaces to be tested in a manner that will not affect the integrity of the coating, nor leave a residue. Surface abrasion may introduce flaws and should generally be avoided.

A light abrasive-coated paper, 400 grit or finer, should be used only if needed to remove loose or weakly adhered surface contaminants.

- Mix the adhesive specified and/or agreed upon in accordance with the manufacturer's recommendation. (Note: Many clients allow the adhesive Super Glue™ Gel to be used because of its rapid curing time.) Apply the adhesive between the test dolly and the surface to be tested, and place the dolly on the test area perpendicular to the surface.
- Carefully remove the excess adhesive from around the dolly. (Caution: Movement, especially twisting, can cause tiny bubbles to coalesce into large holidays that constitute discontinuities during testing.)
- Allow enough time for the adhesive to set up and reach the recommended cure. A constant contact pressure should be maintained on the dolly during adhesive set and the early cure stage. Magnetic or mechanical clamping systems may be used. Clamping systems, such as masking tape, which depend on tack should be used with care to ensure they do not relax with time and allow air to intrude between the dolly and the test area.
- Scoring around the dolly violates the fundamental in-situ criterion that an unaltered coating be tested (see ASTM D 4541). If scoring is done it must be reported.
- If the substrate is thin, usually less than 6.4 mm (0.25 in.) in thickness, a bearing ring may be used. The ring should be placed concentrically around the dolly on the coated surface.



Figure 11.31: Close Up of Indicator

- After the adhesive is cured and the area is ready for testing, position the adhesion tester over the dolly and rotate the hand wheel carefully until the central grip of the tester just makes contact with the test dolly. Align the device according to the manufacturer's instructions, and set the force indicator to zero.

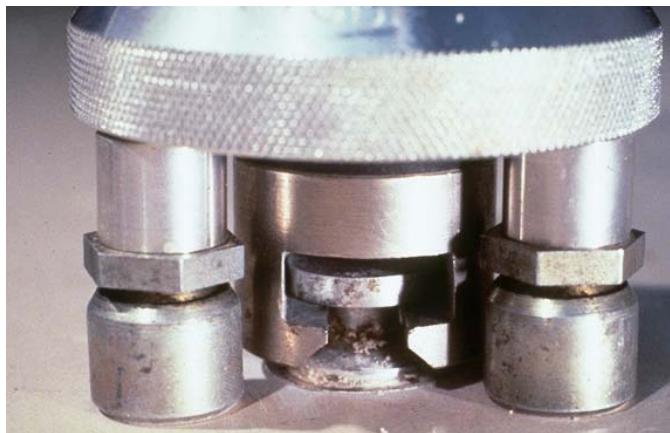


Figure 11.32: Placing Claw Over Dolly

- Increase the load in a smooth continuous manner at a rate of no more than 1 MPa/s (150 psi/s) so failure occurs, or the maximum stress is reached in about 100 seconds or less.



Figure 11.33: Turning Hand Wheel

- Read along the force indicator scale and determine the highest value attained at failure, or the maximum force applied. If a plug of material is detached, label and store the dolly for qualification of the failed surface.

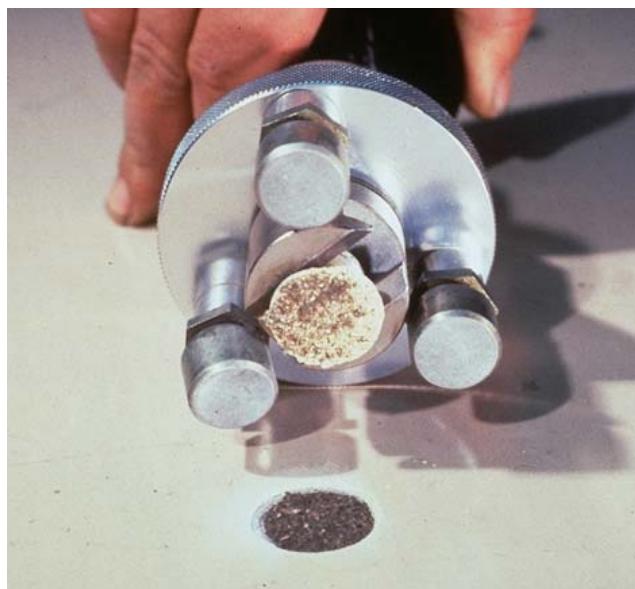


Figure 11.34: Close Up of Dolly After Pulling



Figure 11.35: Dollies with Various Amounts of Coating Adhered

- For all tests to failure, estimate the percent of adhesive and cohesive failures in accordance with their respective areas and locations within the test system comprising the coating and adhesive layers. One scheme to make this determination is as follows:
 - Describe the test specimen as substrate A, upon which successive coating layers B, C, D, etc., have been applied, including the adhesive Y which secures the dolly Z to the topcoat.
 - Designate cohesive failures by the layers within which they occur as B, C, etc., and the percent of each.
 - Designate adhesive failures by the interfaces at which they occur as A/B, B/C, C/D, etc., and the % of each.

Self-Aligning Adhesion Tester Type III (HATE VII Hydraulic Tester)

Another type of adhesion test instrument described in ASTM D 4541 is the Self-Aligning Adhesion Tester Type III, which is known as the Hate Mark VII Hydraulic Adhesion Tester.

The design of this tester is simple. The load is applied through the center of the dolly by a piston and pin. The hemispherical tip of the pin ensures a point loading of the force. Consequently, the force reached in the dolly is a uniform, purely tensile load. The idea is to avoid loading shear of the test dolly, which could produce inaccurate results.



Figure 11.36: HATE Adhesion Tester

The diameter of the piston bore is sized so the area of the bore is equal to the net area of the test dolly. The pressure reached by the dolly is the same as the pressure it bore which is transmitted directly to a pressure gauge. This area ratio is 1:1, and a direct reading from the pressure gauge ensures respectable accuracy on the order of $\pm 1-9/10$, compared to an accuracy of $\pm 10\%$ for mechanical adhesion testers.



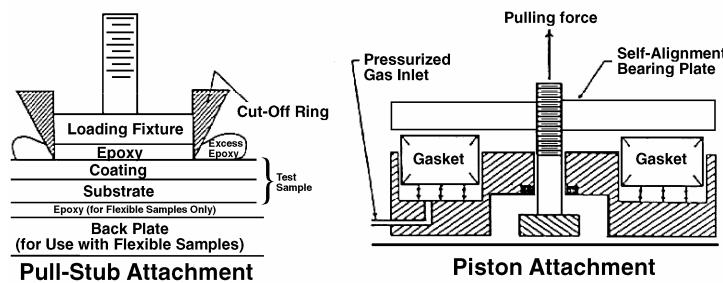
Figure 11.37: Pulling Dolly with HATE Adhesion Tester

When the handle is turned clockwise, a finely threaded plunger decreases volume and increases the hydraulic pressure on the oil within the body. The hydraulic gauge on the instrument gives the adhesion test results in pounds per square inch (psi).

Test dollies that have been machined to fit the specified OD and ID of pipe are available for testing of coating and linings on piping.

Self-Aligning Adhesion Tester Type IV (Pneumatic Adhesion Tensile Testing Instrument [PATTI])

This test apparatus described in ASTM D 4541, Annex 4, uses compressed air to supply a continuous load to a 0.5-in. (13-mm) OD aluminum pull-stub bonded to the coating surface. Failure occurs in the weakest layer of the test specimen.



**Figure 11.38: Pneumatic Adhesion
Tensile Testing Instruments**

The maximum pressure at failure is measured and converted to pounds per square inch (psi) by referencing a table supplied with the unit. Test specimens may be flexible or rigid, flat or curved.

Hardness Testing

The hardness of a coating may be regarded as an indication of its cure and, hence, its expected performance. There are several methods for determining hardness of a coating, but only two will be explored in this course:

- Pencil hardness
- Indentation (impressor) hardness

The rapid determination of the film hardness of an organic coating by the pencil hardness test is useful in developmental work and in establishing performance criteria for various coatings.

This hardness test is best performed under laboratory conditions; however, it may be performed in the field. The coating inspector should become familiar with this test procedure and should be able to perform this test in field conditions.

Indentation (impressor) hardness is useful for rating coatings or rigid substrates for their resistance to mechanical abuse such as that produced by blows, gouges, and scratching.

Pencil Test

The pencil test for film hardness is based on ASTM D 3363, *Standard Test Method for Film Hardness by Pencil Test*.

This standard test method covers the procedure for determining the film hardness of an organic coating on a substrate in terms of drawing leads or pencil leads of known hardness.

The purpose of the test is to determine the hardness of a coating as required by the specifications, or as referenced as performance data for the coating material furnished. The hardness values are often correlated as a function of the cure of a coating.

Many coating manufacturers use this test method in developmental work, production control testing, and as an indication of the performance of a given coating. Within reason, the harder the coating, the more complete the cure; hence, the better performance of the coating.

Because results vary between different operators and between different laboratories, every effort should be made to standardize the hardness of the lead used and the technique followed.



If used as a basis for a purchase agreement, this method will achieve maximum precision if a given set of referee pencils is agreed upon by the purchaser and the seller.

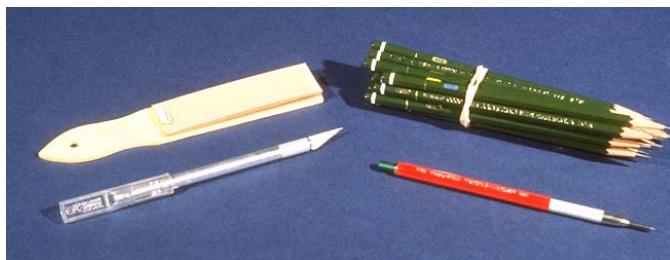


Figure 11.39: Tools for Pencil Test

Test Procedure

- Conduct the test at $25 \pm 2^{\circ}\text{C}$ ($73 \pm 4^{\circ}\text{F}$) and $50 \pm 5\%$ relative humidity. Use drawing leads or equivalent calibrated wood pencils from the same manufacturer which meet the following scale of hardness: 6H, 5H, 4H, 3H, 2H, H, F, HB, B, 2B, 3B, 4B, 5B, 6B (hardness ranges from 6H as the hardest to 6B as the softest).
- Peel the wood or paper away from the point of the pencil for 5 to 6 mm (0.19 to 0.25 in.) to expose an undisturbed smooth cylinder of lead. Rub the lead against a piece of abrasive paper, maintaining a 90° angle to the paper to attain a flat, smooth circular cross section.

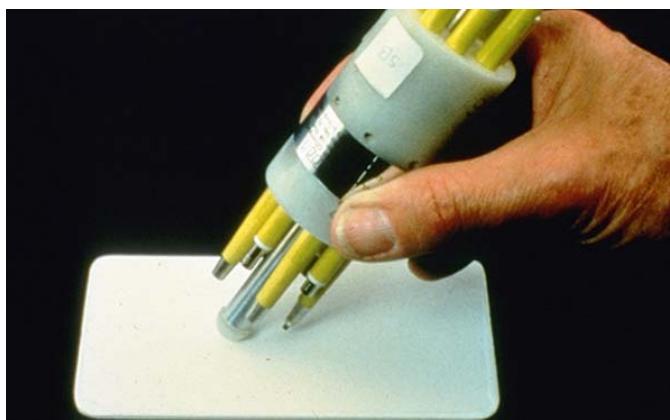


Figure 11.40: Pencils in Holder



Figure 11.41: Performing Test with Single Pencil

- When performing this test, hold the pencil firmly at a 45° angle to the coating film, with the point away from the operator. Push away from the operator in a 6.5-mm (0.25-in.) stroke.
- Start with the hardest pencil (6H) and continue down the scale (6H to 6B) to either of two end points:
 - The pencil that will not cut into or gouge the coating film (gouge hardness [often considered as pencil hardness]), or
 - The pencil that will not scratch the film (scratch hardness).
- Exert enough uniform pressure downward and forward either to cut the film, or to crumble the edge of the lead.
- Repeat the process down the hardness scale until a pencil is found that will not cut through the film to the substrate, or to the previous coat for a distance at least 3 mm (0.13 in.). This is the gouge hardness.
- Continue the process until a pencil is found that will neither cut through nor scratch the surface. This is the scratch hardness. Any defacement of the film other than a cut (gouge) is considered a scratch.
- Conduct a minimum of two tests for gouge hardness or scratch hardness for each pencil or lead.

- Record each end point (if applicable) for gouge and scratch hardness, the make and grade of lead or pencil, and any deviations from standard conditions, including roughness in the finish.

Ambient conditions, operator technique such as differences in the angle of incidence of the pencil, and pressure exerted on the pencil may affect the accuracy and reproducibility of the test.

If the leads or pencils are as specified, there should be no reason for the test not to work. If the leads are faulty, the test will not work properly.

According to ASTM D 3363, the two end points are as follows:

- *Gouge Hardness*: The hardest pencil that will leave the film uncut for a stroke length of at least 3 mm (0.13 in.).
- *Scratch Hardness*: The hardest pencil that will not rupture or scratch the film.

For example, the coating consists of two coats of material. A 6H and 5H pencil both cut through the film to the substrate, and a 4H pencil cuts through the topcoat to the top of the primer (first coat). The 3H pencil leaves the film uncut. In this example, the *gouge hardness* is 3H.

Continuing the process along the hardness scale, a 2H and an H pencil both scratch the surface, but the next pencil, F, does not; thus, the *scratch hardness* is F.

The Pencil Hardness Test cannot be calibrated.

Advantages

- Portable
- Easy to use

Disadvantages

- The test is subjective.
- It is not generally for field use. The test is usually performed in the laboratory. Tests between operators in the same lab or between labs can vary as much as one pencil lead unit in the scale described above.

Barcol Impressor

There are several hand-held, portable hardness testers available for use in the field. Most of these instruments rely on the indentation (or impression) of a plunger or pin into soft metals, sheet materials such as rubber, and reinforced or nonreinforced rigid plastics. One such instrument is the Barcol impressor.



Figure 11.42: Barcol 934

Use of the Barcol impressor is based on ASTM D 2583, *Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor*. This test method covers the indentation hardness of both reinforced and nonreinforced rigid plastics.

This test method may be specified for many materials but with some procedural modifications that would take precedence when adhering to the specification.

Therefore, it is advisable for the user to refer to the specification before using this test method. The ASTM

Classification System D 4000 lists the ASTM materials standards that are pertinent.

The inspector must be fully aware of the requirements of the client in specifying an indentation hardness test and must thoroughly review the standard, or its adaptation being considered.

Some users consider hardness as a function of coating cure and coating performance; that is, within limits, the harder the chemically induced or heat-induced polymerized coating, the more complete the cure and the better the performance of the coating.

Many users specify this type of test method for such coatings as glass-filled polyesters, vinyl esters, epoxies, etc., as an indication of its cure. However, some instruments, such as the Barcol impressor, are best suited for use on homogeneous materials.

When applied to reinforced plastic (non-homogeneous) materials, the Barcol impressor will produce greater variations in hardness readings than those for non-reinforced (homogeneous) materials.

These variations may be caused mainly by the differences in hardness between resin and filler materials in contact with the small diameter 0.157-mm (0.0062-in.) indenter. There is less variation in hardness readings on harder materials in the range of 50 Barcol and higher and considerably more variation in readings of softer materials.

In general, hardness readings by a given test method will be affected by:

- Type of coating, sheet, or filled material
- Cure
- Ambient temperature
- Thickness of material to be tested
- Size of test sample

Indentation hardness readings are numeric. These readings correspond to reference standards established by the manufacturer of the test equipment, or by consensus of industry. There are several manufacturers of hardness testers, such as:

- Rockwell
- Vickers
- Brinell
- Barcol

There is no direct relationship between the hardness scales; however, one scale may be correlated with another by use of an appropriate conversion chart.

These charts enable the inspector to correlate one manufacturer's hardness scale with another. For example, a review of a Barcol conversion chart shows that a reading of 73 on a Brinell scale would compare with other manufacturer's values as follows:

Sample Reading				
Brinell	Vickers	Rockwell B	Rockwell E	Rockwell H
73	81	39	81	101

The Impressor

The indenter of the impressor consists of a hardened steel truncated cone, with an angle of 26° with a flat tip 0.157 mm (0.0062 in.) in diameter. The indenter fits into a hollow spindle and is held down by a spring-loaded plunger.

The indicating dial has 100 divisions, each representing a depth of 0.0076 mm (0.0003 in.) penetration. The higher the reading, the harder the material.

Calibration

Hard and soft aluminum alloy disks supplied by the instrument manufacturer are the standards used in calibrating the instrument.

With the upper plunger guide backed out until it just engages the spring, the impressor is placed on a glass surface and pressed down until the point is forced all the way into the lower plunger guide.

The indicator should now read 100. If it does not, the lock-nut must be loosened and the lower plunger guide should be turned in or out to obtain a 100 reading. Next, the *hard* calibration disk is read; and if necessary, the device is adjusted so the reading is within the range marked on the disk. Then, the *soft* disk is read and adjustments, if any, are made. If these readings cannot be made, then any subsequent readings will not be valid.

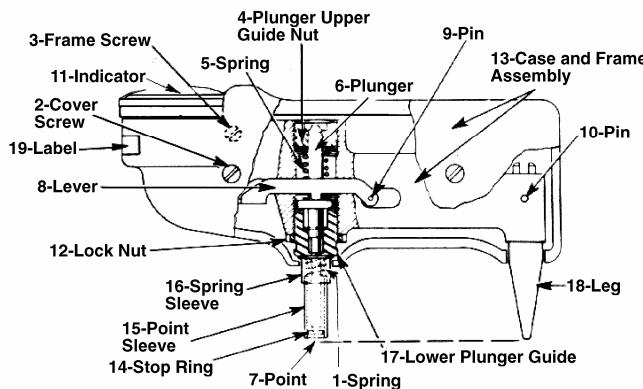


Figure 11.43: Cross Section of Barcol 934

Test Procedure

According to the manufacturer, for accurate readings the test specimen should be at least 0.79 mm (32 mils [0.03 in.]) thick and large enough to ensure a distance of 3 mm (0.13 in.) in any direction from the indenter point to the edge of the specimen.



Figure 11.44: Testing with Barcol Impressor

- Place the impressor, the calibration disks, and the test material on a smooth, hard supported surface.
- Set the point sleeve (indenter housing) on the test surface.
- Set the legs on the same surface, or on solid material of the same thickness so the indenter is perpendicular to the test surface.
- Grasp the instrument firmly between the legs and point sleeve.
- Quickly, by hand, apply increasing force on the case until the dial indication reaches a maximum (Note: Drift-in readings from the maximum may occur in some materials).
- Record this *maximum* reading.

When using a hardness tester, a phenomenon known as *cold flow*, or *creep*, may be observed. This happens when the hardness tester is held in contact with the test material for a period of time. The indenter continues to penetrate the material and the indication dial drifts lower.

This happens because some materials are more plastic than others. A plastic material, if deformed, will more or less stay deformed when the force is released. An example is putty, which has a high degree of plasticity.

An elastic material will more or less return to its original shape when force is reduced. An example would be a tennis ball or rubber ball.

Without regard to the elasticity or plasticity of the test material, in accordance with this test method, the maximum reading is recorded as the hardness rating of the material being evaluated.

The Barcol impressor hardness test used on glass-reinforced materials, such as polyester, should be performed before the gel coat is applied to avoid damage to the seal coat. The gel coat must be repaired if indentation or impressor hardness tests are performed after the gel coat is applied, or a potential failure point could be created.

Cathodic Disbondment

Cathodic disbondment tests are accelerated procedures to determine the comparative degree to which the tested coating may be loosened, or may develop holidays as a result of the action of normal soil potentials or impressed current cathodic protection. ASTM Standard G 8, *Standard Test Methods for Cathodic Disbonding of Pipeline Coatings*, describes in detail how a cathodic disbondment test can be performed.



**Figure 11.45: Cathodic Disbondment Test
ASTM G 95**

Various test methods have been developed and generally include:

- Preparation of a sample consisting of the substrate and the applied coating
- Creation of an artificial holiday in the coating
- Immersion of the sample in a solution of water (preferably distilled):
 - Sodium chloride (NaCl)
 - Sodium sulfate (Na₂SO₄), or
 - Sodium carbonate (Na₂CO₃)
- The sample is electrically connected to an anode, or, if an impressed current method is used, to a DC voltage source.
- At specified intervals the specimen is examined for loosening of the coating around the artificial holiday, new holidays, and other required conditions.

Cathodic protection will be discussed further later in this course.

Other Laboratory Tests

Many laboratory tests for establishing performance criteria of coatings are detailed in reference books, including:

- *ASTM Standards*, Volume 6.01 and 6.02.
- *Paint Testing Manual*, by Gardner and Sward
- *ASTM STP 500: Paint Testing Manual*

These references detail many additional field and laboratory coating test procedures for:

- Permeability
- Hardness
- Penetration
- Melting point
- Adhesion
- Abrasion resistance
- Color retention
- Gloss retention
- Bend
- Salt spray

and other coating characteristics.



Level 2

Chapter 12

NACE Standards

Standards and Technical Reports Applicable to Coating Operations

Introduction

NACE International, organized in 1943, has grown into the largest association in the world dedicated to the science of corrosion and corrosion mitigation. In addition to its technical publications, education and training courses, technical seminars, and other forums on corrosion and corrosion control, NACE is one of the world's largest voluntary standards-development groups.

The standards developed and published by NACE conform to the consensus principles of the association and have met the approval requirements of NACE procedures, rules, and regulations.

A number of other societies develop and publish standards relating to various phases of coatings operations. Some of these organizations are:

- American Water Works Association (AWWA)¹
- SSPC: The Society for Protective Coatings (SSPC)²
- ASTM International (ASTM)³
- International Organization for Standardization (ISO)⁴

Standards such as those discussed below are not legal and binding unless cited in a contract (which includes a coating specification) or government regulations.

¹ American Water Works Association (AWWA), 6666 West Quincy Avenue, Denver, CO 80235.

² SSPC: The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, PA 15222-4656.

³ ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

⁴ International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland.



Many specifiers regard a standard as a “how-to” document or specification rather than a guideline. Other specifiers often refer to a standard in their specifications without a true understanding of the intent and provisions of that standard.

The coating inspector must have access to and thoroughly understand each standard referred to in the specification. Modifications to a given standard may be made by agreement between the owner, contractor, and inspector. Questions about a referenced standard should be addressed and resolved in the pre-job conference.

NACE International Standards

NACE issues a *Book of Standards* based on three classifications:

- Standard Practice (SP)⁵
- Test Method (TM)
- Materials Requirement (MR)

Standard Practices (SPs) include recommendations for:

- Design
- Installation
- Maintenance
- Proper use of a material or a corrosion control system

Some Standard Practices focus on:

- Details of construction of a corrosion control system

⁵ Regarding NACE standards, on June 23, 2006, the designation of *standard recommended practice* was changed to *standard practice*. New standards published after that date will carry the designation (SP), and existing standards will be changed as they are revised or reaffirmed. Previously published standard recommended practices will include the old designation and the new one, e.g., SP0592-2006 (formerly RP0592-2001).

- Methods of treating the surface to reduce corrosion
- Requirements for using devices to reduce corrosion
- Procedures for increasing the effectiveness, safety, and economic benefits of an installation or system

NACE Test Methods (TMs) are related to corrosion prevention and control. They can give the method of conducting tests to ascertain the characteristics of a:

- Material
- Design
- Operation

Materials Requirements (MRs) state the necessary characteristics of a material for which corrosion is a factor in the selection, application, and maintenance of the material.

The coating inspector cannot be expected to memorize all of the various standards available. However, it is the coating inspector's responsibility to know where the standards may be obtained. When a standard is referenced in a specification, the coating inspector must obtain a copy of that standard and become aware of the thrust of that standard.

If there is any part of a referenced standard that is not clear to the inspector, he/she should bring it up at the pre-job conference and seek clarification.

Coating inspectors should stay abreast of changes and revisions in standards with which they may be working on any given project.

Coatings inspectors should also be aware of new standards created to meet the needs of industry. The International Maritime Organization (IMO)⁶ recently

⁶ International Maritime Organization (IMO), 4 Albert Embankment, London, SE1 7SR United Kingdom.

released a new standard with significant impact on the shipbuilding industry.

***International Maritime Organization
Resolution MSC.216(82) Performance
Standard for Protective Coatings for
Dedicated Seawater Ballast Tanks in all
Types of Ships and Double-Side Skin
Spaces of Bulk Carriers***

Recent regulations from the International Maritime Organization (IMO) are designed to control the quality of ballast tank coatings. This standard provides technical requirements (material qualification and quality control inspection) for protective coatings in dedicated seawater ballast tanks of all types of ships of not less than 500 gross tonnage and double-side skin spaces arranged in bulk carriers, 150 m in length and longer, for which the building contract is placed, the keels of which are laid, or which are delivered on or after July 1, 2008. All ships delivered on and after July 1, 2012 will be required to comply with the new regulations.

The intent of this standard and its specifications and requirements is to provide a target useful coating life of 15 years, which is considered to be the time period, from initial application, over which the coating system is intended to remain in *GOOD* condition (as defined by IACS⁷ Recommendation 87, *Guidelines for Coating Maintenance & Repairs for Ballast Tanks and Combined Cargo/Ballast Tanks on Oil Tankers*).

The IMO is the United Nations⁸ Specialized Agency responsible for improving maritime safety and preventing pollution from ships.

⁷ International Association of Classification Societies Ltd. (IACS), 6th Floor, 36 Broadway, London, SW1H 0BH United Kingdom.

⁸ United Nations (UN), First Avenue at 46th Street, New York, NY 10017.



Industry standards are available from the various standards-writing organizations, such as NACE International, SSPC, ASTM, AWWA, ANSI,⁹ ACI,¹⁰ API,¹¹ and ISO, to name a few. These organizations provide a complete listing, on the Internet, of the standards available. Copies of the standards may be obtained via the Internet or by direct mail.

At the end of this chapter is a listing of some NACE/SSPC and ASTM standards, along with a list of some of the revisions and new standards published since the year 2000.

ASTM Standards

Preparation of Surfaces for Painting

- D 2092 Practice for Preparation of Zinc-Coated (Galvanized Steel) Surfaces for Painting
- D 4258 Practice for Surface Cleaning Concrete for Coating
- D 4259 Practice for Abrading Concrete
- D 4260 Practice for Acid Etching Concrete
- D 4261 Practice for Surface Cleaning Concrete Unit Masonry for Coating
- D 4262 Test Method for pH of Chemically Cleaned or Etched Concrete Surfaces
- D 4263 Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method
- D 4285 Test Method for Indicating Oil or Water in Compressed Air
- D 4417 Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel
- D 4940 Test Method for Conductimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives
- E 337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)

⁹ American National Standards Institute (ANSI), 1819 L Street, NW, 6th floor, Washington, DC 20036.

¹⁰ American Concrete Institute (ACI), 38800 Country Club Dr., Farmington Hills, MI 48331.

¹¹ API, 1220 L Street, NW, Washington, DC 20005-4070.



Physical Properties—Wet Films

- D 3925 Practice for Sampling Liquid Paints and Related Pigmented Coatings
D 4212 Test Method for Viscosity by Dip-Type Viscosity Cups

Physical Properties—Cured Films

- D 2240 Test Method for Rubber Property—Durometer Hardness
D 2583 Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor
D 3359 Test Methods for Measuring Adhesion by Tape Test
D 3363 Test Method for Film Hardness by Pencil Test
D 4541 Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
D 4752 Test Method for Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc-Rich Primers by Solvent Rub

Thickness Measurement

- D 1005 Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers
D 1400 Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base
D 4138 Test Method for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means
D 4414 Practice for Measurement of Wet Film Thickness by Notch Gauges
D 7091 Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals

Holiday Detection

- D 4787 Practice for Continuity Verification of Liquid or Sheet Linings Applied to Concrete Substrates
D 5162 Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates

Visual Examination and Appearance

- D 4214 Test methods for Evaluating the Degree of Chalking of Exterior Paint Films
D 4610 Guide for Determining the Presence of and Removing Microbial (Fungal or Algal) Growth on Paint and Related Coatings

General Topics

- D 16 Terminology Relating to Paint, Varnish, Lacquer, and Related Products
- D 3276 Guide for Painting Inspectors (Metal Substrates)
- D 4227 Practice for Qualification of Journeyman Painters for Application of Coatings to Concrete Surfaces of Safety-Related Areas in Nuclear Facilities
- D 4228 Practice for Qualification of Journeyman Painters for Application of Coatings to Steel Surfaces of Safety-Related Areas in Nuclear Facilities
- D 4537 Guide for Establishing Procedures to Qualify and Certify Inspection Personnel for Coating Work in Nuclear Facilities
- D 4538 Terminology Relating to Protective Coating and Lining Work for Power Generation Facilities

NACE International and SSPC: The Society for Protective Coatings standards:

SSPC-VIS 1, Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning

SSPC-VIS 2, Standard Method for Evaluating Degree of Rusting on Painted Steel Surfaces

SSPC-VIS 3, Guide and Reference Photographs for Steel Surfaces Prepared by Hand and Power Tool Cleaning

SSPC-VIS 4/NACE VIS 7, Guide and Reference Photographs for Steel Surfaces Prepared by Waterjetting

SSPC-VIS 5/NACE VIS 9, Guide and Reference Photographs for Steel Surfaces Prepared by Wet Abrasive Blast Cleaning

SSPC-SP 1, Solvent Cleaning

SSPC-SP 2, Hand Tool Cleaning

SSPC-SP 3, Power Tool Cleaning

NACE No. 1/SSPC-SP 5, White Metal Blast Cleaning

NACE No. 2/SSPC-SP 10, Near-White Blast Cleaning

NACE No. 3/SSPC-SP 6, Commercial Blast Cleaning

NACE No. 4/SSPC-SP 7, Brush-Off Blast Cleaning

NACE No. 5/SSPC-SP 12, Surface Preparation and Cleaning of Metals by Waterjetting Prior to Recoating

NACE No. 6/SSPC-SP 13, Surface Preparation of Concrete

NACE No. 8/SSPC-SP 14, Industrial Blast Cleaning

SSPC-SP 15, Commercial Grade Power Tool Cleaning

NACE No. 10/SSPC-PA 6, Fiberglass-Reinforced Plastic (FRP) Linings Applied to Bottoms of Carbon Steel Aboveground Storage Tanks

NACE No. 11/SSPC-PA 8, Thin-Film Organic Linings Applied in New Carbon Steel Process Vessels

NACE No. 12/AWS C2.23M/SSPC-CS-23.00, Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel

SSPC-SP 11, Power Tool Cleaning to Bare Metal

SSPC-PA 1, Shop, Field, and Maintenance Painting of Steel

SSPC-PA 2, Measurement of Dry Coating Thickness With Magnetic Gages

SSPC-AB 1, Mineral and Slag Abrasives

NACE Standard RP0302, Selection and Application of a Coating System to Interior Surfaces of New and Used Rail Tank Cars in Molten Sulfur Service

NACE Standard RP0402, Field-Applied Fusion-Bonded Epoxy (FBE) Pipe Coating Systems for Girth Weld Joints: Application, Performance, and Quality Control

NACE Standard RP0602, Field-Applied Coal Tar Enamel Pipe Coating Systems: Application, Performance, and Quality Control

NACE Standard TM0102, Measurement of Protective Coating Electrical Conductance on Underground Pipelines

There are other new standards in various stages of completion that will be introduced to the coatings industry as they become published.





Level 2

Chapter 13

Peer Review Procedure

Peer Review Procedure

The two main things for you to do this week to prepare for the Peer Review are:

- Review your CIP Level 1 materials to refresh your memory, and take advantage of the time allowed for review this week to ask questions on any items about which you're a little hazy.
- Relax—try not to be worried about the Peer Review.

NACE has tried to make the Peer Review as fair and straightforward as possible.

The review itself has a maximum time duration of 2 hours. The review is divided into two (2) parts: Technical and Practical.

The review is an opportunity to demonstrate your technical and practical knowledge. Be a willing participant in that demonstration.

The question set drawn is representative of a body of knowledge that is consistent with the other question sets. **The question set drawn is used only once.**

The integrity of the process is based upon the integrity of the candidate. Honor your hard work, and the program, by not repeating the questions that you were given in the review.

Place yourself mentally in the role of a NACE Inspector throughout the review.

Arrive at least 30 minutes early. The schedule has a tendency to shift, so don't be alarmed. Be ready and stay flexible. The Lead Peer may contact you to give you an update, especially if the reviews are running ahead of schedule.

In your notebooks is a copy of the Peer Review Procedure. Take a few minutes to read over it, then we'll try to answer any questions you may have.



Provisional time slots for the Peer Review are assigned by NACE staff, who first accommodate those who are taking both Level 2 and the Peer Review. These assignments are provisional because the final determinations are made by the Peers when they arrive.

If you want a slot that someone else in class has, get with that person and work out a swap if you can. You must make that change on the posted schedule or check with the NACE staff representative.

This outline describes the procedure and questions to be used in the NACE Coating Inspector Certification Peer Review.

The Peer Review board shall consist of three persons appointed by NACE.

Expectations

The Technical portion of the review consists of 6 technical questions, each having a maximum time allotment of 10 minutes.

- Take your time to focus on the question, and take time to thoroughly formulate your response.
- When giving your answer, stay focused on what the question is asking, do not stray from the boundaries of the question.
- If you are unsure of what the question is asking, you may request clarification from the Peers. They will assist as much as possible.
- Leave time at the end of each question for Peers to ask clarifying questions, if necessary. Peers “suggest” that a response should begin at, or around, the 6-minute mark.
- Some questions require only a short answer, while others require a more developed response. In all cases, there are no trick questions.

- All questions are drawn from CIP courses and reading material to which you have been exposed at some point during the CIP Program.

The Practical Portion of the review consists of 4 practical questions, each having a maximum time allotment of 15 minutes.

- Review and understand the Attestation and Code of Ethics. Much of what we do as NACE Inspectors is based upon the ideals that are contained in the Attestation and Code of Ethics.
- The Practical portion of the review will have you apply your technical knowledge, field experiences, and logic in order to satisfy the scenario.
- Each Practical question is a scenario in which you are the NACE Inspector. The scenario presents a situation that needs facilitation to resolution. It is quite possible that there may be more than one correct response, so think through the scenario and fully develop your response.
- The scenario may be amended and the Peers may take on roles in order to see how you would respond to a modified situation.

Evaluation

After both parts of the review have been completed, the applicant shall be asked to leave the room, but to wait nearby.

The Peers shall then vote, without discussion, on whether, in each Peer's judgment, the applicant's answers are satisfactory to the extent that the applicant should be judged to have passed the Peer Review, or the applicant's answers are unsatisfactory to the extent that the applicant should be judged to have failed the Peer Review.

Two passing votes are required for the applicant to pass the Peer Review.

If the applicant does not receive a unanimous vote (pass or fail), the Peers may discuss the applicant's answers, and vote a second time.

In any case, the final results shall be noted on a standardized form which shall be forwarded to NACE Headquarters.

Each Peer voting negative must document negative comments on the second page of the form.

Peer Review Results Notification Procedure

When a decision is reached, the candidate shall be called to the Peer Review room by the Lead Peer.

The candidate shall be presented with the decision of the Peer Board by means of the Lead Peer presenting the candidate with a properly executed copy of the appropriate PASS or FAIL letter.

The Peer Board may be available briefly to answer questions, but, if the candidate wishes to discuss the Board's decision in detail, the candidate must make arrangements for a formal appointment with the Peer Board through NACE staff.

It shall be the responsibility of the Lead Peer to immediately communicate the results of the Peer Board to NACE staff.

Candidates who fail the Peer Review on their first attempt must wait a minimum of one week before attempting to retake the Peer Review. Candidates failing on second and subsequent attempts must wait a minimum of six months between attempts.

Questions



Level 2

Chapter 14

Case Study C

Case Study

Simon Peabody of Impeccable Inspections, Inc., arrived for work at his new assignment at 7:00 a.m. sharp, as scheduled. He recently had been relocated to this new assignment after political conflicts on a previous job.

Upon arrival on the site, Simon met with representatives of the contractor and the owner who were constructing a high-pressure gas transmission line on the outskirts of a large metropolitan area. The pipe on the job had been shop-coated with two coats of coal-tar epoxy and delivered to the job site with the ends blasted and covered with plastic. Upon welding, the pipe was 100% ultrasonic tested to ensure there were no weld porosities or voids. The joints were then coated using miniature, prepackaged kits of the same coal-tar epoxy that was used to coat the pipe in the shop.

The contract documents stated there would be weekly inspections of the protective coating system by an independent NACE-Certified Coating Inspector—Level 3. Although the job had been underway for almost two months, the contractor had only recently begun to receive and lay pipe. At this time, the contractor had installed 18 joints of pipe, which were exposed in the ditch and ready for inspection.

The coating specification called for field testing of the coating by high-voltage holiday test at 2,500 V, thickness testing in accordance with SSPC PA-2, and a visual inspection for defects such as runs and sags. The specification specifically noted that destructive tests were not to be performed on the pipe after it had reached the job site.

Simon performed his thickness tests and found the coating to be within the limits of the specification. The overall appearance of the protective coating looked good. As Simon performed the holiday test, however, he noticed as he passed the probe over a welded joint that the patch material seemed to be disbanded where it feathered out onto the shop-applied coating. Curious, Simon pulled out his pocket knife and found that he could run the blade beneath the coating and remove the patch material quite easily. Upon examination, Simon found that the same condition existed at each welded joint. Alarmed at this, Simon went to discuss the matter with the contractor and the owner's representative.

The reception Simon received was explosive. The owner's representative had a fit when Simon told him that he had peeled the patch coating away from every joint. The contractor told Simon that he has no right to perform destructive tests that were specifically excluded by the specification. The contractor estimated that he would

incur losses in excess of \$25,000 from delays while the joints were recoated and cured sufficiently for backfill. The contractor further told Simon that he would sue Impeccable Inspections, Inc. for those and any other losses that were incurred due to Impeccable Inspections' "incompetence."

Discussion questions (state reasons for each answer):

1. Did Simon screw up?
2. What would you have done in this situation?
3. What do you think the contractor's chances are of successfully collecting damages from Impeccable Inspections, Inc.? State your reasons.
4. Would the owner's representative side with Simon in condemning the condition of the coating at the joints? Why or why not?
5. If you were Simon what would you do next?



Level 2

Chapter 15

Self-Study Questions

Chapter 10—Nondestructive Test Instruments

1. Atmospheric monitoring and safety include the use of _____ and _____.
2. Nondestructive test instruments include:
 - a. _____
 - b. _____
 - c. _____
3. A solvent vapor meter can measure:
 - a. _____ gases
 - b. _____ gases
 - c. _____
4. _____ monitor oxygen levels.
5. _____ monitor toxic and/or combustible gases.
6. Drager meter uses _____ for about _____ chemical vapors or gases.
7. A pH meter is calibrated using a _____ solution.
8. According to ASTM D 714 the largest size blister is given a number _____.
9. Moisture meters can be used to measure moisture in _____ and _____.
10. Moisture meters can be used to give a _____ indication of moisture in concrete.
11. The eddy current gauge is used for measuring the DFT of _____ coatings applied to a _____ substrate.
12. Magnifiers may be used to check for contamination, _____, _____, _____, and _____.

Chapter 11—Destructive Test Instruments

1. Some inspection instruments and tests may _____ or _____ a portion of the coating.
2. The Tooke Gauge is considered to be a _____ test instrument.
3. ASTM D 3359 is a test method for measuring the _____ of a coating using _____.
4. The Tooke Gauge is used to measure DFT of coatings up to ___ mils.
5. The Tooke Gauge uses 3 tips numbered __, __, __.
6. The Tooke Gauge _____ be calibrated.
7. According to ASTM D 3359 the cross hatch method is used when the coating thickness is ___ than ___ mils.
8. The hardness of a coating may be regarded as an indication of its ___.
9. According to ASTM D 3363 the first pencil that will not __ __, or ___ the film, is called the ___ hardness or ___ hardness.
10. ASTM G 8 is a standard test method for _____ disbonding of _____ coatings.

Chapter 12—NACE Standards

1. NACE is one of the world's largest _____ standards-development groups.
2. Some other organizations that develop standards are:
 - a. American Water Works Association (_____)
 - b. ___: The Society for Protective Coatings
 - c. ___ International
 - d. International Organization for Standardization (___)
3. Standards are not ___ and ___ unless cited in a _____ (which includes a coating specification) or _____.

4. NACE issues a *Book of Standards* based on three classifications:
 - a. _____ (SP)
 - b. _____ (TM)
 - c. _____ (MR)
5. Coatings inspectors should stay abreast of _____ and _____ in standards with which they may be working on any given project.



Level 2

Chapter 16

Linings and Special Coatings

Linings and Special Coatings

Introduction

Protective coatings are manufactured in the forms of:

- Liquids (dispersions)
- Solid powders
- Polymeric sheet materials
- Ceramics (glass)
- Metallics (hot-dip galvanizing, spray metallizing, electroplating, etc.)

In CIP Level 1, several types of common liquid coatings were discussed, primarily from the standpoint of their use on the exterior surfaces of aboveground structures.

Hot-dip galvanizing and spray metallizing will be discussed. In this segment the focus will be on the following:

- Powder coatings
- Pipeline exterior coating and lining materials
- Thick-barrier linings
- Glass linings
- Unbonded linings



Definitions of Coatings and Linings

In the *Encyclopedia of Chemical Technology*¹, the definition of a coating is divided into two parts, *Coatings* and *Linings*:

- Coatings

A *resistant coating* is a film of material applied to the exterior of structural steel, tank surfaces, conveyor lines, piping, process equipment, or other surfaces, which is subject to weathering, condensation, fumes, dusts, splash, or spray, but is not necessarily subject to immersion in any liquid or chemical. The coating must prevent corrosion or disintegration of the structure by the environment.

- Linings

A *resistant lining* is a film of material applied to the interior of pipe, tanks, containers, or process equipment and is subject to direct contact and immersion in liquids, chemicals, or food products. As such, not only must it prevent disintegration of the structure by the contained product, but it must also prevent contamination of the contained product. In the case of a lining, preventing product contamination may be its most important function.

The Coating Inspector Program recognizes that the broad-based definitions above are based on the intended use without regard to the generic classification of coating materials.

¹ Munger, C. G., Kirk-Othmer, Encyclopedia of Chemical Technology, 3rd Ed. Vol. 6, John Wiley and Sons, New York, NY, p. 445, 1979

Reinforced Plastics

Inert fibers, such as glass and certain synthetics, are used frequently as reinforcing in certain coating systems to provide additional strength. The resin fiber materials can be used for construction and to repair tanks, concrete structures, etc., which have been damaged by chemical attack.

Some types of resins used in reinforced plastic systems include:

- Polyester
- Vinyl ester
- Epoxy

The types of materials used to reinforce plastics include the following:

- Chopped glass (randomly oriented) mat
- Woven glass roving
- Flake glass
- Chopped glass fibers
- Other types of synthetic fibers, such as Kevlar® or polypropylene



Figure 16.1: Glass Fiber Material

These reinforcing materials frequently are treated with a special material called *silane*, which acts as a wetting agent to the inorganic fiber and allows the organic polymer resin to bond to the fibers.

Silane is soluble in water, and it is important that these fiber materials be stored in a dry environment until used. If they become wet, even thorough drying may not restore the wetting properties of the silane.

The term *laminate* or sometimes *laminant* is used to describe a system made up of several layers of reinforcing materials saturated with certain resins. In some cases, different reinforcing materials may be used. These composite materials may range in thickness from 1.5 to 6.25 mm (60 to 250 mils), depending on the particular service requirements.

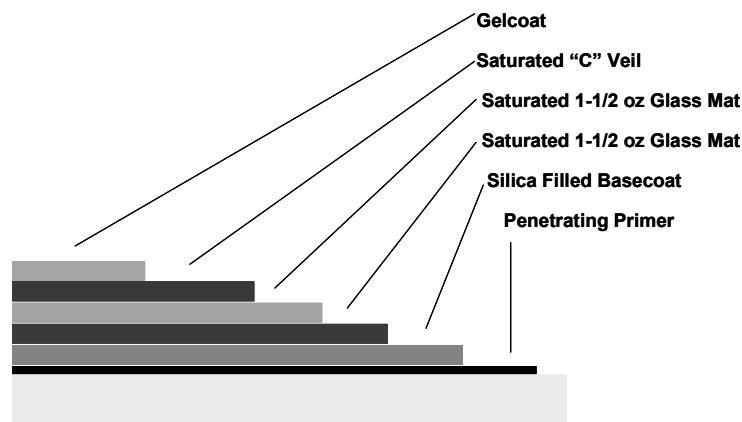


Figure 16.2: Laminate May Consist of One or More Layers of Fiber-Reinforced Plastic

Laminate systems should be applied to relatively smooth surfaces. If the surface is pitted, the pits should be filled with the un-reinforced resin mixture prior to installation.

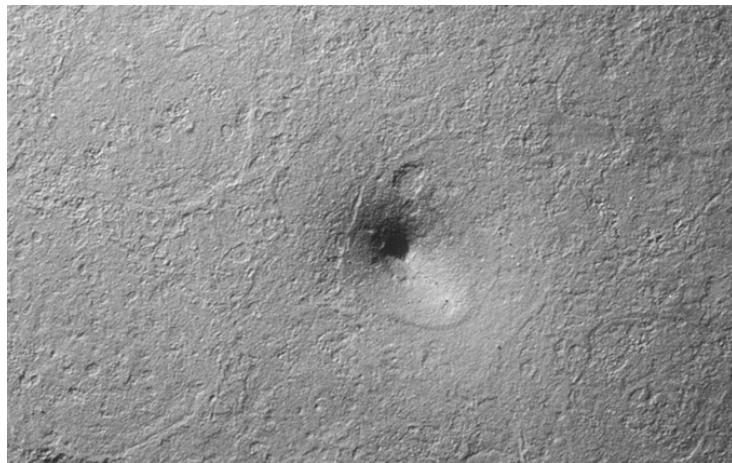


Figure 16.3: Pits Should be Filled

Frequently the un-reinforced resin mixture (saturant) is filled with sand and then is applied by trowel to pits, sharp edges, and corners before applying a glass- or synthetic-fiber reinforcing material.



Figure 16.4: Trowelling Sand/Resin Base Coat to Fill Pits

This trowel coat smoothes the surface so the reinforcing fiber can be installed without wrinkles and voids. The first layer of reinforcing is then completely embedded in the wet trowel coat.

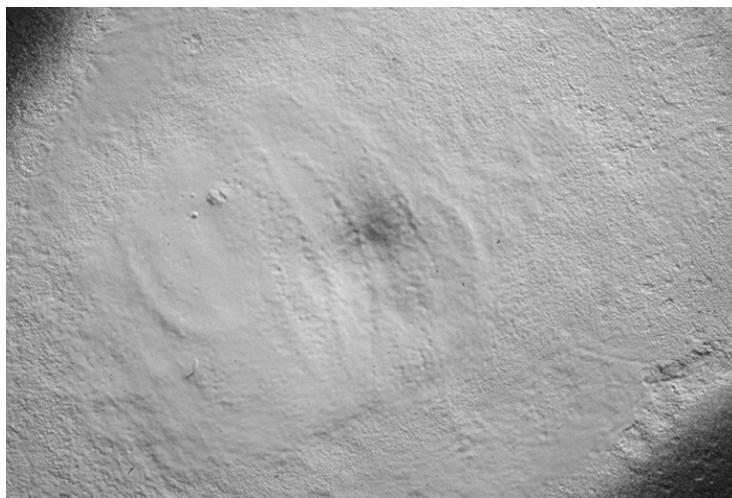


Figure 16.5: Pit after Filling



Figure 16.6: Spreading Glass Mat



Figure 16.7: Fitting Glass Mat into Corners

A special corrugated metal roller is used to work air bubbles out of the laminate and to bring the saturant to the top. Pigmented saturant may be used; however, some installers prefer to use a clear saturant resin, which makes it easier to detect any bubbles in the system.



Figure 16.8: Fitting Glass Mat into Corners

Seen here is an installation of a randomly oriented mat using 100 %-solids epoxy as a saturant.



Figure 16.9: Rolling 100% Epoxy into Glass Mat

Epoxy resin is generally less hazardous than some polyesters and vinyl esters because it does not contain any volatile and flammable styrene monomers.

This type of laminate system is usually referred to as a *hand lay up*. It can be noted that the weld seams in the floor have been filled so that the reinforcement covers them smoothly without gaps or bubbles.

In many cases, the owner will require a resin/glass layer system be applied under the support posts. The built-up system must be thick enough and strong enough to withstand the load.

Each post is raised and supported to give enough clearance for abrasive blast cleaning and application of the coating/glass system.



Figure 16.10: Post Raised and Supported for Blasting Underneath

Additional glass-reinforced plastic (GRP) may be applied to build added thickness. A topcoat, sometimes called a *gel coat*, which consists of the un-reinforced resin mixture, is applied over the final reinforcing layer as a sealer.

Gel coats for vinyl ester and polyester usually contain a small amount of paraffin wax that floats to the surface during cure. This wax layer helps prevent oxygen from retarding the cure of the resins.

Total final cure of these resins is important to their performance. Some users consider hardness as a function of cure and, in a sense, a measure of its performance. Consequently, hardness tests, such as impressor hardness,

may be specified. For this test to be conducted properly, the DFT of the laminate must be minimum, depending on the type of impressor used, up to 1,500 μm (60 mils).

If an impressor hardness test is specified, it should be performed before the gel coat is applied. If the test is conducted after the application of a gel coat, the tested area should be repaired to ensure it is sealed.

The inspector also should check carefully for any fibers that may have been left uncoated with the resin. If left bare, wicking may occur. The fibers act as a wick, drawing out contents of the vessel into the coating system, possibly causing a premature coating failure.

Some spray units are capable of simultaneously applying a two-component coating with chopped glass fibers. Separate components are sprayed from an external-mix gun, while glass roving (rope) fed by an air motor is chopped or shredded into small pieces by a chopper gun fitted inside the gun body.

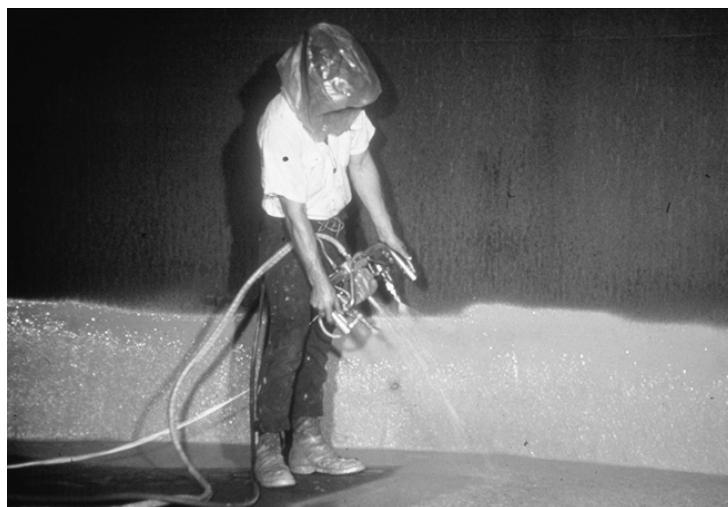


Figure 16.11: Chopper Gun in Use

The coating components and the chopped glass fibers are combined just in front of the gun and are propelled onto the surface. The sole purpose of the chopper gun is to shred or chop the glass roving into small pieces. These small pieces of fiber then become randomly oriented in the coating and act as a reinforcement to the mixture.

Some specifications require holiday testing of the laminate. This test should be conducted after the gel coat has been applied and allowed to cure properly. If any threads of the glass fibers are uncoated, they may be detected by a holiday detector. It is vital to the performance of the system that all glass fibers be completely coated and sealed with the gel coat.



Figure 16.12: Trowelling Coating on Interior Weld Areas



Figure 16.13: Airless Spray of Coating on Tank Roof

Linings

Linings are used to:

- Protect the interior of a vessel, pipeline equipment, etc., from corrosion.
- Protect the contents of a vessel from being contaminated by the substrate.
- Protect the interior of equipment from abrasion and any corrosion that might result if the lining is abraded.



Figure 16.14: Elevated Water Tank to be Lined



Figure 16.15: Aboveground Storage Tank to be Lined



Figure 16.16: Interior of Tank to be Cleaned and Lined

Lining Specifications

Lining operations generally will be governed by specifications. Because of severe service conditions, closely following the specification is highly critical.

Technical service from the coating manufacturer is often written into the specification or contract and may be highly desirable, especially if a new or unfamiliar product is to be applied.

The inspector involved with lining operations should obtain, read, and understand the specification.

Surface Preparation, Application, and Inspection

Surface preparation, application, and inspection standards and techniques and materials are similar to those for external coating operations.

In general, an immersion environment is considered to be more severe, and higher standards of preparation and application may be specified.

Because of the severe service requirements in many lining situations, it is important that surface preparation, application, and inspection be performed correctly. For

example, most specifications now require that all internal edges and corners be stripe coated.

Curing by Heat

Specifications for the lining operation may require the application of heat and proper evacuation of solvents. The heating type, amount, and technique may vary depending on the curing mechanism of the specific material to be used.

- **Solvent-Evaporation-Cure Materials**

Under normal circumstances, evaporation-cure materials go through a process of solvent evaporation during the re-deposition (curing) of the original dissolved resin. It may be desirable to use heat to cure solvent-evaporation materials, because the heating can help:

- Aid in the removal of volatile solvents
- Prevent solvent wash (re-dissolving of liquid lining material)
- Minimize the possibility of solvent entrapment in the lining
- Minimize or eliminate residual solvent odor
- Decrease time between coats
- Accelerate drying (cure)
- Develop optimum film density which improves chemical and permeation resistance

- **Polymerized Coatings**

Coatings that cure by chemical- or heat-induced polymerization are often heated during the curing process to:

- Remove volatile solvents and byproducts of polymerization from the lining and the vessel

- Accelerate the curing process
- Achieve optimum cure (polymerization), which enhances chemical and permeation resistance

In each case, one major reason for heating (with ventilation) is to help remove volatile solvent or water, not only from the lining, but also from the vessel. Heat alone is not enough to effect a proper cure. As with all linings, proper and adequate ventilation are vital in removing solvents.

Unless removed from the vessel during the heating process, a portion of the solvent may be reabsorbed into the lining material, and the cost and time involved in the heating scheme would be all but wasted. Therefore, proper ventilation is essential.

Many types of heating units are available. The inspector should ensure the type used is that called for in the specification and that it is carefully utilized in such a way that the lining is not damaged by either contamination or excessive heat.

Some cautions to observe during heating are:

- Avoid hot spots, which may lead to differential curing.
- Avoid introducing combustion products or water vapor into the vessel (frequently this is done by using heat exchangers and dehumidifiers).
- Thermal shock to lining
- Raise the temperature gradually to avoid thermal shock to the lining

Safety

The importance of safe practices during lining operations cannot be over emphasized, and they should be observed at all stages, including:

- Preparation of the tank or vessel prior to surface preparation
- Surface preparation
- Application
- Curing
- Inspection

Since lining operations take place in enclosed spaces, ventilation is extremely important.

The working environment should be monitored to detect hazards such as concentrations of noxious fumes, presence of splash or spillage of harmful liquids, conditions of excessive heat, and/or areas where the oxygen content of the air may be dangerously low.

Properly tagged valves on all lines routed to the vessel should be chained and locked in the off position.

Adequate protective clothing, including air-supplied respiratory equipment, ventilation equipment, safety shoes, helmets, gloves, eye protection, and skin protection, should be worn as required by safety regulations.

Some lining operations, in a fuel storage tank, for example, take place in potentially explosive atmospheres. Great care should be taken to ensure that no sources of ignition exist which could trigger an explosion. Precautions include the use of explosion-proof lighting equipment and safety-approved hand and power tools.

The inspector working with lining operations should always know and follow the safety rules set forth in the specification by the safety engineer or person responsible for safety on the job, and should immediately report any unsafe practices.

Powder Coatings

The discussion on powder coatings will include a look at each of the following:

- Where powders are used
- What powders contain
- How powders cure
- Generic types of powders
- Powder application temperatures
- Application methods
- Cloud-chamber application
- Inspection

Uses for Powder Coatings

Perhaps the most common area of powder utilization is on domestic appliances, including refrigerators, washing machines, and dishwashers.

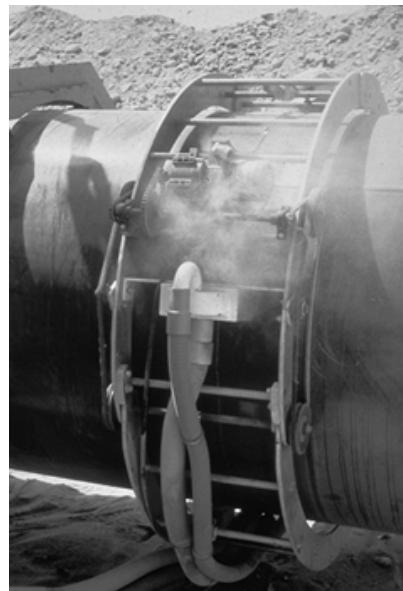


Figure 16.17: Pipeline Coatings

However, in recent years, powders have been used very successfully for heavy-duty industrial applications such as pipeline coatings, for the coating of rebar (reinforcing steel) for use in concrete, pump impellers and impeller housings for chemical service, fabricated piping, pipe fittings, agitation blades, etc.



Figure 16.18: Rebar for Concrete



Figure 16.19: Agitator Blades

Powder Coatings Content

Powder coatings essentially are similar to liquid coatings in their make-up. Common formulations include epoxy, polyester, urethanes, etc.

Powders generally contain the following:

- Pigment
- Resin
- Curing agents (partially reacted solid resins)
- Wetting agents
- Flow-control agents
- Fillers and extenders
- Foam breakers and other additives

All are dry particles and the mixture looks like any fine powder (e.g., flour), except it may be colored green, grey, red, yellow, or any other color, depending on the manufacturer and process.

Powder Coatings Cure

Powders fall into two broad categories:

- Thermoplastic: materials that soften when heated and return to their original hardness when cooled
- Thermosetting: materials that harden when heated and retain their hardness when cooled

The key to the curing mechanism is the transitional heating stage. Once the powder is applied to a heated surface, either in a preheat or post-heat situation, the powder changes its state and temporarily resembles a liquid coating. Once cooled, it forms a homogenous film over the steel surface.

Powders applied to a heat source pass through four distinct stages:

- The flow stage, which occurs when the particles of powder begin to flow, but are not fully liquid

- The wetting stage, which occurs when the particles of powder absorb more heat, fully liquefy, and wet the surface
- The gel stage, which occurs when the particles of the powder begin to gel, converting into a solid
- The curing stage allows for further changes to take place, permitting the powder to cure completely

The complete process—from flow stage to cure—generally takes less than three minutes, which makes this an ideal process for production-line application.

Generic Types of Powder

- Thermoplastic materials:
 - Polyvinyl chloride (PVC)
 - Polypropylene
 - Kynar®
 - Halar®
 - Polyethylene
 - Teflon®
- Thermosetting resins:
 - Epoxy
 - Urethane
 - Polyester
 - Acrylic

Powder Application Temperatures

Thermosetting powders contain partially reacted curing agents and require a heat source to convert them from a powder state to a liquid state. It is important that powders are stored away from any heat source until they are to be applied. In warm climates such as those in the tropics or during shipping in hot temperatures, powders should be stored in refrigerated containers.

The range of application temperatures for powder varies by manufacturer. Thermoplastic powders normally require lower application temperatures, and the manufacturer's data should be consulted for the proper temperature range.

Preheat

The surface or object to be coated may be preheated either by a high-frequency induction coil or in a direct gas-fired oven.

Application Methods

Powders are applied by one of the following methods:

- Flock spray
- Electrostatic spray
- Fluidized bed, dip method
- Roto-lining
- Flame spray
- Cloud chamber



Flock Spray

In this process, the powder is mixed (that is, fluidized) with dry, low-pressure compressed air and passed through a wide-orifice nozzle. The powder is literally blown onto a heated surface.

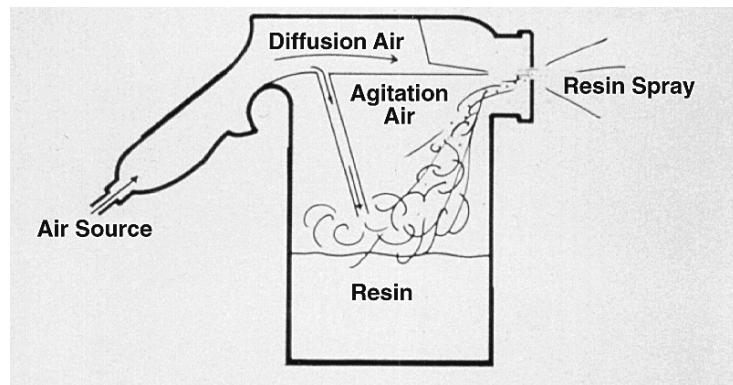


Figure 16.20: Flock Spray

Electrostatic Spray

A more efficient method for spray applying powders is using the electrostatic hand gun. As in the case of flock spray, the powder is conveyed into the gun in fluidized form, but, in this case, it is usually pressurized.

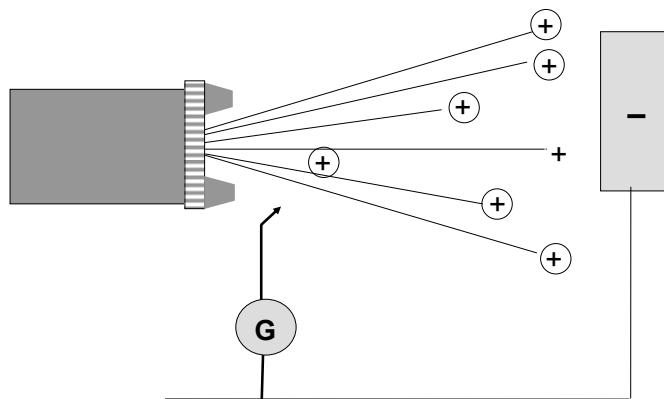


Figure 16.21: Electrostatic Spray Principle

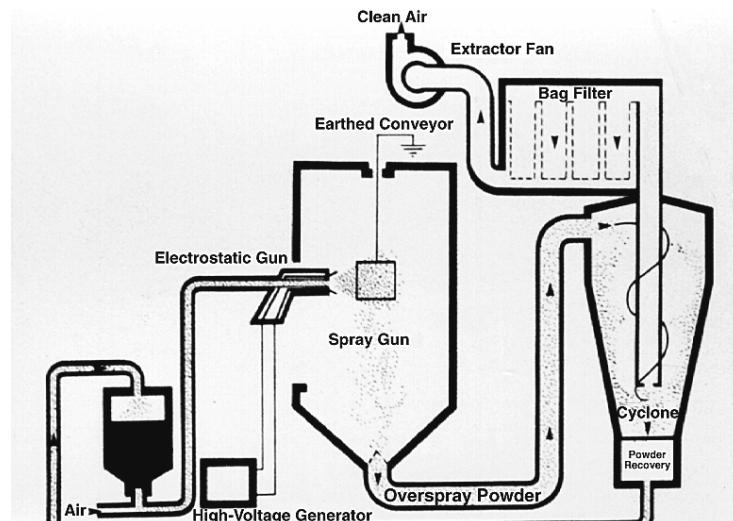


Figure 16.22: Electrostatic Powder Spray Booth

At the gun itself, an electrostatic charge is applied to the stream of fluidized particles so that only charged particles leave the gun. The project to be coated is grounded so the charged particles are attracted to its surface.

As the coating thickness builds up, loss of particle charge to the work piece is prevented; and, as a consequence, the outer layer of particles retain their positive charge. They repel the new, positively charged particles arriving at the surface so an additional increase in thickness is prevented.

An advantage of this method of application is that thickness is somewhat greater at the edges than it is on flat surfaces.

The electrostatic handgun is probably the most popular and versatile method of powder application. It is also one of the most efficient application procedures, providing transfer efficiency of about 98%.



Figure 16.23: Electrostatic Spray Gun

In recesses and inside boxes, efficiency drops considerably due to the *Faraday cage effect*. The famous physicist, Faraday, found that because electrostatic charges concentrate on the outside of a box, it is not possible to charge the inside.

Hence, electrostatic application works very well on the outside of a metal box, such as a refrigerator body or a pipe, but not efficiently on the inside.

Electrostatic application of powder does not require the work piece to be heated before application. The thickness of the coating obtained is then wholly dependent upon the voltage of the applied charge and the resistivity of the powder. Voltages ranging from 30 to 80 kV are commonly used.

However, by preheating the article to above the melting temperature of the powder, thicker coats can be applied. The electrostatic spray gun, therefore, may be used to apply coating thicknesses from approximately 50 μm to more than 500 μm (2 to 20 mils).

Fluidized Bed

An application method known as the *fluidized bed*, which is analogous to *dipping* in the liquid coatings field, was originally developed in Germany in 1953.

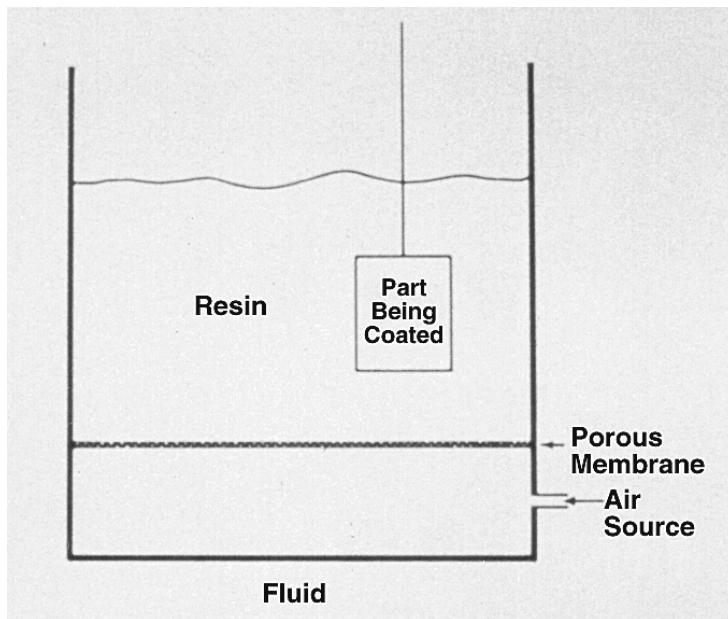


Figure 16.24: Fluidized Bed Dipping

When a finely divided stream of air is passed through a powder, a solid in gas dispersion is formed which behaves like a liquid. A fluidized bed consists of a tank with a false bottom made of porous material. Air pressure is applied below this false bottom so the powder contained above it is lifted and maintained in suspension.

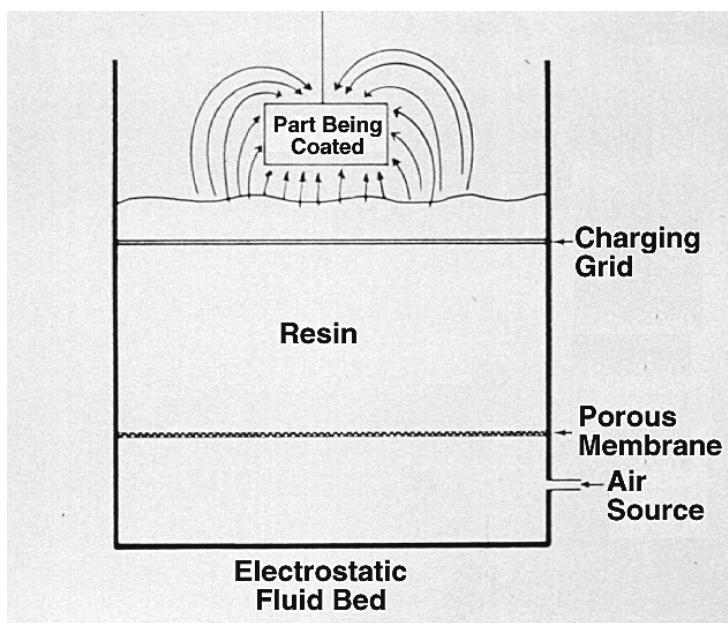


Figure 16.25: Fluidized Bed Chamber

The volume of the powder approximately doubles, and in this fluidized condition, the powder-air mixture behaves as a liquid. When a heated article is inserted into this fluidized bed, the powder adjacent to the article melts and adheres to the surface.

The final thickness of the coating is controlled by the temperature of the article at the time it is inserted into the fluidized bed. The higher the temperature and heat capacity of the item to be coated, the greater the amount of powder that will adhere to the article, thus achieving a greater coating thickness.

After removal from the fluidized bed, the coated article is further heated in an oven to achieve complete fusion of the coating and to form a smooth, coherent film. In the case of thermoset materials, the heating cycle must be adequate to completely cure the coating.

If many articles of high-heat capacity are successively passed through the fluidized bed, the powder becomes heated and may then *agglomerate*. There is a limit to the rate at which articles can be efficiently processed through the fluidized bed.

Roto-Lining

Roto-lining is accomplished by charging a pre-weighed amount of resin into a hollow mold, placing the mold into a heated oven, and rotating the mold about two axes while the mold and the resin are heated. When the interior metal surface is heated above the melting point of the resin, the resin melts on contact with the metal. Upon cooling, the powder/resin has formed a protective coating.



Figure 16.26: Roto-Lining—Pouring Measured Amount of Powder into Fitting

Examples of items and equipment that can be lined by roto-lining include: drums, carboys, storage and process vessels, pipe, pipe flanges, valves, flow meters and pumps, as well as other equipment.

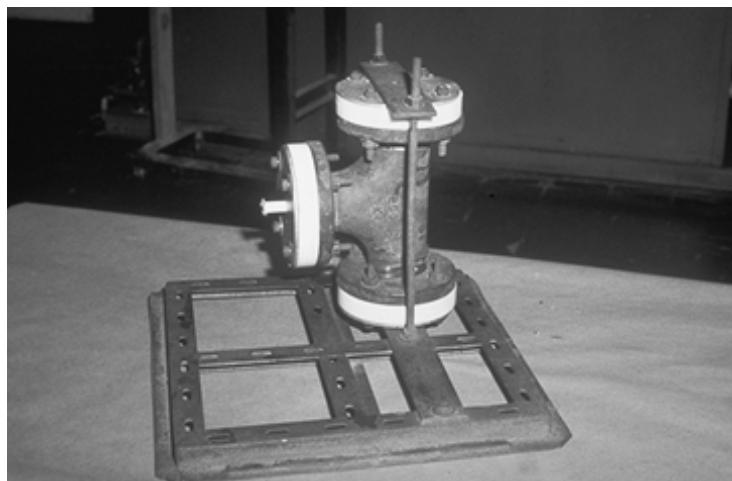


Figure 16.27: Roto-Lining—Flange Fitting onto Rotating Rack

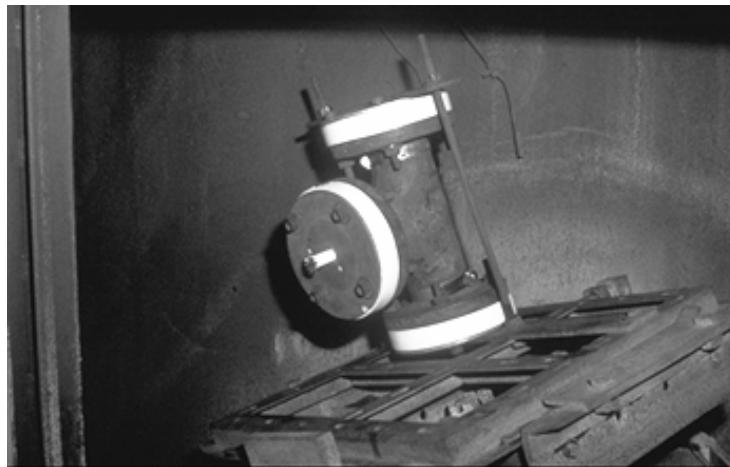


Figure 16.28: Roto-Lining-Fitting in Oven

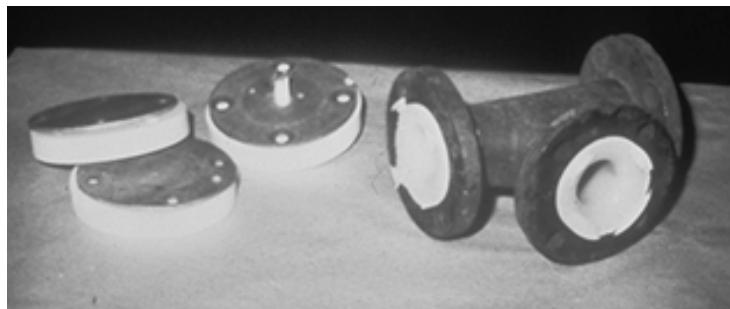


Figure 16.29: Roto-Lining-Finished Piece

Roto-Molding

Careful control of rotation and heating in the roto-molding process is necessary in order to prepare very uniform parts. Following the heating step, the mold is cooled by water spray so the part can be removed.

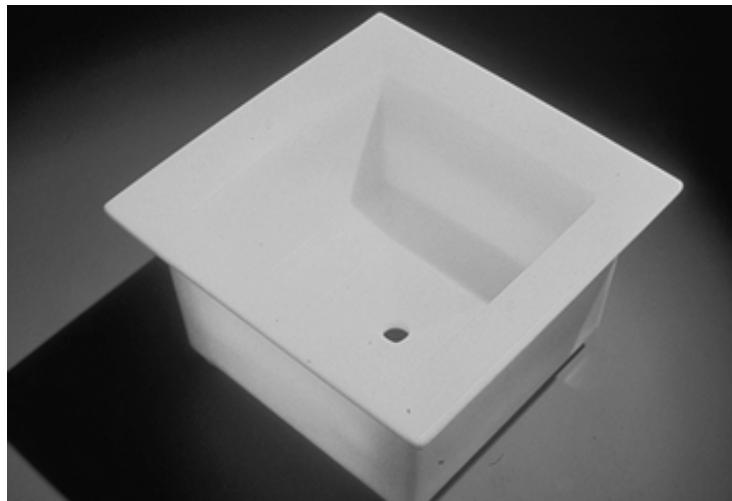


Figure 16.30: Roto-Molded Vat

Flame Spray

Thermoplastic powder particles are blown under low air pressure through a high-temperature, open-flame torch similar to an oxyacetylene blow torch. The particles melt and the surface to be coated is heated at the same time.

Cloud-Chamber Application

To complete this section on powder coatings, some mention must be made of the cloud chamber, which essentially, is a large box with openings for the work piece to pass through the chamber. A cloud of fluidized powder is conveyed from storage hoppers and introduced by one or more distribution heads into the chamber.

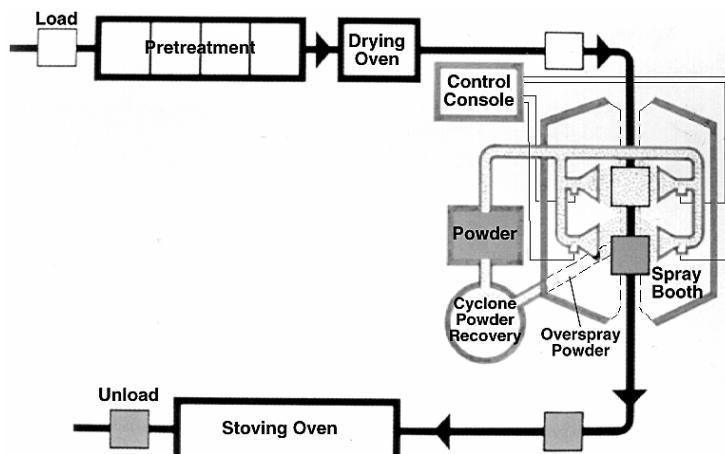


Figure 16.31: Cloud Chamber for Powder Coating

Sufficient velocity is required to maintain the heaviest particles in suspension. This accomplished, work pieces on an overhead conveyor pass through the continuously rotating cloud of powder and become the target for the full spectrum of particle sizes.

Particles that fall to the bottom of the chamber and are recirculated through the distribution heads, together with new material from the hoppers, ensure a consistent and uniform particle utilization.

In general, the correct cloud density is double the quantity of particles being consumed by deposition on the work piece passing through the chamber. Cloud density can be varied in the coating zone. Focusing the particles by electrostatic means enables coating shadow areas or hard-to-reach areas.

A slightly negative pressure is maintained inside the chamber to prevent powder escaping from the open ends. The openings in the end of the chamber may be as large as 1 x 2 m (3.3 x 6.5 ft). Articles to be coated may be either hot or cold, depending upon thickness requirements.

Because it is a totally enclosed recirculating system, no powder is lost; and powder in the system remains there until it is used up. The system is an efficient and economical method for mass production coating of

similar articles using the same powder coating. This process does not lend itself to custom coating work.

Inspection

Inspectors in the powder coatings industry work in a relatively safe environment. Inspection criteria are similar to the liquid coatings industry and include:

- Quality of surface preparation

The requirements for surface preparation in immersion service generally are more critical than for atmospheric service. This preparation must be suitable for the particular coating to be applied and must meet the requirements of the specification. The inspector may be required to perform tests for:

- Ambient conditions such as air and substrate temperatures, relative humidity, and dew point. The inspector should observe the dehumidification system, if any, to see that it is performing properly and that it will “hold the blast” in the event undue changes in temperature occur.
- Fabrication defects such as rough welds, skip welds, pits, crevices, hard-to-reach or even inaccessible areas, etc.
- Soluble chemical salts
- Surface cleanliness and surface profile to specification
- Residual abrasive dust

The inspector should carefully document each item of inspection, noting any potential problem areas that should be brought to the attention of the client for review and/or correction before coating operations proceed.

- Application criteria

The contractor may be required to:

- Observe the condition of the powder to ensure that it has not been allowed to absorb moisture.
- Check the operation of the dehumidification system, if any, including proper air circulation and ventilation to remove solvents, etc.





Level 2

Chapter 17

Special Application

Equipment

Special Application Equipment

Introduction

Conventional air spray and airless spray equipment sometimes are modified for special-use situations. Such specialized equipment includes:

- Plural-component spray systems
- Hot-spray systems
- Electrostatic systems
- Centrifugal spray
- Guniting
- Other specialized equipment

This equipment can be used in manual or automatic installations:

- Manual installations, in which the spray gun is directly operated by a painter
- Automated installations, in which one or a series of spray guns or spray heads are operated mechanically

Plural-Component Spray Systems

Plural-component spraying is the automatic metering, mixing, and application of plural-component (usually two) catalyzed coatings such as polyesters, epoxies, and urethanes. This type of equipment generally is used to apply high-solids coatings (up to and including 100%-solids) that have short pot lives (from as low as three seconds to a few minutes).

Because of the short pot life, coatings can be applied with special spray guns which mix the plural components internally at the gun itself, externally in the spray pattern

in front of the gun, or through the use of a manifold mixer installed inline before the spray gun.

Plural-component spray is used for several reasons, including:

- Ease of applying very high-solids materials which meet or exceed the requirements of environmental regulations limiting solvent emissions Volatile Organic Compound (VOC) regulations.
- Ease of applying 100%-solids materials which may have special performance characteristics for use on steel or concrete at 500 µm (20 mils) or more per coat.
- Efficiency of spraying in continuous operation, multiple-component materials that may not require an induction or sweat-in time.

Perhaps the major advantage of using plural-component spray systems is with materials such as the polyureas, which have a very short pot life (usually less than 10 seconds) and cannot be mixed in an open container prior to application.

These short-pot-life materials, along with regular plural-component epoxies, urethanes, etc., are blended and mixed within the system, not exposed to the atmosphere, and delivered in a proper ratio to the work piece. This process provides great savings in materials usage and reduces the problems and/or costs associated with waste disposal.

Equipment

Plural-component spray equipment is either:

- A fixed-ratio type, or
- A variable-ratio type

The fixed-ratio type can deliver only one volume of the plural component in a ratio such as 1:1. A variable-ratio

system can be adjusted to such proportioning ratios as 1:1 to 18:1 or greater.



Figure 17.1: Portable Plural-Component Spray Outfit

The equipment consists of two or three airless pumps attached to an air motor. Individual pumps deliver separate components from containers to the air motor that delivers metered material through separate lines to:

- A spray gun for delivery, or
- A mixing manifold equipped with static or mechanical mixers; the blended material then passes through a short whip hose 2 to 3 m (8 to 15 ft) long to the spray gun

With the fixed-ratio unit, the pumps are set to deliver equal volumes of the separate components, while the variable-ratio units are equipped with a master pump and a slave pump. The master pump delivers the resin, and the slave pump dispenses the catalyst (activator).

The slave pump is fitted onto a sliding bar that allows it to move forward and backward, and the position of the pump on the bar changes the length of the pump stroke. A short stroke of the pump provides less catalyst, a longer

stroke provides more catalyst; thus, the catalyst-to-resin ratio can be varied.

Heaters are sometimes used to reduce the viscosity of the coating and improve its rate of flow. These heaters can be installed in-line or at the material container, or both. Often, the material hoses are heat-traced or insulated to help maintain the desired material temperature. As not all materials are manufactured to withstand heating, the material data sheet should always be reviewed for heating and temperature requirements.



Figure 17.2: Heated System with Insulated Hoses

Purge Pump

Most variable-ratio units are equipped with a purge pump that delivers solvent to clean out the mixing-and-delivery end of the system.

The purge pump is connected on one end to a container of solvent and at the other end, to the back of the mixing manifold. In the event of a shutdown or mis-metering, or if there is a possibility the mixed coating could set up in the manifold, the whip hose, or spray gun, the purge pump could then be activated to deliver solvent to flush out the mixed material.

Plural-Component Spray Guns

Plural-component spray guns are available for either conventional air spray or airless spray applications.

The materials are mixed:

- Internally, where the coating components are blended together by passing the materials through a static mixer or mechanical mixer just before the spray gun, or inside the gun itself, or



Figure 17.3: Internal-Mix Spray Gun

- Externally, where the coating components are separately sprayed from the gun, then mix in the spray pattern immediately in front of the gun.

External mix spray guns are sometimes used in applications where the addition of chopped glass fibers to the sprayed coating is desired. In these cases, a chopper attachment is frequently used.



Figure 17.4: External-Mix Gun with Glass Chopper

The chopper unit is usually air powered and attached to the top of the gun. A glass-fiber rope, called *roving*, is fed into the chopper, where it is chopped into shreds of the desired length, and then propelled into the spray pattern of the coating. The blended mixture of glass fibers and the coating is then delivered to the surface being coated. This glass fiber/coating system is usually over coated by a gel coat of the coating resin without the glass fiber. The gel coat can be applied by a conventional spray unit or by an airless system.

Manifold Mixing System

In a manifold mixing system, the coating components are drawn from their containers, brought together in a manifold, mixed, and then delivered to the spray gun or spray head for spraying.

These manifolds usually contain a static in-line mixer like the one shown here, which is used in a feed line before it enters the gun. These mixers work by cutting the coating stream in half and turning it 90°. This is done numerous times such that the components are mixed thoroughly when they exit the spray gun.



Figure 17.5: Static Mixer for Manifold Mixing System



Figure 17.6: Mixing Block for Plural-Component Spray Unit with Insulated Hoses

These mixing devices can be used with either conventional air spray or airless spray and are used more commonly for high-viscosity materials. In some manifolds, the ratio or proportion in which the separate coating components are mixed can vary from 1:1 to 18:1 or greater.

Manifold mixing systems are used in field coating applications, as well as in coating shops. Many of the 100%-solids elastomeric and epoxy coatings used for secondary containment are applied with plural-component spray equipment.

Hot-Spray Systems

Heating the coating liquid prior to application is used in air spray and airless spray applications. It is accomplished by either the use of an in-line heater, or a hot box, which heats the coating before it is passed through the spray gun.

The increased temperature of the liquid generally reduces viscosity, allowing the coatings to be applied at a somewhat faster rate. Also, as the coating is propelled into the air, it cools rapidly and viscosity increases shortly after the coating hits the surface. This helps the coating remain in place and reduces sags and curtains, making a more uniform film.

Heating coatings formulated for hot application also allows higher-solids and higher-viscosity materials to be sprayed more efficiently, permitting thicker coats of material to be applied without runs or sags.

When heaters are used, the coating must not be heated to a temperature higher than allowed by the specification or recommended by the manufacturer.

In-Line Coating Heaters

Coating heaters come in a number of sizes, shapes, and forms. They generally preheat the coating to temperatures ranging from 35°C (95°F) to 93°C (200°F).

Some heaters are portable and may be attached to the spray man's belt; those being electric require a cord. Along with the weight of the heater itself, this makes the equipment somewhat more cumbersome and may create a safety issue for the painter.

The coating may also pass through a stationary heater situated between the pump and the gun. The in-line heaters mounted on the pump are 4,000-watt, thermostatically controlled units that can heat either component to 70°C (158°F). Even with such heaters, there can be considerable heat loss with this method,

depending on the length of the hose. Using insulated and heat-traced hoses reduces the heat loss.

To help avoid heat loss, spray hoses sometimes are heat-traced, as shown in this slide. In this case, the two components are mixed just after the point where the orange hoses emerge from the blue heat-traced jacket.



Figure 17.7: Hoses May Be Insulated or Heat Traced

The benefits of applying heated coatings by either airless or conventional air spray are approximately the same for both. Many shop-finish application units use airless spray and in-line heaters as standard procedure. They are used less often on large structural steel units, such as offshore rigs, bridges, and large storage tanks.

Advantages and Disadvantages

Some advantages of heated spray include:

- Coatings may have more uniform viscosity.
- Even coverage may be achieved, reducing runs and sags.
- Drying time may be shorter.
- Faster applications may be possible due to the lower viscosity.

- Coatings can be sprayed readily at lower ambient temperatures.
- There may be less solvent fumes because no solvents are added.
- Coating thickness may increase per unit of application.
- Finer atomization with lower application pressures may be possible.
- Coating adhesion may be improved with reduced viscosity.
- Longer lengths of hose, if required, may be used.



Figure 17.8: Men Spraying Pipe with Heated Material

The major disadvantage of heated spray is that the coating may be damaged by incorrect heating.

Also, poor mixing ratios can result if the equipment metering devices fail, or are not set properly.

Electrostatic Spray

Electrostatic spray may be used with either conventional air spray, airless, or air-assisted airless spray equipment, in manual or automatic settings.



Figure 17.9: Electrostatic Spray Gun

In electrostatic spray operations:

- A rather high charge (to 75 KV for hand-held guns; to 180 KV for some automated setups) is applied to the coating particles as they pass away from the spray gun.
- The coating particles are given an electrical charge, and the work piece is grounded. The charge on the particle may be positive or negative, but is more often positive.
- When the charged coating passes through the spray gun and into the air, the opposite charges attract each other; and the finely divided coating is attracted to all sides, edges, outside corners, and some recesses of the object being coated.

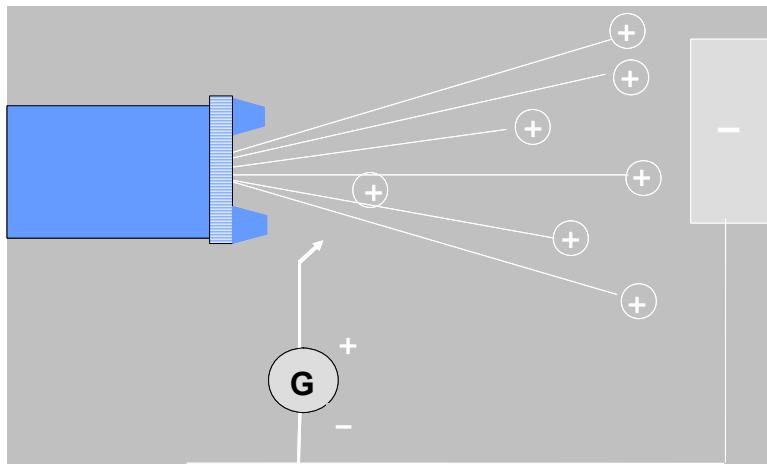


Figure 17.10: Electrostatic Spray with Positive Charge on Coating and Negative Charge on Object

- The opposite side of the object may be coated if the distance the coating must travel is not too far from the spray gun.

Generally, most of the coating arrives on the surface to be coated with very little loss. This means good transfer efficiency.

Electrostatic spray application is ideally suited for application in plant production finishing. It is not as suitable for maintenance coatings, or for high-performance coatings on complex structures.



Figure 17.11: Electrostatic Spray in Booth

One of the advantages of electrostatic spray is that it tends to be self-limiting (only a certain thickness can be applied before the piece is effectively insulated and no more paint is attracted).

Advantages of electrostatic spray may include:

- Fairly complete coverage of odd shapes
- Fairly complete use of the liquid coating
- Reduced coating loss due to overspray
- Very uniform film build
- Better coverage at edges



Figure 17.12: Electrostatic Powder Spray—Note Wraparound Effect

Disadvantages of electrostatic spray may include:

- The formulation of each coating is critical; it must be designed for electrostatic spray. Not all coatings can be applied by this means. Fineness of grind, correct mixing, proper solvents, and nonconductive pigments are major considerations in formulating a coating to be applied electrostatically.
- It can only be used on bare metal or a suitable conductive surface. The electrostatic procedure cannot be used on a nonconductive surface.

- Usually, only one coat of the material is applied electrostatically because of the insulating characteristics of the original material. Newer technologies now allow for the application of more than one coat under certain circumstances.
- The equipment is more expensive than comparable conventional air or airless spray setups.
- Because of the very high voltage used, there is a safety hazard of electrical shock during application.

Safety Features

Regarding safety, the newer solid-state power units are more efficient than the conventional-type units and are much safer to operate.

Many of these units feature variable voltage settings from 0 to 75,000 V, with “fold-back” circuitry which automatically reduces the voltage of the power supply to a level that is not hazardous if 95- to 100-mA (mA = 1/1000 Amp) current levels are exceeded.

Variable voltage settings are more efficient and allow for variations in the conductivity of the material being sprayed and the distance from the spray gun to the object.

Detectors monitor the current output and reduce the voltage in the event of a sudden rise in the output current. If an object rapidly approaches the spray apparatus, the detection system can “sense” the sudden change and prevent a dangerous discharge.

Most of these power units will immediately de-energize if the system somehow exceeds 128 μ A. This prevents any current discharge in the event of a failure, such as a cable fracture or breakage of the spray apparatus. It functions similar to a fuse in a circuit.

To ensure maximum safety, a ground-sensing circuit prevents the power supply from operating if the “third-wire” ground is not satisfactory.

In operation, a separate power supply generally is used for each gun to restrict voltage control of the spray gun exclusively to the operator of the gun.

Centrifugal Spray

Centrifugal spray equipment uses a rapidly spinning disc, brush, or other device to atomize the coating.



Figure 17.13: Centrifugal Spray

Centrifugal spray equipment may be used with or without electrostatic charge.

This type of equipment is used widely in lining pipe in specialized shop operations.

Guniting

Gunit and *guniting* are terms originally registered and/or trademarked by the Allentown Pump and Gun Company of Pennsylvania. This company manufactures equipment for delivering cementitious products to concrete or metal

surfaces with compressed air, rather than by troweling or casting in place.



Figure 17.14: Guniting



Figure 17.15: Guniting Equipment

The trademarks have expired, and now the terms *gunite* and *guniting* are generic designations for the air delivery system for applying cementitious coatings.

The American Concrete Institute (ACI) has since defined the product being applied as either *dry shotcrete* or *wet shotcrete*, and these terms are generally accepted in industry.

Some applicators still regard *gunite* as the dry product and *shotcrete* as the wet product. The ACI designation will be used in this course.

Application

In the guniting process, dry mixtures of shotcrete are pre-dampened when they are first introduced into the system at the gun (see schematic); and as they are propelled through the hose, a wetting agent (usually water) is added to the dampened powder at the nozzle.

The nozzle consists of a brass body and ring. The mixture is propelled through the nozzle and adheres to the surface. Adjustments to the amount of liquid are critical and require a skilled operator. Typical liquid content may fall in the range of 6 to 7%. In general, the gunited surface in the area under the stream will show a silky, glistening sheen if the mix ratios are correct; a rippling, wet one if the shotcrete is too wet; and an expanding granular one if it is too dry. Sometimes a gelling agent may be added to the mixture. This helps bind the materials together for better bond to the substrate. For corrosion-resistant materials, the liquid may be a special formulation called a *binder*.

Specified thicknesses of the gunited material vary depending on the application. Most systems for corrosion applications have a minimum thickness of 38 mm (1.5 in.). If shotcrete is used to replace deteriorated concrete, as much as 9 to 25 cm (6 to 10 in.) of the material may be applied to bring the surface up to the original grade.

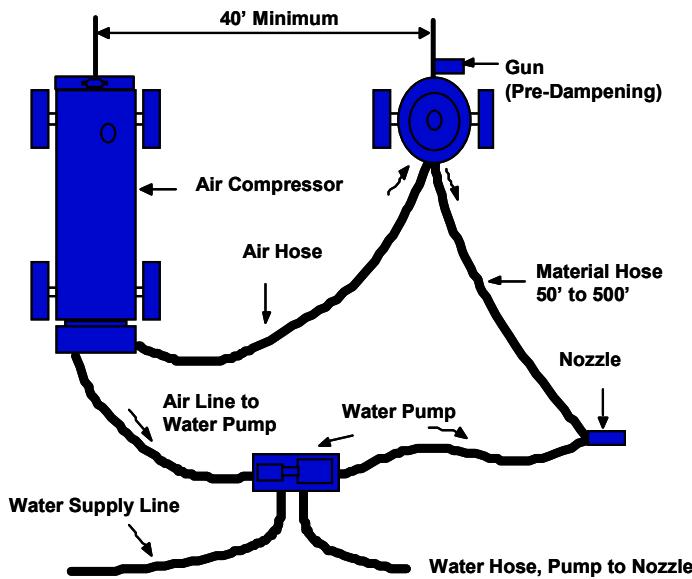


Figure 17.16: Gunite Operation

Much like applying thin-film coatings, there are specific parts of the application process that must be controlled. If the mixture is too wet, it will not hang on the surface (even over anchoring devices). If the mixture is too dry, it will bounce off rather than adhere to the surface.

The degree to which the material will not adhere, called *rebound*, is critical. Transfer efficiency should be carefully watched and rebound kept to a minimum.

Gunited, corrosion-resistant cementitious materials are used in high-temperature linings of exhaust stacks and in wastewater treatment plants where hydrogen sulfide (H_2S) and microbiologically influenced corrosion (MIC) occurs.

These materials also are used in some secondary containment structures in chemical process industries, such as in the lining of a petroleum cracking tower.

Rebound

Rebound can be dangerous, the material returning at speeds of up to 150 km/h (90 mph). Operators must wear safety glasses and safety clothing. Typical rebound

percentages are shown below. Rebound is similar to overspray in coatings applications.

Working Surfaces	Rebound Percentages
Floor Slab	5 to 10%
Sloping/Vertical Walls	15 to 30%
Overhead	40 to 50%

On all overhead, and most vertical, surfaces anchoring devices and systems are used to hold the wet gunited product in place until it can cure. The anchoring system may provide some additional reinforcing, just as rebar does for regular concrete.

Anchoring

The density and thickness of the gunited coating, plus the specific application determines the requirements for anchoring devices or systems. In some cases, anchoring devices such as "T" or Longhorn studs are attached to the substrate in a specific pattern.

Typical anchor spacing is as follows:

- Ceiling or Roof 15 to 20 cm (6 to 8 in.)
- Walls 20 to 30 cm (8 to 12 in.)
- Floor 30 to 41 cm (12 to 16 in.)

At other times a wire mesh is required in addition to the anchors. The mesh is anchored at least 1.25 cm (0.5 in.) above the surface being gunited.

Overhead coatings require the densest spacing of anchors; vertical or sloping walls, the next densest spacing; and floors the least dense spacing. Anchors are placed usually in a random, rather than a specific, geometric pattern.



Figure 17.17: Anchoring

When a membrane is used in conjunction with the system, the anchoring system should be installed first, then coated with the membrane. Membranes are discussed in more detail in the section on special coatings.

Gunited products are applied from the ground up to prevent application over rebound that may have fallen onto the surface.

The inspector must pay particular attention to:

- Surface preparation
- Equipment
- Rebound

Gunite System Advantages

The gunite process offers certain advantages over brick/mortar and cast/troweled systems. For example:

- Application is 5 to 10 times faster.
- The product is seamless and improves protection.
- The material covers complex configurations.
- Applications can be made year-round.
- The product has good insulation qualities.
- The process is economical.
- The process offers long-term protection.

The guniting process also has some disadvantages:

- The process is wind sensitive and cannot be applied even in a slight breeze.
- Application requires a five-man crew.
- Application requires bulky equipment.

Other Specialized Equipment

High-Volume Low-Pressure Spray Systems

High-volume low-pressure (HVLP) spray systems use a high volume of air delivered at 69 kPa (10 psi) or less to atomize a fluid coating into a soft low-velocity pattern. This reduction in the air stream, compared with the 243 to 283 kPa (40 to 70 psi) typically delivered by conventional air spray methods, results in:

- A more controlled spray pattern
- Reduced bounce back
- Reduced overspray

- Reduced VOC emissions
- Savings in materials usage
- Less hazardous waste
- Enhanced transfer efficiency, often more than 65%



17.18: HVLP Spray Outfit

Transfer efficiency can be defined as the amount of the sprayed coating that goes onto the work piece, compared with the amount lost to overspray and bounce back.

High transfer efficiency enhances productivity and finish quality. Reduced overspray improves visibility, which reduces operator error; improves finish quality; and reduces material usage and waste disposal. For example, two-thirds or more of every gallon of coating sprayed by conventional methods can be lost to overspray, compared with one pint per gallon or less lost when using HVLP.

The focus of the use of HVLP is made more graphic by the current trend toward legislation regarding transfer efficiency. For instance, in the United States, southern California enacted legislation requiring all spray equipment to deliver at least 65% transfer efficiency; similar legislation is pending in other states.

In establishing VOC emission requirements, in the United States the California South Coast Air Management District (SCAQMD) specifies HVLP and electrostatic as the only two methods that meet requirements. The District defines HVLP as any spray finishing that delivers

air-operating pressure of 0.69 to 69 kPa (0.1 to 10 psi) at the air cap. (Note: It is believed that some other systems have been modified to meet this requirement. These modified units utilize a low-pressure airless pump and a modified version of an air-assisted airless gun.)

HVLP generally is compared to a conventional air spray system. Both use compressed air for atomization. The major difference is that HVLP is limited to a maximum of 69 kPa (10 psi). Conventional air spray is limited only by the available air supply; pressures of 345 to 414 kPa (40 to 70 psi) or higher are common in conventional air spray systems.

An HVLP system consists of a material supply, a source of high-volume air, and special guns that control the air atomization pressure to kPa (psi) maximum. Special air caps and tips ensure proper atomization.

In general, HVLP can be used with most low- to medium-solids materials such as two-component epoxies, urethanes, acrylics, enamels, lacquers, stains, etc.

Air-Assisted Airless Spray

Air-assisted airless technology combines the best features of air spray and airless spray to create a new spray finishing capability.

Conventional air spray produces a very high quality finish, but uses large volumes of air (8 to 30 cfm). The turbulence generated by air spray can create excessive overspray, resulting in a loss of materials and a lower transfer efficiency.

Airless spray minimizes overspray and improves transfer efficiency, using high fluid pressure to force the coating through a small orifice to achieve atomization.



17.19: Air-Assisted Airless Spray

The degree of atomization achieved is dependent upon the tip size and fluid pressure. In general, the paint particles in airless spray are not atomized as finely as with air spray, which makes airless inappropriate for most fine-finish work.

The major components of an air-assisted airless gun are the airless tip and the air cap. A regular airless fluid spray tip is used to atomize the coating and to shape it into a fan pattern at low fluid pressure, usually below 7 MPa (1,000 psi).

At this low pressure, good atomization is obtained, but the spray pattern is not acceptable because it creates heavy edges called *tails*.

To eliminate the tails and to assist the atomization, air is added at low volume (1 to 3 cfm) and low pressure, usually 69 to 207 kPa (10 to 30 psi).

This "air-assist" is directed to the airless spray pattern through horns on a special air cap, which eliminates the tails and develops a proper spray pattern.

Some advantages of air-assisted airless spray include:

- Good finish appearance
- Excellent transfer efficiency (30 to 35% better than air spray)
- Wide range of fluid flow rates (0.15 to 1.5 L/min [5 to 50 fl. oz/min])
- Reduced overspray
- Less tip wear and longer pump life due to lower fluid pressure compared with regular airless
- Very efficient method of atomizing liquid

Air-assisted airless spray guns have been used to apply alkyds, lacquers, catalyzed varnishes, urethanes, epoxies, water-based coatings, and zinxs.



Level 2

Chapter 18

Concrete and Inspection

Introduction

The coating inspector encounters many different substrates in his/her duties. Often times, the inspector is assigned varying tasks related to all phases of either new construction or the retrofit of existing structures. Therefore, NACE feels it to be important that the inspector also acquire a basic knowledge of concrete, its properties, and inspection needs before and during coating operations.

Concrete may provide the largest surface area of all construction materials. While emphasis has been placed on steel as a surface for coatings, it is believed that concrete provides an even greater surface area, although many concrete surfaces do not require coating.

Concrete in itself is considered a coating and is sometimes applied over steel to prevent corrosion. Where concrete is dense and well poured, it is one of the most corrosion-resistant coatings available for steel. It provides a thick, dense, water-resistant barrier, and creates an inhibitive atmosphere that prevents steel from corroding.

Cement mortar coatings have maintained their properties and prevented steel from corroding under water pipe conditions for up to 100 years. There are few other coatings that can make an equivalent claim.

Other reasons cement linings are used for steel are that they are relatively inexpensive and they are durable. Unlike most materials that form a bonded lining, cement linings are often not bonded to the substrate. They may have minor cracks, but the cracks tend to "heal" themselves. Very pure water tends to leach and attack the lining, and rocks or other abrasive materials may erode the lining very quickly. In these instances, the cement lining may require an additional overlay of a protective coating.

To appreciate the inspection aspects of coating operations performed with concrete and other cementitious

materials, some background about concrete itself is helpful.

One of the reasons for the wide use of concrete is that it can be an extremely durable material. Some of the properties that give concrete its strength and its durability are listed below:

Concrete is inorganic. It is essentially a rock. Very few organisms, such as fungi or bacteria, attack it as they do organic materials. It doesn't rot in the common sense of the term. It is unaffected by sunlight, weather, moisture, dryness, or other similar conditions.

Concrete is hard. It doesn't wear away easily. Its abrasion resistance is determined by the aggregate used. The use of hard, durable, granitic aggregates makes it very abrasion resistant even though hydrated cement alone is not a highly abrasion-resistant material.

Concrete has good compressive strength, which is one of its outstanding physical properties. Few normally occurring conditions, outside of earthquakes, cause it to fail by compression.

Concrete can improve with age. Underwater, crystallization continues over a long period, increasing its hardness and compressive strength. In many cases, such crystallization actually will heal minor cracks in a concrete structure. Because it contains considerable lime, concrete reacts with carbon dioxide from the air to form calcium carbonate or limestone. This also increases its hardness and compressive strength.

How Concrete is Made

Concrete is formed by mixing Portland cement, aggregate, and water.

Concretes can be made with many different types of aggregates, ranging from river sand to granite, and may include various fibrous types of aggregates, such as glass and asbestos. Each concrete and aggregate mix can create a different surface.

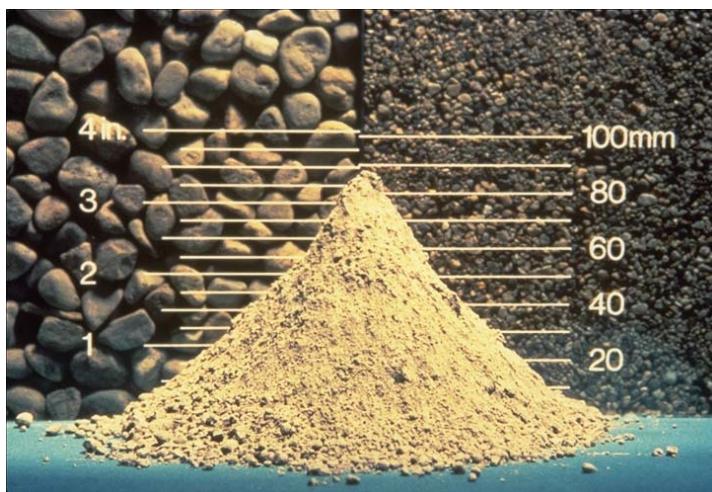


Figure 18.1: Components of Concrete

Concrete and concrete products usually are made locally because of their heavy weight and high transportation costs. For this reason alone, a wide range of materials is encountered.

Concrete Cure Process

To understand the requirements for coating on concrete, it is helpful to know something of the process by which concrete cures.

At least 28 chemical reactions have been identified as taking place in concrete as it cures, which makes it a very complex process.

When water is added to the cement/aggregate mixture, a process called *hydration* takes place. The water and the cement combine chemically, and the concrete sets up and hardens.

The lime content of the cement provides the high alkalinity of concrete. The pH may be as high as 13.

This high alkalinity provides corrosion resistance for steel coated with concrete because many grades of steel are passivated when the alkalinity reaches a pH of 11.5 or higher.

This same strong alkaline condition can cause problems with coatings applied over a concrete surface, and can make the concrete vulnerable to corrosive attack from common acidic field conditions.

Concrete Curing Times

The hydration, or curing, process begins as soon as water contacts the Portland cement, and it continues for an extended length of time.

In general, poured concrete should be cured for a minimum of 30 days at temperatures above 21.1°C (70°F) before coating, to help ensure that it has the desired surface pH, hardness, and tensile strength and for evaporation of excess water from the surface.

While this is not a hard and fast rule, some coatings have been specifically developed for application to concrete immediately after the forms are removed. These coatings can also be used on green (uncured) concrete.

Other curing times for poured or other concrete or cementitious surfaces may be required by the specification. The inspector should ensure that the surface to be coated has cured for the specified period of time prior to application of the coating.

There also are coatings formulated for use as a curing membrane, (i.e., can be applied immediately after the concrete is poured and forms [if any] are removed). This helps prevent the structural problems that can occur with concrete if the moisture in the concrete comes off too quickly and hydration does not proceed to the desired extent.

Concrete Surfaces

A wide variety of concrete and cementitious surfaces may be encountered, including:

- Poured
- Concrete block

- Special concrete surfaces
 - Gunite
 - Asbestos cement
 - Glass fiber cement products

Poured (Wet-Cast) Concrete

Wet-cast concrete is poured with a high moisture content to allow the concrete to flow into the form. Laitance, holes, and air bubbles commonly are encountered in wet-cast concrete, even on vertical surfaces.

Poured concrete can be affected by:

Ambient conditions: Hot weather causes concrete to cure more rapidly than otherwise, resulting in a greater possibility for voids, and a dusty, low-strength surface.

Applying a curing compound can help mitigate the effects of these conditions.

Vibration: This is done to remove air pockets, and can cause the heavy aggregate to sink to the bottom of the form. This results in a weak, sandy surface, creating a fragile layer of sand and cement known as laitance. This condition can occur both at the upper surface and at the concrete/form surface or interface.

Finishing operations: A variety of finishing operations may be performed on concrete:

- *Steel Trowelling* smoothes the surface. Sometimes a sand/mortar mix is applied to the poured surface before trowelling to provide a very smooth, hard, dense surface.
- *Wood floating* is a procedure using a wood trowel to smooth the poured concrete. Because the wood trowel has a relatively rough surface, sand grains are brought to the surface creating a granular surface. Wood floating may also create more laitance on the surface.

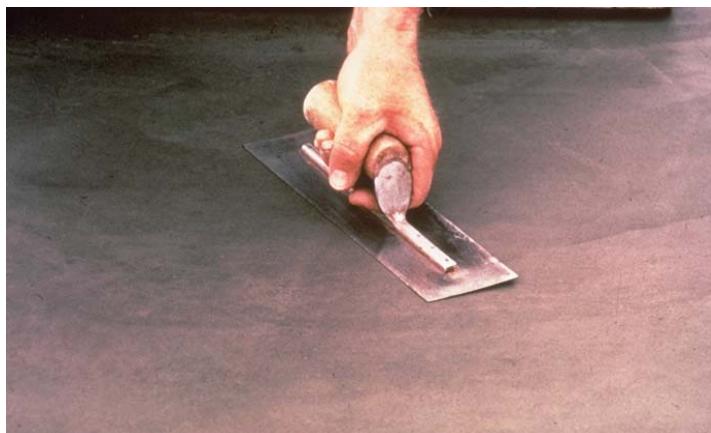


Figure 18.2: Hand Trowelling



Figure 18.3: Wood Float

Brooming is the use of a stiff-bristle broom to provide a rough surface to the cement.



Figure 18.4: Brooming

Concrete Surfaces Poured Using Forms

Surfaces will differ from those obtained by the previously described finishing methods when concrete is poured using forms.

Pinholes, rock pockets, air pockets, cavities, tie holes from tie wires, and other imperfections in the surface may develop.



Figure 18.5: Bugholes

Many poured concrete surfaces have offsets at the junction between form sections or between pours. Fins may form where concrete enters the space between the forms.

In addition to these visible imperfections, there may be hidden cavities just below the surface. Even light abrasive blasting may be sufficient to open up such cavities. Opened or not, cavities can cause the applied coating to blister or bubble.



Figure 18.6: Blisters in Concrete Coating

Special Concrete Surfaces

Guniting is the process of spraying or slinging shotcrete onto a surface as a coating to restore concrete to its original grade. Shotcrete is a dense mixture of cement and relatively small aggregate and has a low moisture content. Frequently a filling agent is added to help hold the shotcrete in place until it cures.



Figure 18.7: Guniting Equipment

Thicknesses up to 100 mm (4 in.) are not uncommon; depending upon the application, the thickness may be as high as 250 mm (10 in.). Unless its surface is trowelled smooth, it is unusually rough and dense, but has few pinholes, air pockets, or subsurface cavities.

Asbestos cement products have higher tensile strength compared to other concretes, but may also be brittle.

Glass-fiber cement products contain glass fiber for reinforcing.

Coating Concrete

Concrete and other cementitious surfaces may be coated for a variety of reasons.

Decoration may be an important reason to use coatings in architectural service. The color and appearance of architectural features may be an essential element of the design of a building or structure.

Although concrete can be formed in such a way that it will not transmit liquid water, it is a porous material and is generally not impervious to moisture vapor transmission. Concrete may be coated, or "waterproofed" to mitigate moisture vapor transmission.

Without waterproofing, concrete will allow water to enter and pass through its porous structure. While the concrete is relatively new, efflorescence is highly likely.

Although it is highly alkaline when first placed, the alkalinity is depleted by moisture passage, and the onset of corrosion of the surface may be accelerated by moisture passage.

Waterproofing of the exterior surface (buried or aboveground) can help overcome these problems by preventing water or moisture from passing through the concrete.

Enhancing chemical resistance is important because concrete is a very reactive material. It is essential to protect concrete from other reactive materials, either to prevent corrosion of the concrete or contamination of the chemical product.

Chemicals, mineral acids, food acids, carbonic acid solutions, pure water, and climate—all can take their toll on uncoated concrete.

Protection against freeze-thaw cycles that can cause concrete to crack and break up. Concrete, because of its

water and moisture content, is very susceptible to damage caused by freeze-thaw conditions.

The physical forces of ice are greater than the strength of the concrete, and will cause the concrete to spall and shatter. The most practical protection is to maintain the concrete with as little contained water as possible, for which coatings are sometimes used.

Design considerations that allow run-off and avoid water entrapment in depressions or crevices, also can prevent freeze-thaw cycles.



Figure 18.8: Deterioration of Concrete and Corrosion of Rebar Due to Action of Chloride Ions on Steel

Protection for reinforcing steel can seriously corrode if the concrete is porous such that chloride, sulfate, or other less common ions and oxygen permeate to the reinforcing steel.

Most of these substances, if left unchecked, cause corrosion cells (pits) to form on the reinforcing steel, which leads to breaking and spalling of the concrete.

High-performance coatings applied to the concrete surface can protect the concrete and reinforcing steel embedded in it. In addition, the reinforcing steel itself can be coated before the concrete is poured around it.

Decontamination—Concrete is porous and tends to absorb contaminants readily. Coating the concrete

prevents the absorption of contaminants. This is especially important in nuclear power plants and other areas where radiation may be present.

Surface sealers are often applied to concrete surfaces, especially floors, to prevent the concrete from dusting.

Protection against abrasion and erosion—Coating the concrete helps resist abrasion from both foot traffic and equipment traffic, and makes the concrete resistant to erosion from the flow of water or other fluids across the surface.

Color coding—Many facilities use color coding to identify different areas for safety and for identification of areas that may require frequent maintenance.

Protecting purity of water or other products contained in concrete vessels is another reason to coat concrete. Without coating, the concrete will absorb the liquids that may be stored in the tank or vessel and contamination of the product may result.

Improving and simplifying cleaning—Porous concrete is very difficult to clean unless it is sealed by either a clear or pigmented coating.

Skid resistance—Concrete that has been steel trowelled to a smooth hard surface may be slippery when wet. Coatings may be applied to make the surface skid resistant by the addition of some type of fine aggregate to the coating. While this makes the surface more difficult to clean, the safety concerns are more important than ease of cleaning.

Surface Preparation of Concrete/Cementitious Surfaces

Introduction

When coatings are applied to concrete or cementitious surfaces, the operation generally includes:

- Inspection of the surface before any operations are performed, which may include pre-cleaning, steam cleaning, and/or chemical cleaning.
- Inspection after pre-cleaning
- Surface preparation
- Inspection of surface preparation
- Treatment of cracks and expansion joints
- Coating
- Inspection after each coat in a multi-coat system
- Inspection of the completed coating system

Inspection of the Surface

The surface to be coated is first inspected for any conditions or defects the specification requires be corrected, or that may be damaging to the coating process.

Some of the conditions the coating inspector may encounter include:

- Laitance, which is a weak surface layer of water-rich cement mixture on the surface of fresh concrete caused by the upward movement of water.
- Pits
- Voids

- Efflorescence, which is caused by moisture passing through the concrete and carrying soluble concrete salts with it to the surface. The salts react with carbon dioxide in the atmosphere creating a fluffy white crystalline deposit on the surface.
- Projections
- Porosity
- Moisture content
- Form release oils
- Location of expansion joints
 - Mark to uncover after coating.
 - Special treatment may be required.
- Visible residues of dirt, chemical salts, or other foreign substances likely to cause coatings problems (e.g., poor adhesion)
- Ice or ice crystals on the surface, which require particular attention when coating outdoors in very cold weather
- Water on the surface.

Surface Preparation of Set Concrete

Introduction

In order to prepare concrete or other cementitious substrates for coating, a number of operations may be specified for:

- Pre-cleaning
- Surface preparation
- Surfacing/filling voids

Pre-Cleaning

- All surfaces to be coated should be inspected for the presence of chemical contaminants, oil, and grease. These should be removed prior to surface preparation by either steam cleaning or cleaning with chemicals or detergents.
- In cases of extreme contamination, it may be impossible or impractical to remove the contaminants, in which case it might be necessary to remove and replace the concrete.

Surface Preparation

Surface preparation is generally performed by:

- Abrasive blast cleaning
- Hand and power tool cleaning
- High-pressure waterjetting or blasting
- Acid etching
- Stoning
- Centrifugal blasting
- Scarifying

Abrasive Blast Cleaning

Depending on the nature of the job, almost any of the abrasive blast cleaning methods may be used.

Abrasive blast cleaning will provide a roughened, irregular surface and will remove laitance. Abrasive blasting also opens holes and voids so they can be sealed more effectively.

NACE No. 6/SSPC-SP 13, Joint Surface Preparation Standard for Surface Preparation of Concrete, is attached at the end of this chapter.

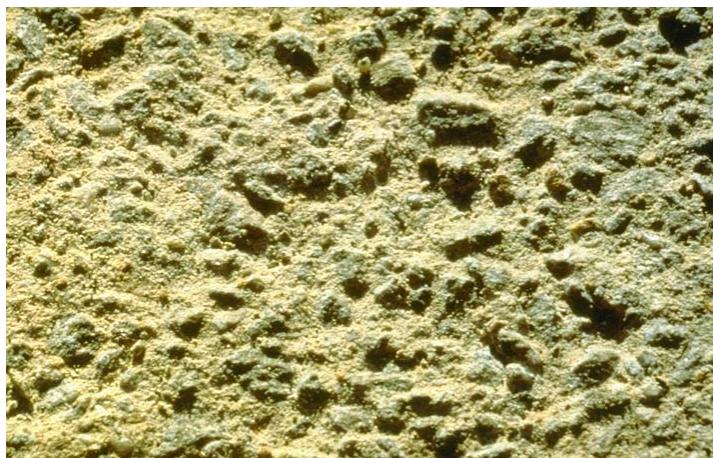


Figure 18.9: Abrasive Blast Cleaned Surface

Some practical considerations in surface preparation of concrete include:

- Holding the blast nozzle somewhat farther from the work than when blast cleaning steel
- Using pressures lower than those used on steel
- Moving the blast nozzle as rapidly as practicable, consistent with obtaining the specified surface, to avoid gouging the surface and exposing large areas of bare aggregate
- Using a finer-size abrasive than is used on steel; coarse abrasives may remove too much concrete

Abrasive blast cleaned concrete presents an anchor pattern different than that for abrasive blast cleaned steel. It is vital that the inspector have a clear understanding of the degree of cleanliness required in the specification.

The abrasive blast cleaned concrete surface is rougher than the surface of abrasive blasted steel, and more coating is required to cover the same area. Thicker coatings than those typically applied to steel are not uncommon.

The specification may call for the abrasive blast cleaned concrete to have:

- A finish coat of mortar applied by any of the methods previously discussed
- The primary coating system applied directly
- A sealer coat applied prior to application of the primary coating

Hand or Power Tool Preparation Cleaning

Many hand and power tool techniques are used for surface preparation of concrete surfaces, and they generally are time consuming and costly.

The surface resulting from hand or power tool cleaning can vary from great roughness and opening of voids to not much more than removing dust.

The use of hand or power tools removes loose, powdery, and weak concrete at the surface, but this technique is a slow procedure and does not open the air pockets as well as abrasive blasting.

High-Pressure Water Washing

Power washing at 21 to 31 MPa (3,000 to 4,500 psi) is frequently used on poured concrete surfaces. It generally does not open up subsurface voids and pockets, or provide a profile on sound, dense concrete as well as abrasive blasting does.

If too much pressure is used, the waterjet stream may actually cut the concrete.

Wet abrasive blasting also may be used.

The advantages of waterjetting and wet abrasive blasting include:

- Fast cutting of the surface
- Washing dust away
- Reducing abrasive and concrete particles in air

Acid Etching (ASTM D 4260)

Acid etching involves the use of a dilute acid solution to remove laitance and roughen the concrete surface.

The procedure for acid etching requires the operator to:

- Carefully inspect and remove any grease or other residues from the surface.
- Apply the acid to the oil and grease-free concrete surface.
- Allow the acid to react with the cement until its quits bubbling. Typically, the dwell time of the acid is 5 to 10 minutes.
- Wash the surface thoroughly to remove the acid salts; brooming is sometimes used with this washing and flushing process.



Figure 18.10: Acid Etching

The most common acid for this purpose is hydrochloric acid. Several etchings may be required to do the job. Unlike blasting and power tool cleaning, it is difficult for the operator to see when sound concrete has been reached.

Acid etching is difficult to use on vertical surfaces because the acid may run off before it has had time to thoroughly react.

Other acids, such as phosphoric, citric, or sulfamic, may be used, but they are less widely encountered than hydrochloric. Hydrochloric acid should not be used where chlorides are prohibited.

Each of these acids is toxic and corrosive and should not be allowed to contact skin or clothing. They will rapidly disintegrate clothing and wherever acid may splash on cotton surfaces, a hole will soon form. Goggles, rubber gloves, and rubber boots should be used where acid etching is in progress.

On completion of acid etching, the surface is generally water rinsed to neutralize acidic deposits. pH paper may be used to determine whether the surface is alkaline or acidic.

Smoothing Concrete Surfaces and Filling Voids

Smoothing concrete surfaces may be done at any one of the following times:

- When the concrete is freshly poured, before any surface preparation
- After pre-cleaning and surface preparation

If the smoothing is done after surface preparation, surfaces should be carefully inspected to ensure they are suitable for coating without additional surface treatment.

Surfacing and filling voids may be done either with cementitious materials (as in sacking, stoning, or steel trowelling), or by using synthetic putties or grouts, such as epoxies and urethanes.

Sacking

Sacking consists of scrubbing a mixture of cement mortar over the concrete surface using a cement sack, gunny sack, or sponge rubber float.

Great care must be taken to ensure that the mortar is correctly proportioned, mixed, and cured before coating.

Fins and projections should be removed before sacking, when the concrete is very green (uncured).

It is important to start sacking as soon as possible after the concrete is poured and the forms have been removed to allow the mortar applied by sacking to cure at nearly the same rate as the surface to which it is applied. This will improve the adherence of the sack coat to the substrate.

The sacking process generally involves:

- Wetting down the substrate with water to prevent the concrete from sucking all the water out of the sack coat, making it too dry to finish correctly
- Applying the mortar by rubbing it over the surface in a circular manner, taking care to thoroughly fill all voids
- When the surface is almost dry, it is gone over again to remove as much of the sacking material from the surface as possible, taking care not to remove it from the voids as well

Stoning

Stoning is similar to sacking, except that a carborundum brick, or other appropriate abrasive block, is used to smooth the surface of the concrete.



Figure 18.11: Stoning

The brick grinds down surface imperfections, opens up surface cavities, and works the mortar into the cavities.

Frequently, the surface is rubbed with a sack after stoning in order to smooth it even more.

Steel Trowelling

This method uses a steel trowel to move mortar over the surface to fill holes, and provides a reasonably pore-free surface over which to apply coatings.

Excessive trowelling, however, may result in a too smooth, shiny surface that may require roughening before coating.



Figure 18.12: Steel Trowelling

When surfacing concrete with cementitious materials, it is important that these materials cure completely and bond properly. To do this the concrete substrate must be wetted thoroughly before application of the mortar. The mortar must remain damp during its entire cure cycle.

Many coatings have failed due to the loss of adhesion between the cementitious material and the concrete.



Figure 18.13: Centrifugal Blasting



Figure 18.14: Scarifying

Treatment of Cracks and Expansion Joints



Figure 18.15: Cracks in Concrete

Cracks may be classified as either:

- Active, which are *self-made* expansion joints, and because they are subject to movement, must be handled like an expansion joint.
- Static, which do not move, and may be filled or covered without projecting through the topcoat.

Sometimes cracks may be repaired or corrected by the injection of 100%-solid epoxies or urethane resins, that help restore the monolithic character of the structure.

Expansion joints are always a serious concern in concrete service, and the methods of treatment depend on the severity of the service. Inspectors should refer to the written specification for the outlined methods of treatment.

Inspection of Surfaces Prior to Coating

The coating inspector's job regarding surface preparation of concrete and cementitious surfaces may include:

- Observing surface preparation that is performed to ensure that all operations are performed as specified
- Inspecting the prepared surface prior to coating to ensure that the surface has been prepared as specified.

Specific items the coating inspector may be required to inspect for, detect, and record, or require be corrected include:

- Removal of laitance
- Removal of projections
- Treatment of hollow areas, voids, and other imperfections to see that they are filled and/or struck flush with the surface, as required by the specification. It should be noted, however, that some coating systems are installed with the primer applied before filling voids, the voids filled in intermediate steps.
- Removal of the byproducts of acid etching
- Recording pH
- Determining that abrasive blasting has been performed as specified
- Removal of sand, dust, and other contaminants as specified, usually by vacuuming or blowing down with compressed air that is free of both oil and water

The specification may require the surface to be tested for complete removal of sand, dirt, etc., by the application of a small piece of clear plastic tape. The tape's adhesive surface should be clean when the tape is removed.

Concrete Coating Operations

Depending on the formulation of the coating, the most common methods of application are:

- Conventional air spray or airless spray
- Hand lay up, by which a thick mastic-type coating is trowelled or otherwise spread onto the surface with or without glass fiber reinforcing mat



Figure 18.16: Applicator Spraying Concrete

Coatings for Concrete

Coatings adhere to concrete by penetrating the surface to obtain a bond. In the book, *Corrosion Protection By Protective Coatings*, Charles Munger states that, "penetration is to concrete what surface profile is to steel."

Coatings that penetrate the surface can achieve an excellent bond.

Several generic types of coatings may be used over concrete including:

- Bituminous cutbacks
- Chlorinated rubber
- Vinyl

- Epoxy
- Novalac epoxy
- Elastomeric polyurethane
- Sheet materials (e.g., rubber)
- Glass-fiber-reinforced plastics
- Furan resins

Bituminous Cutbacks

Bituminous cutbacks are solvent solutions of coal tar or asphalt, both of which have been used extensively on concrete.

Bituminous cutbacks may be applied alone, or, when used as waterproofing for the exterior of concrete structures, they may be installed as a built-up membrane of several coats and include glass fibers as reinforcement

Waterproofing is also done, particularly to the exterior of underground structures, to help prevent infiltration of water from the outside of the structure. If water infiltrates the concrete it could disbond coatings on the interior.

Bituminous coatings also are available as water emulsions. Specifications for applying a bituminous emulsion to concrete may require the surface to be dampened prior to coating application. This helps effect deeper penetration and greater adhesion, and helps mitigate the tendency of dry concrete to "suck" in the water and some resin along with it, leaving a powdery, chalky film of pigment on the surface. This last condition could affect adhesion of any subsequent coats applied.

Chlorinated Rubber

Chlorinated rubber coatings have been used extensively for coating concrete water tanks and swimming pools. They perform well under conditions of high humidity.

Because of their resistance to ultraviolet light, chlorinated rubber coatings may be applied as a final topcoat when solvent-based bituminous coatings are applied to exterior surfaces.

Vinyl

Vinyl coatings have been used on concrete in a wide range of situations. Vinyl systems usually consist of a vinyl primer, thinned to specification, that will penetrate the concrete surface and provide a good base for subsequent applications of regular vinyl coatings.

Vinyl coatings can dry rather quickly. The applicator should use caution, particularly when coating warm concrete surfaces, to avoid solvent entrapment and subsequent blistering. This may occur when the surface of the coating film dries while there are still solvents in the pores of the concrete surface.

Chlorinated rubber and vinyl have been used widely in years past, but environmental considerations are making them less attractive as currently formulated.

Epoxy

Epoxy coatings are available in several types of formulations and are used often for concrete.

Epoxy coatings, relatively thin, applied over thoroughly prepared concrete surfaces have been described previously. These are usually solvent-based epoxies using relatively high molecular weight resins similar to many epoxies used for steel. These liquid epoxy-based coatings may be applied to the original concrete surface. They provide good surface penetration and serve as a base for other epoxy topcoats.

“Thin coatings” is a relative term. Because of the comparatively deep surface profile typical of concrete surfaces, a coating system that would be considered relatively thick on steel (508 μm [20 mils], for example) might barely cover the peaks of a prepared concrete surface.

A thick epoxy, applied by trowel, spray, or a combination of the two, may be applied directly to a clean but otherwise unprepared concrete surface. It also fills the concrete surface imperfections. It can be used alone or with additional coats of epoxy topcoats that are fortified with sand.

Coal-Tar Epoxy

Coal-tar epoxy combines the properties of both coal tar and epoxy, and is one of the few coatings that will withstand the corroding action of domestic wastes. They have been used extensively as coatings for concrete in this area.

Coal-tar epoxy is particularly useful in environments where water may permeate the concrete and cause the coating to blister.

Novalac Epoxy

Novalac epoxy is a more recent addition in the coating industry. These materials are comparable to an epoxy phenolic and exhibit some characteristics of both materials.

Generally novalac epoxies are 100%-solid materials. They can be applied by the airless spray method. These materials bond well to concrete, and develop a tight, dense film. These products are very acid-resistant.

Elastomeric Polyurethane

Elastomeric polyurethane coatings (100% solids) are usually applied by a plural-component spray rig. They can be applied in multiple passes to 6.3 mm (0.25 in.), if required. These materials are applied usually over an epoxy-based primer. The polyurethanes are used for secondary containment and quite often are used to coat concrete sewer pipe.

Inspection of Coatings on Concrete

When inspecting coatings on concrete, the inspector first may be required to:

- Ensure that the concrete has cured for the specified time prior to coating
- Determine the moisture level of the concrete

The moisture level in concrete may be inspected by:

- Plastic sheet method (ASTM D 4263)
- Moisture detector

Some coatings are very intolerant to moisture in concrete; others may bond well to concrete that is only surface dry.

Inspection Procedures

During the coating operation the inspector may be required to:

- Determine that the coating being used is the coating specified
- Ensure that the coatings are stored as specified
- Observe the mixing and thinning operations
- Observe application operations
- Monitor ambient conditions

The inspector should make a visual inspection of the coated surface after each coat has been applied to check for:

- Pinholes (detected either visually or by a holiday detector)
- Bare spots
- Runs
- Blisters

Blisters can occur frequently on concrete. Concrete is porous and it holds air which expands when the concrete heats up. This problem can sometimes be avoided by:

- Using a special primer
- Shading the concrete surface from direct sunlight
- Using no more solvent than necessary
- Timing the application so that ambient temperature is decreasing when coating is being applied. In this way, the coating is “sucked” into the pores of the cement.

The inspector may also check:

- For ridges in the coating
- To see if the coating is cured properly by:
 - Hardness test (impressor)
 - Solvent wipe
- To see if the recoat time is as specified
- Minimum and/or maximum DFT
- For any overspray or damage to adjacent areas

The coating inspector can provide the client with a valuable service by being alert to items to be coated which are not listed on the work schedule. If some areas are not coated, they could lead to premature failure of the items that are listed on the work schedule.

For example, when a below-grade concrete basin is coated, but the lip of the basin is not, premature failure of the coated portions may result due to moisture vapor transmission. The moisture vapor could enter at the uncoated lip, and could migrate through the concrete and apply hydrostatic pressure against the coated surfaces. Other items, such as uncoated concrete drains leading into or out of coated concrete structures, may have similar effects.

Tests

Coating Thickness

Since concrete is nonmagnetic, magnetic test instruments cannot be used to measure dry-film thickness.

DFT of coatings on concrete may either be estimated from WFT readings, by calculation based on the quantity of coating applied to a given area, or sometimes, by core sample.

More recently, an electronic device based on ultrasound was developed to determine the DFT of a coating or concrete.

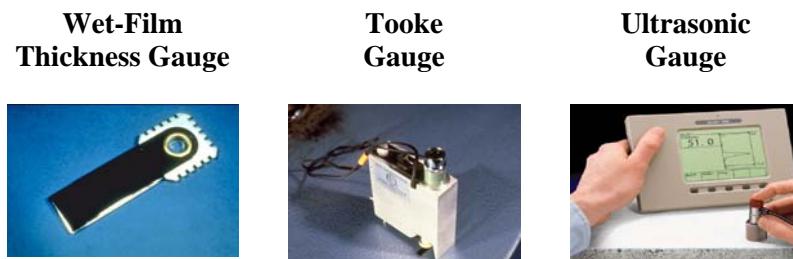


Figure 18.17: Inspection Tools

In some cases, a Tooke gauge is specified to obtain an accurate spot determination of DFT. In this case, a repair procedure is usually specified also.

Pinholes

Visual inspection for pinholes may be specified. In some cases, a holiday detector also may be specified. A low-voltage wet-sponge-type holiday detector and/or high-voltage DC type may be used.

Holiday detectors can detect pinholes in coatings on concrete and cementitious surfaces because the concrete normally contains enough moisture to be conductive.



Figure 18.18: DC Holiday Detector in Use

When using a holiday detector on coated concrete, the inspector should keep in mind that concrete is not a uniform, homogenous substance, and that the conductivity of the substrate can vary from point to point.

It is also very important to get a suitable ground. This may be done, when using low voltage, by connecting the ground of a detector to a rebar, or by placing a bag of wet sand over the ground wire positioned on the concrete surface. The concrete in contact with the ground wire should be wetted down.

Maintenance Concrete Coating

Concrete coating projects for immersion service can be classified in two primary categories: coating old concrete, (concrete with a service life of less than five years) or coating freshly placed concrete. One of the major differences between coating old concrete vs. new concrete is that repairs often are necessary before topcoating old concrete structures.

These structures usually have experienced concrete degradation due to chemical attack that has progressed through a pinhole or discontinuity in the original coating. Minimal repairs are required before coating new concrete

if good placement techniques were utilized during construction.

One aspect common to coating both old and new concrete is the pre-planning of the coatings project, especially if the concrete surface area is large, concrete repairs are extensive, and work needs to be complete within a short time period.

Typical problems associated with coating and lining old concrete are those involving porosity; air pockets; surface irregularities such as construction joints, expansion joints, control joints, and cracks; concrete strength; contaminants left on the concrete surface; and problems associated with ground water.

Few visual standards are available for concrete surface preparation. However, ASTM has developed several Standard Practices that may be specified, including;

- ASTM D 4258, Standard Practice for Surface Cleaning Concrete for Coating;
- ASTM D 4259, Standard Practice for Abrading Concrete
- ASTM D 4260, Standard Practice for Acid Etching Concrete
- ASTM D 4261, Standard Practice for Surface Cleaning Concrete Unit Masonry for Coating
- ASTM D 4262, Standard Method for Testing pH of Chemically Cleaned or Etched Concrete Surfaces
- ASTM D 4263, Standard Tests Method for Indicating Moisture in Concrete by the Plastic Sheet Method

A Successful Concrete Coating Project

The first step to a more successful coatings project is pre-planning the project. This includes the inspection of the existing concrete-coated surface several weeks in advance of work getting under way.

During this time, it should be apparent if concrete repairs are necessary and it can be established if the job will be considered a large or small concrete coatings project, which depends on the magnitude of coating failure and anticipated concrete repairs.

In most cases, minor concrete repairs will be required. Time should be allotted in the schedule whether or not the repairs are necessary during the preliminary inspection.

Concerns during the initial inspection include determining the previous service conditions for the coating. For instance, was the coating exposed to chemicals in immersion or splash? Are there damages associated with abrasion, erosion, or chemical attack? The inspection also should include checks for porosity, exposed aggregate, exposed rebar, protrusions, cracks, oils, or other contaminants.

The inspection should include checking the coating for holidays, if applicable, using high- or low-voltage holiday detectors to determine the extent of the coating failure and to identify areas where severe localized failures have occurred.

Enough emphasis cannot be placed on the importance of pre-planning a concrete coatings project. As mentioned earlier, it is best to establish immediately if the project will be considered large or small. If the project will take several workers approximately three days to a week to complete, the job can be considered small. If the job will require more than 10 workers or more than two months to complete, the project may be considered large. This should be illustrated with a schedule to show all work activities and the completion date. If the work cannot be completed in the allotted time, the situation should be evaluated immediately.

A common mistake in maintenance concrete coating is to proceed with activities that realistically cannot be completed in the time allotted. In some instances, it is best to put a maintenance concrete coatings project on

hold until special provisions can be made to successfully complete the work within the proper time frame.

Inspection of the maintenance concrete coatings project should be emphasized also. As part of the written specifications, hold points should be established and specific inspection instruments and standards clearly stated, along with repair procedures. In addition, if a third-party inspector is used, the scope of his/her authority should be clearly defined. A third-party inspector is invaluable on large concrete coatings projects and projects requiring specialized knowledge for a particular coatings application. The third-party inspector can help ensure a quality concrete coatings project which will minimize costs.

Summary

As mentioned earlier, coating concrete does not have to be a bad experience, although a reasonable number of unexpected unknowns often occur during such projects.

Key points in a more successful concrete coatings project include:

- Inspect the concrete and coated surface thoroughly prior to the job start.
- Establish the magnitude of the project.
- Schedule each work activity and establish a realistic completion date.
- Select suitable products for the application.
- Develop thorough specifications.
- Select an experienced contractor.
- Use experienced inspectors to ensure the specification has been followed.



Item No. 21082

Joint Surface Preparation Standard

NACE No. 6/SSPC-SP 13 Surface Preparation of Concrete

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Foreword

This standard covers the preparation of concrete surfaces prior to the application of protective coating or lining systems. This standard should be used by specifiers, applicators, inspectors, and others who are responsible for defining a standard degree of cleanliness, strength, profile, and dryness of prepared concrete surfaces.

This standard was originally prepared in 1997 by NACE/SSPC Joint Task Group F on Surface Preparation of Concrete. It was reaffirmed in 2003 by NACE Specific Technology Group 04 on Protective Coatings and Linings—Surface Preparation and SSPC Group Committee C.2 on Surface Preparation. This standard is issued by NACE International under the auspices of STG 04, and by SSPC Group Committee C.2.

Joint Surface Preparation Standard

NACE No. 6/SSPC-SP 13 Surface Preparation of Concrete

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Section 1: General

1.1 This standard gives requirements for surface preparation of concrete by mechanical, chemical, or thermal methods prior to the application of bonded protective coating or lining systems.

1.2 The requirements of this standard are applicable to all types of cementitious surfaces including cast-in-place concrete floors and walls, precast slabs, masonry walls, and shotcrete surfaces.

1.3 An acceptable prepared concrete surface should be free of contaminants, laitance, loosely adhering concrete, and dust, and should provide a sound, uniform substrate suitable for the application of protective coating or lining systems.

1.4 When required, a minimum concrete surface strength, maximum surface moisture content, and surface profile

range should be specified in the procurement documents (project specifications).

1.5 The mandatory requirements of this standard are given in Sections 1 to 7 as follows:

- Section 1: General
- Section 2: Definitions
- Section 3: Inspection Procedures Prior to Surface Preparation
- Section 4: Surface Preparation
- Section 5: Inspection and Classification of Prepared Concrete Surfaces
- Section 6: Acceptance Criteria
- Section 7: Safety and Environmental Requirements

1.6 Appendix A does not contain mandatory requirements.

Section 2: Definitions

Coating: See *Protective Coating or Lining System*.

Concrete: A material made from hydraulic cement and inert aggregates, such as sand and gravel, which is mixed with water to a workable consistency and placed by various methods to harden and gain strength.

Curing (Concrete): Action taken to maintain moisture and temperature conditions in a freshly placed cementitious mixture to allow hydraulic cement hydration so that potential properties of the mixture may develop.

Curing Compound (Membrane Curing Compound): A liquid that can be applied as a coating to the surface of newly placed concrete to retard the loss of water.¹

Efflorescence: A white crystalline or powdery deposit on the surface of concrete. Efflorescence results from leaching of lime or calcium hydroxide out of a permeable concrete mass over time by water, followed by reaction with carbon dioxide and acidic pollutants.²

Fin: A narrow linear projection on a formed concrete surface, resulting from mortar flowing into spaces in the form work.¹

Finish: The texture of a surface after consolidating and finishing operations have been performed.¹

Finishing: Leveling, smoothing, consolidating, and otherwise treating surfaces of fresh or recently placed concrete or mortar to produce desired appearance and service.¹

Hardener (Concrete): A chemical (including certain fluorosilicates or sodium silicate) applied to concrete floors to reduce wear and dusting.¹

High-Pressure Water Cleaning (HP WC): Water cleaning performed at pressures from 34 to 70 MPa (5,000 to 10,000 psig).³

High-Pressure Waterjetting (HP WJ): Waterjetting performed at pressures from 70 to 210 MPa (10,000 to 30,000 psig).³

Honeycomb: Voids left in concrete due to failure of the mortar to effectively fill the spaces among coarse aggregate particles.¹

Laitance: A thin, weak, brittle layer of cement and aggregate fines on a concrete surface. The amount of laitance is influenced by the type and amount of admixtures, the degree of working, and the amount of water in the concrete.²

Lining: See *Protective Coating or Lining System*.

Placing: The deposition, distribution, and consolidation of freshly mixed concrete in the place where it is to harden.¹

Porosity: Small voids that allow fluids to penetrate an otherwise impervious material.

Protective Coating or Lining System (Coating): For the purposes of this standard, protective coating or lining systems (also called *protective barrier systems*) are bonded thermoset, thermoplastic, inorganic, organic/inorganic hy-

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brids, or metallic materials applied in one or more layers by various methods such as brush, roller, trowel, spray, and thermal spray. They are used to protect concrete from degradation by chemicals, abrasion, physical damage, and the subsequent loss of structural integrity. Other potential functions include containing chemicals, preventing staining of concrete, and preventing liquids from being contaminated by concrete.

Release Agents (Form-Release Agents): Materials used to prevent bonding of concrete to a surface.¹

Sealer (Sealing Compound): A liquid that is applied as a coating to a concrete surface to prevent or decrease the penetration of liquid or gaseous media during exposure. Some curing compounds also function as sealers.

Soundness: A qualitative measure of the suitability of the concrete to perform as a solid substrate or base for a coating or patching material. Sound concrete substrates usually exhibit strength and cohesiveness without excessive voids or cracks.

Spalling (Concrete): The development of spalls which are fragments, usually in the shape of a flake, detached from a larger mass by a blow, by the action of weather, by pressure, or by expansion within the larger mass.¹

Surface Porosity: Porosity or permeability at the concrete surface that may absorb vapors, moisture, chemicals, and coating liquids.

Surface Preparation: The method or combination of methods used to clean a concrete surface, remove loose and weak materials and contaminants from the surface, repair the surface, and roughen the surface to promote adhesion of a protective coating or lining system.

Surface Profile (Texture): Surface contour as viewed from edge.

Surface Air Voids: Cavities visible on the surface of a solid.

Section 3: Inspection Procedures Prior to Surface Preparation

3.1 Concrete shall be inspected prior to surface preparation to determine the condition of the concrete and to determine the appropriate method or combination of methods to be used for surface preparation to meet the requirements of the coating system to be applied. Inherent variations in surface conditions seen in walls and ceilings versus those in floors should be considered when choosing surface preparation methods and techniques. For example, walls and ceilings are much more likely than floors to contain surface air voids, fins, form-release agents, and honeycombs.

3.2 Visual Inspection

All concrete surfaces to be prepared and coated shall be visually inspected for signs of concrete defects, physical damage, chemical damage, contamination, and excess moisture.

3.3 Concrete Cure

All concrete should be cured using the procedures described in ACI⁽¹⁾ 308.⁴ Curing requirements include maintaining sufficient moisture and temperatures for a minimum time period. Surface preparation performed on insufficiently cured or low-strength concrete may create an excessively coarse surface profile or remove an excessive amount of concrete.

3.4 Concrete Defects

Concrete defects such as honeycombs and spalling shall be repaired. The procedures described in NACE Standard RP0390,⁵ ICRI⁽²⁾ 03730,⁶ or ACI 301⁷ may be used to ensure that the concrete surface is sound prior to surface preparation.

3.5 Physical Damage

3.5.1 Concrete should be tested for soundness by the qualitative methods described in NACE Publication 6G191⁸ or Paragraph A1.4.3.

3.5.2 When qualitative results are indeterminate, or when a quantitative result is specified, concrete shall be tested for surface tensile strength using the methods described in Paragraph A1.6.

3.5.3 Concrete that has been damaged because of physical forces such as impact, abrasion, or corrosion of reinforcement shall be repaired prior to surface preparation if the damage would affect coating performance. Repairs should be made in accordance with ACI 301,⁷ NACE Standard RP0390,⁵ or Paragraph A1.4.

3.6 Chemical Damage

3.6.1 Concrete is attacked by a variety of chemicals, as detailed in ACI 515.1R⁹ and PCA⁽³⁾ IS001.¹⁰

⁽¹⁾ American Concrete Institute International (ACI), 38800 International Way, Country Club Drive, Farmington Hills, MI 48331.

⁽²⁾ International Concrete Repair Institute (ICRI), 3166 S. River Road, Suite 132, Des Plaines, IL 60018.

⁽³⁾ Portland Cement Association (PCA), 5420 Old Orchard Rd., Skokie, IL 60077.

3.6.2 All concrete surfaces that have been exposed to chemicals shall be tested and treated for contamination as described in Paragraph 3.7.

3.6.3 Concrete that has been exposed to chemicals shall be tested for soundness by the qualitative methods described in NACE Publication 6G191⁸ or Paragraph A1.4.3.

3.7 Contamination

3.7.1 Contamination on concrete surfaces includes all materials that may affect the adhesion and performance of the coating to be applied. Examples include, but are not limited to, dirt, oil, grease, chemicals, and existing incompatible coatings.

3.7.2 Contamination may be detected by methods described in NACE Publication 6G191⁸ and Paragraph A1.5. These methods include, but are not limited to, visual examination, water drop (contact angle) measurement, pH testing, petrographic examination, and various instrumental analytical methods. Core samp-

ling may be required to determine the depth to which the contaminant has penetrated the concrete.

3.7.3 Concrete surfaces that are contaminated or that have existing coatings shall be tested by the method described in Paragraph A1.6.3 to determine whether the contamination or existing coating affects the adhesion and performance of the coating to be applied. Concrete surfaces that have existing coatings shall also be tested by the method described in Paragraph A1.6.3 to determine whether the existing coating is sufficiently bonded to the concrete.

3.7.4 In extreme cases of concrete damage or degradation, or thorough penetration by contaminants, complete removal and replacement of the concrete may be required.

3.8 Moisture

Moisture levels in the concrete may be determined by the methods described in Paragraph 5.6.

Section 4: Surface Preparation

4.1 Objectives

4.1.1 The objective of surface preparation is to produce a concrete surface that is suitable for application and adhesion of the specified protective coating system.

4.1.2 Protrusions such as from burrs, sharp edges, fins, and concrete spatter shall be removed during surface preparation.

4.1.3 Voids and other defects that are at or near the surface shall be exposed during surface preparation.

4.1.4 All concrete that is not sound shall be removed so that only sound concrete remains.

4.1.5 Concrete damaged by exposure to chemicals shall be removed so that only sound concrete remains.

4.1.6 All contamination, form-release agents, efflorescence, curing compounds, and existing coatings determined to be incompatible with the coating to be applied shall be removed.

4.1.7 The surface preparation method, or combination of methods, should be chosen based on the condition of the concrete and the requirements of the coating system to be applied.

4.1.8 All prepared concrete surfaces shall be repaired to the level required by the coating system in the intended service condition.

4.2 Surface Cleaning Methods

4.2.1 The surface cleaning methods described in Paragraphs 4.2.2 and 4.2.3 shall not be used as the sole surface preparation method of concrete to be coated as they do not remove laitance or contaminants or alter the surface profile of concrete. These methods shall be used as required, before and/or after the mechanical and chemical methods described in Paragraphs 4.3 and 4.4.

4.2.2 Vacuum cleaning, air blast cleaning, and water cleaning as described in ASTM⁽⁴⁾ D 4258¹¹ may be used to remove dirt, loose material, and/or dust from concrete.

4.2.3 Detergent water cleaning and steam cleaning as described in ASTM D 4258¹¹ may be used to remove oils and grease from concrete.

4.3 Mechanical Surface Preparation Methods

4.3.1 Dry abrasive blasting, wet abrasive blasting, vacuum-assisted abrasive blasting, and centrifugal shot blasting, as described in ASTM D 4259,¹² may be used to remove contaminants, laitance, and weak concrete,

⁽⁴⁾ ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

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to expose subsurface voids, and to produce a sound concrete surface with adequate profile and surface porosity.

4.3.2 High-pressure water cleaning or waterjetting methods as described in NACE No. 5/SSPC-SP 12,² ASTM D 4259,¹² or "Recommended Practices for the Use of Manually Operated High Pressure Water Jetting Equipment,"⁽⁵⁾¹³ may be used to remove contaminants, laitance, and weak concrete, to expose subsurface voids, and to produce a sound concrete surface with adequate profile and surface porosity.

4.3.3 Impact-tool methods may be used to remove existing coatings, laitance, and weak concrete. These methods include scarifying, planing, scabbling, and rotary peening, as described in ASTM D 4259.¹² Impact-tool methods may fracture concrete surfaces or cause microcracking and may need to be followed by one of the procedures in Paragraphs 4.3.1 or 4.3.2 to produce a sound concrete surface with adequate profile and surface porosity. The soundness of a concrete surface prepared using an impact method may be verified by one of the surface tensile strength tests described in Paragraph A1.6.

4.3.4 Power-tool methods, including circular grinding, sanding, and wire brushing as described in ASTM D 4259,¹² may be used to remove existing coatings, laitance, weak concrete, and protrusions in concrete. These methods may not produce the required surface profile and may require one of the procedures described in Paragraphs 4.3.1 or 4.3.2 to produce a concrete surface with adequate profile and surface porosity.

4.3.5 Surface preparation using the methods described in Paragraphs 4.3.1 through 4.3.4 shall be performed in a manner that provides a uniform, sound surface that is suitable for the specified protective coating system.

4.4 Chemical Surface Preparation

Acid etching, as described in ASTM D 4260¹⁴ and NACE Standard RP0892,¹⁵ may be used to remove laitance and weak concrete and to provide a surface profile on horizontal concrete surfaces. This method requires complete removal of all reaction products and pH testing to ensure neutralization of the acid. Acid etching is not recommended for vertical surfaces and areas where curing compounds or sealers have been used. Acid etching shall only be used where procedures for handling, containment, and disposal of the hazardous materials are in place. Acid etching with hydrochloric acid shall not be used where corrosion of metal in the concrete (rebar or metal fibers) is likely to occur.

4.5 Flame (Thermal) Cleaning and Blasting

4.5.1 Flame cleaning using a propane torch or other heat source may be used to extract organic contaminants from a concrete surface. To remove the extracted contaminants this type of cleaning may need to be followed by the cleaning methods described in ASTM D 4258.¹¹

4.5.2 Flame cleaning and blasting using oxygen-acetylene flame blasting methods and proprietary delivery equipment may be used to remove existing coatings, contaminants, and laitance and/or create a surface profile on sound concrete.

4.5.3 The extent of removal when employing flame methods is affected by the rate of equipment advancement, the flame adjustment, and the distance between the flame and the concrete surface. Surface preparation using flame methods shall be performed in a manner that provides a uniform, sound surface that is suitable for the specified protective coating system.

4.5.4 High temperatures reduce the strength of or damage concrete; therefore, surfaces prepared using flame methods shall be tested for soundness and surface tensile strength. Concrete surfaces found to be unsound or low in tensile strength shall be repaired or prepared by other mechanical methods described in Paragraph 4.3.

4.6 Surface Cleanliness

After the concrete surface has been prepared to the required soundness and surface profile, surfaces may still need to be cleaned by one of the methods described in Paragraph 4.2 to remove the residue created by the surface preparation method or to remove spent media.

4.7 Moisture Content

If the moisture level in the concrete is higher than the specified limit tolerable by the coating, the concrete shall be dried or allowed to dry to the level specified in the procurement documents before inspection and application of the coating (see Paragraph 5.6).

4.8 Patching and Repairs

4.8.1 Prior to proceeding with patching and repairs, the prepared concrete surface shall be inspected according to Section 5. After the patching and repairs of the concrete surface are completed, the repaired areas shall be reinspected according to Section 5.

4.8.2 All gouges, surface air voids, and other surface anomalies shall be repaired to a level required by the coating system as specified in the procurement documents.

⁽⁵⁾ WaterJet Technology Association, 917 Locust, Suite 1100, St. Louis, MO 63101-1419.

4.8.3 All repair materials, both cementitious and polymeric, should be approved or recommended by the coating manufacturer as being compatible with the coating to be applied. Repair materials not recommended or approved by the coating manufacturer shall be tested for compatibility prior to their application.

4.8.4 The repair material shall be cured according to the manufacturer's published instructions.

4.8.5 The repaired section may require additional surface preparation prior to coating application.

Section 5: Inspection and Classification of Prepared Concrete Surfaces

5.1 Surface Tensile Strength

5.1.1 All prepared concrete surfaces should be tested for surface tensile strength after cleaning and drying but prior to making repairs or applying the coating.

5.1.2 Surface tensile strength should be tested using a method agreed upon by all parties. (See Paragraph A1.6 for commentary on these methods.)

5.2 Coating Adhesion

5.2.1 If specified in the procurement documents and accepted by all parties, a test patch shall be applied to determine the compatibility of and adhesion between the prepared surface and the coating system. (See Paragraph A1.6.3 for commentary on this method.)

5.2.2 Coating adhesion should be tested using one of the methods agreed upon by all parties. (See Paragraph A1.6 for commentary on these methods.)

5.3 Surface Profile

5.3.1 If a specific surface profile is required for the performance of the coating system to be applied, the profile shall be specified in the procurement documents.

5.3.2 The surface profile of prepared concrete surfaces should be evaluated after cleaning and drying but prior to repairs or application of the coating.

5.3.3 The surface profile may be evaluated by comparing the profile of the prepared concrete surface with the profile of graded abrasive paper, as described in ANSI⁽⁶⁾ B 74.18,¹⁶ by comparing the profile with the ICRI Guideline No. 03732¹⁷ (surface profile chips), or by another agreed-upon visual comparison.

5.4 Surface Cleanliness

5.4.1 All prepared concrete surfaces shall be inspected for surface cleanliness after cleaning and drying but prior to making repairs or applying the coating. If the concrete surfaces are repaired, they shall be reinspected for surface cleanliness prior to applying the coating.

5.4.2 Prepared concrete surfaces may be inspected for surface cleanliness by lightly rubbing the surface with a dark cloth or pressing a translucent adhesive tape on the surface. The test method and acceptable level of residual dust shall be agreed on by all parties.

5.4.3 The method used to verify compatibility of the coating to be applied over a contaminated surface or over contaminated surfaces that have been cleaned and prepared should be approved by the coating manufacturer and specified in the procurement documents.

5.5 pH

5.5.1 If a specific pH range is required for proper performance of the coating system to be applied, the pH of the concrete shall be specified in the procurement documents.

5.5.2 The pH of concrete surfaces prepared by acid etching should be tested after etching and rinsing but before the prepared surface has dried.

5.5.3 ASTM D 4262¹⁸ should be used to determine pH.

5.6 Moisture Content

5.6.1 If a specific moisture content is required for proper performance of the coating system to be applied, the moisture content of the concrete shall be specified in the procurement documents.

5.6.2 Prepared concrete surfaces should be tested for residual moisture after cleaning and drying but prior to the application of the coating.

5.6.3 ASTM D 4263,¹⁹ ASTM F 1869,²⁰ or ASTM F 2170²¹ should be used to determine the residual moisture content in concrete.

5.6.4 If required or accepted by all parties, any of the methods described in Paragraph A1.8.4 may be used to determine the moisture content of the concrete surface.

⁽⁶⁾ American National Standards Institute (ANSI), 1819 L Street NW, Washington, DC 20036.

Section 6: Acceptance Criteria

6.1 The acceptance criteria for prepared concrete surfaces shall be specified in the procurement documents.

6.2 The procurement documents may refer to the specifications in Table 1.

Table 1:
Suggested Acceptance Criteria for Concrete Surfaces After Surface Preparation

Property	Test Method	Light Service ^(A)	Severe Service ^(B)
Surface tensile strength	See Paragraph A1.6	1.4 MPa (200 psi) min.	2.1 MPa (300 psi) min.
Surface profile	Visual comparison ¹⁶	Fine (150) abrasive paper min.	Coarse (60) abrasive paper min.
Surface cleanliness	Visible dust ¹¹	No significant dust	No significant dust
Residual contaminants	Water drop ^{15,22}	0° contact angle	0° contact angle
pH	ASTM D 4262 ¹⁸	(pH of rinse water) -1, +2 ^(C)	(pH of rinse water) -1, +2 ^(C)
Moisture content ^(D)	ASTM D 4263 ¹⁹	No visible moisture	No visible moisture
Moisture content ^(D)	ASTM F 1869 ²⁰	15 g/24 hr/m ² (3 lb/24 hr/1,000 ft ²) max.	15 g/24 hr/m ² (3 lb/24 hr/1,000 ft ²) max.
Moisture content ^(D)	ASTM F 2170 ²¹	80% max.	80% max.

^(A) Light service refers to surfaces and coatings that have minimal exposure to traffic, chemicals, and changes in temperature.

^(B) Severe service refers to surfaces and coatings that have significant exposure to traffic, chemicals, and/or changes in temperature.

^(C) The acceptance criterion for ASTM D 4262 is as follows: The pH readings following the final rinse shall not be more than 1.0 lower or 2.0 higher than the pH of the rinse water (tested at the beginning and end of the final rinse cycle) unless otherwise specified.

^(D) Any one of these three moisture content test methods is acceptable.

Section 7: Safety and Environmental Requirements

7.1 Disposal of contaminants, old coatings, acid from etching, and contaminated water and blasting media shall comply with all applicable facility, local, state, and federal regulations.

7.2 Handling of hazardous materials, machinery operations, worker protection, and control of airborne dust and fumes shall comply with all applicable facility, local, state, and federal health and safety regulations.

References

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2. SSPC-Guide 11 (latest revision), "Guide for Coating Concrete" (Pittsburgh, PA: SSPC).
3. NACE No. 5/SSPC-SP 12, "Surface Preparation and Cleaning of Metals by Waterjetting Prior to Recoating" (Houston, TX: NACE, and Pittsburgh, PA: SSPC).
4. ACI 308 (latest revision), "Standard Practice for Curing Concrete" (Farmington Hills, MI: ACI).
5. NACE Standard RP0390 (latest revision), "Maintenance and Rehabilitation Considerations for Corrosion Control of Existing Steel-Reinforced Concrete Structures" (Houston, TX: NACE).
6. ICRI Guideline No. 03730 (latest revision), "Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion" (Des Plaines, IL: ICRI).
7. ACI 301 (latest revision), "Specifications for Structural Concrete" (Farmington Hills, MI: ACI).
8. NACE Publication 6G191 (withdrawn), "Surface Preparation of Contaminated Concrete for Corrosion Control" (Houston, TX: NACE). (Available from NACE as an historical document only).
9. ACI 515.1R (latest revision), "Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete" (Farmington Hills, MI: ACI).

10. IS001 (latest revision), "Effects of Substances on Concrete and Guide to Protective Treatments" (Skokie, IL: PCA).
11. ASTM D 4258 (latest revision), "Standard Practice for Surface Cleaning Concrete for Coating" (West Conshohocken, PA: ASTM).
12. ASTM D 4259 (latest revision), "Standard Practice for Abrading Concrete" (West Conshohocken, PA: ASTM).
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14. ASTM D 4260 (latest revision), "Standard Practice for Acid Etching Concrete" (West Conshohocken, PA: ASTM).
15. NACE Standard RP0892 (latest revision), "Coatings and Linings Over Concrete for Chemical Immersion and Containment Service" (Houston, TX: NACE).
16. ANSI B74.18 (latest revision), "Specifications for Grading of Certain Abrasive Grain on Coated Abrasive Products" (Washington, DC: ANSI).
17. ICRI Guideline No. 03732 (latest revision), "Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays" (Des Plaines, IL: ICRI).
18. ASTM D 4262 (latest revision), "Standard Test Method for pH of Chemically Cleaned or Etched Concrete Surfaces" (West Conshohocken, PA: ASTM).
19. ASTM D 4263 (latest revision), "Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method" (West Conshohocken, PA: ASTM).
20. ASTM F 1869 (latest revision), "Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride" (West Conshohocken, PA: ASTM).
21. ASTM F 2170 (latest revision), "Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using In Situ Probes" (West Conshohocken, PA: ASTM).
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24. T. Dudick, "Concrete Standards for Resinous Toppings," *SSPC 93-06: Innovations for Preserving and Protecting Industrial Structures*, November 13-18, 1993 (Pittsburgh, PA: SSPC, 1993).
25. R. Boyd, "Quality Control in Cleaning and Coating Concrete," *SSPC 91-19: Protective Coatings for Flooring and Other Concrete Surfaces*, November 10-15, 1991 (Pittsburgh, PA: SSPC, 1991), pp. 5-7.
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28. ASTM PCN: 03-401079-14, "Manual of Coating Work for Light-Water Nuclear Power Plant Primary Containment and Other Safety-Related Facilities" (West Conshohocken, PA: ASTM, 1979), pp. 114-119.
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Appendix A: Comments (*This section does not contain any mandatory requirements.*)

A1.1 General^{23,24,25,26}

A1.1.1 This standard does not recommend surface preparation methods or differentiate levels of surface preparation that are specifically required for various protective system designs, types, thicknesses, and end-use requirements. These specifications should be decided and agreed upon by all parties (the specifier, facility owner, coating manufacturer, and contractor).

A1.1.2 Concrete and its surfaces are not homogeneous or consistent and, unlike steel, cannot be discretely defined. Therefore, visual examination of a concrete surface is somewhat subjective. The acceptance or rejection of a prepared concrete surface should be based on the results of specific tests, including, but not limited to, tests for surface tensile strength, contamination, and moisture.

A1.1.3 Joints, cracks, and curing shrinkage of concrete should be considered in the design of the protective coating system; however, these topics are beyond the scope of this standard. See NACE Standard RP0892,¹⁵ ACI 515.1R,⁹ and NACE 6G197/SSPC-TU 2²⁷ for more information.

A1.1.4 When a significant amount of weak, deteriorated, or contaminated concrete is removed during the course of surface preparation to achieve a sound surface, the profile of the remaining concrete is often too rough for the intended coating system. In these cases, and where form voids and surface air voids must be

filled, patching or grouting materials are specified to repair or level the concrete surface. See NACE Standard RP0892,¹⁵ ACI 515.1R,⁹ NACE Standard RP0390,⁵ NACE 6G197/SSPC-TU 2,²⁷ and Paragraph A1.4.4 for more information about patching materials.

A1.2 Concrete Finishing and Surface Characteristics²³

A1.2.1 The method used to finish concrete surfaces affects the concrete's surface profile, composition, porosity, and density. These surface properties affect the adhesion and performance of concrete coatings. Typical surface properties obtained using the most common finishing methods are given in Table A1. These properties are evaluated prior to surface preparation.

A1.2.2 No preferred method of finishing concrete to accept coatings has been established by the concrete coating industry. The surface cure, surface preparation method, and type of coating system to be applied are all factors in determining the suitability of any specific concrete finishing method. For example, broom finishing is sometimes used because it gives a profile for the coating; however, most of the profile may be removed during surface preparation if the surface is not properly cured, negating this inherent advantage of the broom finish. When sacking is used to fill voids in formed concrete surfaces, subsurface voids are created, and the added cement is usually removed during surface preparation due to improper cure of the added cement paste.

Table A1:
Typical Surface Properties of Finished Concrete

Method	Profile ^(A)	Porosity ^(A)	Strength ^(A)	Problems
Formed concrete	Smooth to medium	Low to medium	Medium	Voids, protrusions, release agents
Wood float	Medium	Medium	Medium	
Metal trowel	Smooth	Low	High	
Power trowel	Smooth	Very low	High	Very dense
Broom finish	Coarse to very coarse	Medium	Medium	
Sacking	Smooth	Low to medium	Low to high ^(B)	Weak layer if not properly cured
Stoning	Smooth to medium	Low to medium	Low to high ^(B)	Weak layer if not properly cured
Concrete block	Coarse to very coarse	Very high	Medium	Pinholes
Shotcrete ^(C)	Very coarse	Medium	Medium	Too rough for thin coatings

^(A) These surface properties are based on similar concrete mix, placement, and vibration and prior to surface preparation.

^(B) Strength depends on application and cure.

^(C) Shotcrete may be refinished after placement, which would change the surface properties given in this table.

A1.2.3 Use of a metal trowel is gaining acceptance as the preferred finishing method for horizontal surfaces to be coated, provided the surface is not excessively trowelled, the concrete is cured properly, and the laitance is removed prior to coating.

A1.2.4 Photographic examples of concrete finishes are shown in ASTM PCN:03-401079-14.²⁸

A1.3 Concrete Cure²⁹

A1.3.1 Maintaining sufficient moisture and proper temperature in concrete in the early stages of cure is important to ensure development of the designed strength. Keeping the surface moist until sufficient strength has developed at the surface is important to ensure formation of sufficient surface strength, to reduce curling, and to reduce surface cracking.

A1.3.2 ACI 308⁴ recommends seven days of moist curing for Type I portland cement concrete and three days for Type III portland cement concrete, if the temperature is above 10°C (50°F). ACI 308 also recommends numerous methods to properly cure concrete, including the use of sealing materials and other methods to keep concrete moist.

A1.3.3 ACI 308⁴ also gives recommendations on the use of curing compounds, which are commonly used immediately after placement and finishing of concrete surfaces to reduce moisture loss and improve surface cure. The curing compound should either be compatible with the coating or be removed during surface preparation.

A1.4 Identification and Repair of Surface Defects and Damage³⁰

A1.4.1 Physical and Chemical Damage

A1.4.1.1 Existing concrete structures that have been subjected to mechanical damage (caused by impact or abrasion), chemical attack, or rebar corrosion are restored to provide a uniform, sound substrate prior to coating application.

A1.4.1.2 In order to best receive and hold the patching material all deteriorated concrete should be removed and the surrounding sound concrete cut using the procedures described in ICRI 03730.⁶ Some contaminants have a detrimental effect on the rebar or the applied coating if they are not completely removed.

A1.4.1.3 A number of polymeric grouts and patching materials can be used, especially when the coating is to be applied immediately. These materials should be compatible with the coating to be applied.

A1.4.2 Other Defects and Imperfections

A1.4.2.1 Defects such as honeycombs, scaling, and spalling do not provide a sound, uniform substrate for the coating. These defects are repaired by removing all unsound concrete and then patching the concrete prior to surface preparation. NACE Standard RP0390⁵ and ICRI 03730⁶ describe removal and repair procedures for concrete

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that is spalled because of rebar corrosion.

A1.4.2.2 Surface air voids, pinholes, or excessive porosity may affect the application or performance of the coating. The maximum substrate void size or surface porosity that can be tolerated depends on the coating system under consideration. If voids are not filled before the coating is applied, the trapped air vapor expands and contracts and may affect the performance of the coating. For liquid-rich coatings, excess porosity at the surface may result in pinholes in the coating. Voids are usually filled after surface preparation and prior to coating application.

A1.4.2.3 Protrusions such as form lines, fins, sharp edges, and spatter may cause holidays or thin sections in the coating if they are not removed. Protrusions and rough edges are usually removed during surface preparation.

A1.4.3 Testing for Surface Soundness

A1.4.3.1 NACE Publication 6G191⁸ describes the following commonly used methods for determining surface soundness:

A screwdriver, file, or pocket knife is lightly scratched across the concrete surface. If the metal object rides over the surface without loosening any particles and leaves no more than a shiny mark, the surface is sound. If this process gouges the surface, the surface is not sound.

The concrete surface is lightly struck with the edge of a hammer head. If the hammer rebounds sharply with no more than a small fracture at the impact area, the surface is sound. If it lands with a dull thud and leaves powdered dusts in the indentation, the surface is not sound.

A chain is dragged across horizontal concrete surfaces. Differences in sound indicate unsound concrete and holes or pockets within the concrete.

A1.4.4 Patching of Concrete Surface Imperfections

A1.4.4.1 Materials such as grouts, putties, and sealers are used to repair, patch, smooth, or seal the concrete surface to provide a substrate that is suitable for the coating system to be applied. These materials are applied after surface preparation and require the following characteristics:

- (1) good adhesion;
- (2) adequate strength;
- (3) low volumetric and linear shrinkage;

(4) compatibility with the coating to be applied; and

(5) proper consistency for the application.

In addition, the patching material is often required to cure sufficiently, be traffic bearing, and be ready to recoat in a short time frame (usually within 24 hours).

A1.4.4.2 Shrinkage of the patching material may reduce the adhesion of that material to the concrete substrate. Differences in thermal expansion between the concrete, patching material, and coating system cause stresses during thermally induced movement that may reduce adhesion between these layers.

A1.4.4.3 The most common types of patching materials are cementitious, polymer-modified cementitious (usually acrylic), and polymeric (usually epoxy). Cementitious materials are lower in cost than polymeric materials, but polymeric materials generally cure faster and have higher strengths, better adhesion, and increased chemical resistance.

A1.4.4.4 Patching materials are available in a range of consistencies for application to vertical or horizontal surfaces by a variety of methods. The amount of filler also varies. For example, grouts for deep patching are typically highly filled, while porosity sealers may be minimally filled or unfilled. Numerous proprietary materials are low-shrinking, nonshrinking, or expanding.

A1.4.4.5 Additional surface preparation may need to be performed on cured patching materials to ensure that the laitance is removed and/or that the patched surface meets the profile requirements of the coating system.

A1.4.4.6 Photographic examples of patched concrete surfaces are shown in ASTM PCN:03-401079-14.³¹

A1.5 Identification and Removal of Contaminants^{22,32,33,34}

A1.5.1 Hydrophobic Materials

A1.5.1.1 Hydrophobic materials such as form-release agents, curing compounds, sealers, existing coatings, oil, wax, grease, resins, and silicone may be detected by a simple water drop test. Analytical techniques such as infrared analysis or gas chromatography may also be used to detect and identify these contaminants.

A1.5.1.2 Oils and greases can be removed by steam cleaning, flame blasting, baking soda blasting, or using degreasers and absorbents.

A1.5.1.3 If they are incompatible with the coating to be applied, existing curing compounds, sealers, form-release agents, and coatings should be removed by the least destructive, most practical, economical, and safe method that is successful. Methods such as grinding, abrasive blasting, wet abrasive blasting, waterjetting, scarifying, flame blasting, or paint stripping may be used.

A1.5.2 Salts and Reactive Materials

A1.5.2.1 Salts and reactive materials such as laitance, efflorescence, acids, alkalis, and by-products of chemical attack of concrete can sometimes be detected by pH testing, soundness testing using the screwdriver test, or visual examination (see PCA IS214).³⁵ When these methods are not successful, chemical analysis techniques are required.

A1.5.2.2 Residual acids and alkalis are first neutralized and then removed by high-pressure water cleaning. Salts and efflorescence can be removed by abrasive blasting, high-pressure water cleaning, or applying a weak acid or alkali solution and then high-pressure water cleaning.

A1.5.3 Microorganisms

A1.5.3.1 Microorganisms such as fungus, moss, mildew, algae, decomposing foods, and other organic growths can sometimes be detected by visual examination (see PCA IS214).³⁵

A1.5.3.2 Microorganisms are removed by washing with sodium hypochlorite (household bleach) and rinsing with water. High-pressure water cleaning or abrasive blasting may also be used.

A1.6 Adhesion Testing³⁶

The two commonly used methods for testing adhesion of coatings to concrete substrates are ASTM D 4541³⁷ (modified for concrete substrates as discussed in Paragraph A1.6.1) and ACI 503R.³⁸ Testing for surface tensile strength consists of scoring (core drilling) the concrete surface, bonding a test fixture with an adhesive, pulling the fixture with an adhesion tester, and noting the pull-off strength or adhesion value. Testing for coating adhesion is performed using the same procedure, noting the adhesion value, and noting the adhesion failure mode (see Paragraph A1.6.4).

A1.6.1 The procedure described in ASTM D 4541³⁷ may be used to determine pull-off strength or coating adhesion strength using a portable adhesion tester, typically either a manual tester with a 20-mm (0.78-in.)-diameter loading fixture (test dolly) or a pneumatic adhesion tester with a 13-mm (0.5-in.) loading fixture. ASTM D 4541 states that "Scoring around the fixture violates the fundamental *in situ* criterion that an unaltered coating be tested," but it also states that scoring

should be noted in the results when employed.³⁷ The procedure in ASTM D 4541 should be modified for use on concrete substrates by scoring or core drilling prior to attaching the loading fixture. Scoring around the test fixture ensures that the pulling force is applied only to the area directly beneath the fixture. Without scoring, stress is transferred through the coating film beyond the area of the test fixture. This could result in significant error when testing thick or reinforced coatings. A water-lubricated diamond-tipped core bit should be used for scoring to reduce the possibility of microcracks in either the coating or the concrete substrate. The procedure may also be modified by using a larger (5-cm [2-in.] or more) loading fixture. A larger test fixture typically yields more accurate results than a smaller fixture because the greater surface area reduces the effect of inconsistencies, such as a piece of aggregate or a void, in the substrate.

A1.6.2 ACI 503R³⁸ discusses the process of applying a coating or adhesive coring to the substrate, bonding a 5-cm (2-in.) pipe cap to the coating, and applying tension with a mechanical testing device attached to a dynamometer. As with ASTM D 4541,³⁷ the tensile load and mode of failure are noted.

A1.6.3 A test patch involves applying the coating system to a small section (with the minimum size to be specified) of prepared concrete and testing for tensile strength and adhesion by either of the methods described in Paragraphs A1.6.1 and A1.6.2. The prepared concrete substrate—at least the portion to be patched—should meet the acceptance criteria as detailed in Section 6. The coating system should be applied in accordance with the coating manufacturer's published instructions. The last coat of the coating system serves as the adhesive for the loading fixture, or, when this is not recommended (e.g., for solvent-based topcoats), the loading fixture is attached to the coating system by an adhesive. If agreed by all parties, the primer alone may suffice as the test patch and the adhesive for the loading fixture.

A1.6.4 The acceptable adhesion strength and mode of failure may vary depending on the type of coating tested. The coating manufacturer should be consulted to determine the preferred test method, the suitability of that method, and acceptance criteria for the specified coating. When adhesion testing is performed, the mode of failure should be noted. The failure can be described using one or more of the following terms.

(1) Concrete (substrate) cohesive failure: This failure mode is defined as failure within the concrete, below the concrete/coating interface. This result, if the adhesion value is sufficient, is considered to be the most desirable for coatings applied to concrete. If concrete cohesive failure occurs but the adhesion value is low, the failure may be because of low concrete strength or microcracking from scoring. If only a thin layer of concrete is pulled with the fixture and the adhesion value is

low, it may be because of a weak concrete surface layer or laitance.

(2) Coating adhesive failure: This failure mode is defined as failure directly at the concrete/coating interface. For most coating systems, failure in this mode indicates a problem with surface preparation, residual contamination, or the coating.

(3) Coating cohesive failure or coating intercoat adhesion failure: This failure mode is defined as failure within the coating system, above the concrete/coating interface. This mode of failure indicates a problem with the coating material or with the coating application.

(4) Fixture adhesive failure: This failure mode is defined as failure within the fixture adhesive or at the fixture adhesive/coating interface. When this failure mode is encountered, the test should be repeated.

A1.7 Surface Profile

A1.7.1 In addition to removing laitance, weak concrete, and contamination at the concrete surface, surface preparation usually opens the pores and/or creates a profile on the concrete surface. Profile increases the surface area available for bonding between the concrete and the coating, enhances adhesion at the concrete/coating interface, and helps the coating resist peeling and shear forces.

A1.7.2 The depth of surface profile required depends on:

- (1) tensile and shear strength of the concrete and the coating system;
- (2) adhesion of the coating system to the concrete;
- (3) internal stresses in the coating system created during application (e.g., from shrinkage);
- (4) difference in the coefficient of thermal expansion between the coating and the concrete;
- (5) modulus or stress-relaxation properties of the coating system;
- (6) thermal and chemical exposure environment; and
- (7) coating thickness.

A1.7.3 At this time, no recognized testing equipment or method is used to quantify the surface profile of concrete that is analogous to the replica tape method used on steel. The profile can be subjectively compared to the standard classification for coated abrasive paper as described in ANSI B74.18,¹⁶ or by comparing the profile with the ICRI Guideline No. 03732¹⁷ (surface profile chips). For extremely coarse prepared concrete surfaces (assuming that the coating system can cover and

perform over such a substrate), the profile may be estimated as an average distance between peaks and valleys on the concrete surface and quantified in mm (mils).

A1.8 Moisture in Concrete^{39,40,41,42}

A1.8.1 The movement of moisture in concrete during the curing process and after application of the coating is important to consider in the design of the concrete structure. Concrete is normally placed with water levels in excess of that required to completely hydrate the cement. Excess free water in the concrete can adversely affect the application and cure of many coatings. Pressure caused by excess moisture in the concrete or from ground water may be substantial and, in some instances, may be sufficient to disbond barrier coating systems that appear to be well bonded. These pressures are commonly referred to as hydrostatic, capillary, and osmotic pressures.

A1.8.2 Concrete has traditionally been coated no sooner than 28 days after concrete placement (see Paragraph A1.10). In addition to allowing the concrete to sufficiently cure (see Paragraph A1.3), this waiting period allows excess moisture to evaporate prior to applying a barrier coating system. The waiting period is especially important if a vapor barrier (or positive-side waterproofing) is installed, which prevents moisture from exiting into the ground.

A1.8.3 The drying rate of concrete is a function of the concrete temperature, thickness, porosity, and initial free-water content. The drying rate is also a function of the velocity and dew point of the drying air. Excess free water can be removed by dehumidifiers, surface air movers, or surface heaters provided that (1) the forced drying does not begin until sufficient concrete strength is developed and (2) it does not adversely affect the concrete properties. Dehumidifiers lower the air dew point, can increase the air temperature, and perform best when the area is enclosed. Surface air movers direct low-dew point air across the concrete surface at high velocities, but they should be periodically repositioned to ensure uniform drying over the entire surface. Surface heaters increase the mobility of free water; they work best if the heat penetrates the concrete and if they do not raise the dew point of the drying air.

A1.8.4 Moisture Test Methods^{40,41}

The following are some of the common methods used to identify or quantify the free moisture in concrete prior to the application of coatings.

ASTM D 4263, Plastic sheet method¹⁹

ASTM F 1869, Calcium chloride test²⁰

ASTM F 2170, Relative humidity test²¹

ASTM E 1907, Conductivity test⁴³

ASTM E 1907, Calcium carbide method⁴³

ASTM E 1907, Capacitance-impedance method⁴³

A1.8.5 Use and Interpretation of Moisture Test Methods

A1.8.5.1 The plastic sheet method¹⁹ and the calcium chloride test are commonly used and accepted in the United States. The hygrometer and conductivity tests are cited in numerous British standards and are accepted in the United Kingdom, while the carbide method is accepted in other parts of Europe.

A1.8.5.2 All of these methods are quantitative except the plastic sheet method.¹⁹ The plastic sheet, calcium chloride, and capacitance-impedance methods are nondestructive, while the hygrometer, conductivity, and calcium carbide methods involve drilling into the concrete.

A1.8.5.3 Testing duration is 16+ hours for the plastic sheet method¹⁹ and 72 hours for the calcium chloride and relative humidity tests. The other methods give results immediately if the testing equipment has been calibrated.

A1.8.5.4 The plastic sheet method may indicate whether excess moisture is present at the time of the test. However, because the method depends on a moisture differential—a higher relative humidity in the concrete than in the air above the concrete surface—during the test span, potential problems are not always evident at the time the test is performed.

A1.8.5.5 Information on the tolerance of a specific coating system for free water or moisture migration should be provided by the coating manufacturer. A free water content of less than 5% by weight is acceptable for most coatings. Alternatively, concrete with a relative humidity of less than 80% or a moisture transmission rate of less than 15 g/24 hr/m² (3 lb/24 hr/1,000 ft²) has proved acceptable for most coatings.

A1.8.5.6. Occasionally, despite moisture testing, a problem is not identified until after a low-permeability coating is applied.

A1.9 Surface Preparation Methods^{17,32,44,45,46}

The surface preparation methods described in this standard are listed in Table A2 with their intended use, profile cre-

ated, typical problems encountered when using each method, and solutions to those problems.

A1.9.1 Photographic examples of prepared concrete surfaces are shown in ASTM PCN:03-401079-14.⁴⁷

A1.10 The 28-Day Waiting Period^{48,49}

A1.10.1 The traditional 28-day waiting period after concrete placement and prior to coating installation is a controversial topic that involves all parties. Although the waiting period is not usually required for surface preparation, it affects the timing of surface preparation because many coatings are applied within 24 hours after surface preparation.

A1.10.2 The 28-day waiting period originated from the structural benchmark to test concrete strength at 28 days after placement to verify that the tested strength met the design strength. The 28-day benchmark became the industry standard to identify the point in time when the concrete was considered fully cured. The 28-day waiting period was adopted by the coating industry because it usually allows sufficient time for concrete surface strength to develop and for excess moisture to evaporate.

A1.10.3 Many factors can reduce or increase the time required for strength and moisture levels to be acceptable. In addition, many construction schedules do not allow for a 28-day waiting period. For these reasons, quantifying surface requirements as in Paragraph A1.12 are preferred over the traditional 28-day waiting period.

A1.10.4 NACE Standard RP0892¹⁵ and ACI 515.1R⁹ do not recommend a specific cure period but do address surface dryness, surface strength requirements, and other surface quality issues.

A1.11 Temperature Considerations

The temperature of the surface at the time of the coating application and the temperature progression during the application are both important. Rising concrete temperatures during the application of the coating systems may cause blistering and pinhole problems in the coating caused by out-gassing from the concrete. Coating application during periods of falling temperatures may be required to prevent this problem. Although controlling the ambient temperature in outdoor installations is difficult, concrete is often shaded from direct sunlight during coating application. In addition to potential problems from moisture in the concrete as described in Paragraphs A1.8.1 and A1.8.2, monitoring the dew point during periods of changing weather is often recommended to ensure that coatings are not applied over moisture that has condensed on the concrete surface.

Table A2:
Surface Preparation Methods

Preparation Method	When Used	Profile Created ^(A)	Problems	Solutions
Dry abrasive blasting	Removal, profile, cleaning	Fine (150) to extra coarse (40)	-Dust on surface -Airborne dust -Noise	-Vacuum cleaning -Vacuum attachments -None
Wet abrasive blasting	Removal, profile, cleaning	Fine (150) to extra coarse (40)	-Wets concrete -Creates sludge	-Let concrete dry -Cleaning
High-pressure water cleaning	Removal, cleaning	Fine (150) to extra coarse (40)	-Wets concrete -Creates sludge	-Let concrete dry -Cleaning
Waterjetting (with or without abrasive)	Removal	Rougher than extra coarse	-Creates sludge -Wets concrete -Coarse profile	-Cleaning -Let concrete dry -None ^(B)
Impact tools	Removal, profile, cleaning	Rougher than extra coarse	-Airborne dust -Fracturing -Coarse profile	-Vacuum attachments -Other methods -None ^(B)
Power tools	Removal	Smooth (no grit equivalent)	-Airborne dust -Fine profile	-Vacuum attachments -Other methods
Flame blasting	Removal, profile, cleaning	Rougher than extra coarse	-Excess removal -Damages concrete	-Experience ^(B) -Remove damaged concrete
Acid etching	Profile, cleaning	Fine (150) to coarse (60)	-Hazardous -Not for vertical or overhead surfaces -Neutralization -Wets concrete -Curing membrane	-Other acids -Other methods -pH testing -Let concrete dry -Other methods

^(A) Profile is described using graded abrasive paper sizes. These are typical surface profile values only. Results may vary significantly because of concrete properties and surface preparation practices.

^(B) For coating systems that do not perform over a coarse profile, refinishing the concrete or an underlayment may be required.

A1.12 Recommendations for Procurement Documents (Project Specifications) for Concrete Surface Preparation

Because of the wide range of concrete types, existing concrete conditions, ambient conditions, types of protective coatings to be applied, and project scheduling, producing a comprehensive standard that can be used as a project specification is not possible. Therefore, the following is a checklist of items that should be included in a comprehensive procurement document.

A1.12.1 NACE No. 6/SSPC-SP 13

A1.12.2 Contaminants

A1.12.2.1 Types anticipated

A1.12.2.2 Detection methods

A1.12.2.3 Preferred removal method

A1.12.2.4 Other acceptable removal methods

A1.12.3 Surface Preparation

A1.12.3.1 Preferred method

A1.12.3.2 Other acceptable methods

A1.12.4 Surface Tensile Strength

A1.12.4.1 Minimum allowable

A1.12.4.2 Test method and mode of failure

A1.12.5 Surface Profile

A1.12.5.1 Minimum and maximum allowable

A1.12.5.2 Test method or visual comparison

A1.12.6 Surface Uniformity

A1.12.6.1 Maximum allowable void size

A1.12.7 Repairs and Patching

A1.12.7.1 Preferred materials

A1.12.7.2 Other acceptable materials

A1.12.8 Cleanliness

A1.12.8.1 Maximum allowable residual dust level

A1.12.8.2 Test method or visual comparison

A1.12.9 Moisture Content

A1.12.9.1 Maximum allowable

A1.12.9.2 Test method and when to test (e.g., before or after surface preparation, or immediately before coating)

A1.12.10 Surface Flatness and Levelness

A1.12.10.1 Minimum and maximum slope allowed

A1.12.10.2 Minimum flatness allowed

A1.12.10.3 Test method or visual comparison



Level 2

Chapter 19

Surface Preparation, Coating, and Inspection of Special Substrates

Surface Preparation, Coating, and Inspection of Special Substrates

Introduction

In Level 1, we discussed two general types of substrates:

- Carbon steel
- Concrete and other cementitious surfaces

From time to time, other substrates also may be coated, including:

- Special metal substrates
 - Copper
 - Aluminum
 - Galvanized
- Other substrates
 - Wood
 - Polymeric materials (plastics)

These substrates may be coated for a variety of reasons, including:

- To enhance corrosion resistance based on the NACE definition of corrosion in its broadest sense, namely, *the deterioration of a substance or its properties because of a reaction with its environment.*
- Decoration
- Marking or identification

Little has been written specifically about these substrates compared with the information published about steel and concrete. Consequently, the inspector must be

particularly careful to develop a complete understanding of the coating specification and manufacturer's data sheets for the specific job.

Special Metal Substrates

The coating inspector occasionally may encounter coating of nonferrous metals such as copper, nonferrous alloys such as brass, and alloys of ferrous and nonferrous metals such as stainless (or corrosion-resistant) steel.

These metals include:

- Stainless steel
- Nickel
- Copper/nickel alloys
- Aluminum
- Aluminum bronzes
- Copper
- Bronzes
- Brass
- Tin
- Cadmium
- Lead
- Magnesium
- Zinc (includes hot-dipped galvanizing)

Although a number of nonferrous metal substrates can be coated, an inspector is not likely to encounter most of these metals and alloys except in exceptional circumstances or where the surface areas to be coated are small. However, the coating inspector should be aware of

problems that may be encountered in coating any of the above.

Protective Oxide Film

Many of the above metals and alloys react with the atmosphere to produce an oxide film. The oxide film is an essential part of the corrosion protection, such as in the case of stainless steel. If a substantial oxide film forms, there is the danger that a subsequent organic coating may adhere well to the *oxide film*, but the oxide film may be too thick to allow the coating to penetrate to the surface of the metal. Also, the oxide film may have low strength so that the paint film and part of the oxide film can easily detach.

Generally, the protective oxide films of:

- stainless steel
- nickel
- tin
- cadmium

are tough and adherent, and after degreasing and water washing the surface, they are ready for priming. Some types of stainless steel tend to become rust-spotted when exposed to an unsuitable environment. If this occurs, it may be necessary to either totally or partially remove the rust by dry or wet abrasive blasting using a nonmetallic abrasive or by vigorous scrubbing with water and a stiff-bristle brush or scrubber.

One primer that may be used on these films is a vinyl wash primer. The coating supplier may offer specific primers for particular metals or alloys.

Aluminum

Aluminum may develop a protective oxide film that exhibits low adhesion to the substrate. If coated with an organic coating, this oxide film may detach from the surface.

However, with anodized aluminum, the oxide film exhibits strong adhesion to the substrate and may be coated with an organic coating with little surface preparation other than lightly abrading the surface.

Surface preparation of the aluminum may vary with the circumstances. In some situations, only degreasing and water rinsing may be appropriate.

In other situations, it may be necessary after degreasing to prepare the surface to be coated by wet or dry abrasive blasting with a fine-particle sand or plastic abrasive. A high surface profile should be avoided.

Vinyl wash primer or other special primers such as two-pack epoxy may be used before topcoating with an organic coating.

Copper

Copper and various copper alloys usually present only small surface areas to be coated. Generally, these areas may be prepared by degreasing and water rinsing followed by abrading with wet or dry abrasive-coated paper with appropriate grit size.

Copper frequently is used in an architectural environment where protection (such as a roof) and appearance are important. In some cases, the designer may use soft copper, which develops a greenish oxide called *patina*.

Certain copper alloys used for architectural purposes may be degreased, rinsed, acid etched, then treated with a special solution to aid in developing the patina. These surfaces with the patina are not topcoated.

Lead

Lead usually does not require a topcoating. Because only small surface areas are likely to be encountered, surface treatment of degreasing and water rinsing followed by light abrasion using wet or dry abrasive paper should be adequate for coating.

Galvanizing

Galvanized zinc surfaces react with the moisture and carbon dioxide in the atmosphere to form a passive film of zinc carbonate, zinc oxide, and zinc hydroxide. This passive film, which develops even in a corrosive environment, can inhibit further corrosion of the zinc underneath.

Zinc also can be attacked by acids and alkalis. In an acid environment, such as in hydrochloric acid, zinc reacts to form an acid salt, zinc chloride. In an alkaline environment, such as in sodium hydroxide, zinc reacts to form an alkaline salt, zinc hydroxide. Some of these salts are water-soluble and must be removed before topcoating.

Topcoating galvanized surfaces with organic coatings can present many problems. Generally, newly galvanized surfaces are allowed to weather; that is, they remain unprotected in the atmosphere for a period of months before topcoating. This weathering process allows the slick zinc surface to develop a tightly bonded passive film before being topcoated. Some users simply wash this passive film thoroughly, then they apply a wash primer or special tie coat before applying a topcoat.

In some cases, galvanized zinc surfaces to be coated are treated with a mordant solution, which normally is a weak acid solution containing other chemicals such as copper salts.

In sequence, the zinc surface is degreased, rinsed, and then swabbed down with the mordant solution. If the zinc

surface has been properly cleaned, the mordant solution reacting with the zinc creates a dark-brown color. If this color does not develop, it may signify that the surface has not been adequately cleaned. The mordant solution can be rinsed off with clean water; after the surface is dried it may then be topcoated.

Proper personal protective clothing, including a respirator and eye protection, may be required when working with a mordant solution.

Protection for Nonferrous Metals

Protection is necessary for certain nonferrous metals that may be in constant contact with such building materials as:

- Concrete
- Cement and cement mortar
- Lime mortar
- Brickwork

Protection can be easily obtained by coating the nonferrous metal with an appropriate alkali-resistant coating.

Aluminum and lead must be protected from direct contact with alkaline metals such as:

- Magnesium
- Zinc
- Cadmium
- Copper

Insulating spaces may be specified with these materials to prevent formation of a galvanic couple.

Hardwoods, such as oak, chestnut, and tung, release acidic materials. Lead and tin must be protected if they are to be in contact with these materials.

Cleaning of Joints

Where joints are soldered, welded, or brazed, care should be taken to remove flux before coating.

Standards

Several standards regarding surface preparation of nonferrous metals include:

ASTM

D 1730 *Preparation of Aluminum and Aluminum Alloy Surfaces for Painting*

D 1731 *Preparation of Hot Dip Aluminum Surfaces for Painting*

D 1732 *Preparation of Magnesium Surfaces for Painting*

Wood

Wood may be coated for the following reasons:

- Decoration
- Protection
- Sealing
- Stabilization
- Preservation
- Flame retardance

Decoration

Coating and finishing of wood may be required for decorative and protective purposes. Wood is one of few substrates that may demand transparent finishes that enable the substrate to be seen. Many finishes enhance the appearance of the wood surface because they are absorbed to a varying extent over the surface and make the wood grain more visible.

Protection

Wood may also be coated for protective purposes including:

- Sealing

Untreated wood surfaces may absorb liquids, stain readily, and may be difficult to clean.

- Stabilization

Wood changes its dimensions with moisture content to a different extent in the three grain directions such that it changes shape as well as size.

A coating may be applied to help prevent access of water and slow the passage of water vapor. Coatings best help stabilize wood against dimensional change when applied to all surfaces. Particular attention should be given to protect end grain surfaces.

- Preservation

Although special coatings have been developed as wood preservatives, many coatings are not wood preservatives in the strictest sense; that is, they are not toxic to wood-destroying organisms and do not prevent the decay of damp wood.

Coating damp wood may trap moisture and encourage decay. Moisture entering open joints or unprotected end grain can be held in the wood by a coating, resulting in blistering of the coating film and/or decay of the wood.

On the other hand, an intact coating on all surfaces of dry wood may help prevent the wood from becoming damp enough to swell or warp or support fungal growth. An intact coating also may help prevent erosion of the wood surface which could lead to development of mold, soft rot, and/or algae.

- Flame Retardance

Coatings may be applied to wood or other combustible surfaces to raise the performance according to the flame spread test.

Seasoning

Wood that is to be coated should be seasoned to an appropriate moisture content if it is to be used in building. The moisture content at the time of coating should not exceed the specification. If wood is not properly seasoned, the coating may not adhere properly or it may subsequently blister. The substrate may also warp and/or shrink.

Woods fall into two basic categories:

- Hardwoods
- Softwoods

Some of the hardwoods are difficult to coat due to their inherent oil content.

Polymeric Materials

The term *polymeric materials* (plastics) covers a wide variety of materials and it is not always possible to identify the precise type by simple examination. Various plastic materials are widely used in buildings, tanks, rainwater goods, claddings, wall and floor coverings, pipe, decorative panels, and, in expanded form, as insulating linings, wall and ceiling tiles, etc.

Some polyvinyl chloride (PVC) articles found in buildings present certain difficulties, particularly when they are new and not weathered. These materials may suffer surface degradation on exposure, particularly to sunlight. Other forms of plastic materials accept coating more readily after a period of exposure.

Inspection of Special Substrates

The same general inspection principles for steel and concrete apply to the special substrates as well. The inspector should:

- Read and understand the specification
- Ensure proper surface preparation
- Ensure correct application procedures
- Inspect each coat as applied, and inspect the finished job
- Keep records and submit reports as required by the specification or the owner's representative



Level 2

Chapter 20

Thick Barrier Linings

Thick Barrier Linings

Introduction

The next group of materials for review is thick barrier linings. Some of these materials are:

- Chemical-resistant masonry, such as brick and tile
- Reinforced plastic materials, such as fiberglass, used with polyesters, vinyl esters, epoxy, novolac epoxy, etc.
- Polymeric sheet materials, including polyethylene
- Rubber linings
- Glass linings

Chemical-Resistant Brick and Tile

Introduction

Some chemical-resistant linings can be made using chemical-resistant brick or tile, attached with chemical-resistant, resin-based mortars and grouts. Depending upon the clays used, brick and tile can be formulated to be:

- Acid-resistant, or
- Caustic- (alkali-) resistant

These special mortars and grouts generally are based on these resins:

- Furan
- Phenolic
- Polyester

- Epoxy and novalac epoxy
- Vinyl ester

There are different grades of brick and tile. Bricks are available in various sizes and shapes: flat, curved, etc.

To join the bricks or tiles, the applicator spreads on the mortars or grouts and/or setting beds with a plasterer or a bricklayer's trowel.

The mortar must:

- Set quickly to allow laying the next course of brick
- Be resistant to the contents of the vessel, or in the case of floors, the chemical environment
- Not adversely affect, discolor, or otherwise contaminate the contents of the storage or containment facility



Figure 20.1: Acid-Resistant Brick

Brick linings are used in storage or containment structures, in exhaust stacks, in pickling tanks and on floors where corrosion-resistant service is required. Such linings frequently are used in power generation, food and beverage, pharmaceutical, the pulp and paper industries, etc.

ASTM Standards for Chemical-Resistant Brick and Tile

Chemical-resistant brick and tile normally conforms to one of three ASTM standards:

ASTM C 279 *Chemically-Resistant Brick and Tile for Tank Construction*

ASTM C 980 *Acid-Proof Brick for Chimney Construction*

ASTM C 490 *Acid-Proof Brick for Industrial Flooring*

Brick can be installed in both full and half-brick configurations and may be in multiple layers. The half-brick is called “thin-set.”

Installation of Brick and Tile

In the *bricklayer's* method of installation, the brick is *buttered* on two sides and stacked one upon the other. In the *tile setter's* method, the brick or tile is placed on a setting bed of chemical-resistant resin, and the joints in between are filled with the resistant mortar. The most common method of joining brick or tile is the *tile setter's* method.

Tiles and bricks used for flooring systems installed by the tile setter's method usually are coated with an inert wax on the exposed surface. This wax allows easy clean up after the grout has been applied because the grout will not adhere to the wax.

Epoxy setting beds may be used for systems on concrete floors, where brick or tile is used with acid-cured furan grouts between the brick or tile.

Acid-cured furans, which make up most of this class of resin, will not bond effectively to concrete. Alternatively, an alkaline-cure, furan resin may be used on concrete surfaces.



Use of Membranes

The mortar between the bricks can be damaged or cracked from unusual structural movement. If this happens, then corrosive contents may course their way through the crack and to the substrate.

Therefore, in such corrosive conditions, generally it is desirable to use a membrane lining between the substrate of the vessel and the chemical-resistant brick.

The brick provides a heat barrier, physical protection, and corrosion resistance. The membrane provides a back-up chemical barrier between the lining and the substrate of the vessel.

Rubber lining materials often are used as membranes in heated acid-pickling tanks or vats that operate at higher temperatures up to 82°C (180°F). Here the brick contains the acid and provides heat insulation to the rubber membrane. The rubber membrane provides additional protection from the acid should it leak through the brick or the mortar.

Types of Membranes

The corrosion-resistant coatings most widely used today as membrane linings can be applied by brush, mop, roller, or spray.

Membrane materials include:

- Hot-applied asphalt enamel or pitch
- Elastomeric polyurethanes, cold- or hot-applied
- Asphalt or coal-tar solvent cut backs, cold-applied

Sheet elastomers and plastics, which vary in thickness from about 2.5 to 6.5 mm (100 to 250 mils), may be used as membranes. These are bonded continuously to the surface with an appropriate adhesive or primer.

Because of various environmental and health issues, sheet lead, which was used extensively in the past, is not used often and is being replaced by elastomers and plastic materials.

Some important quality-assurance considerations for chemical-resistant masonry include:

- Surface preparation
- Type and grade of brick, tile, or masonry used
- Installation of membrane and brick or tiles

Inspection

The coating inspector should ensure that the materials conform to appropriate standards (such as ASTM) and that the application is in accordance with the specifications. The inspector normally will be checking for:

- Type, grade, mixing, and preparation of mortars and grouts
- Workmanlike installation of membrane, if used. This includes:
 - Check for holidays
 - Correct thickness (DFT can be measured by DFT gauge, pit gauge, or ruler, whichever is required by the specification)
 - Workmanlike installation of brick and cement lining and expansion joints

Furan Products

Some chemical-resistant masonry mortars were based on furan resins.

In addition to their use as mortars, furan resins often are used in the formulation of polymer cements. The most commonly encountered furan products are derived from furfural alcohol, a byproduct of petroleum refining, or from furfural, a byproduct of oat hulls, rice hulls, or corn cobs.

Furan resins are used widely with lining systems in the fabrication of corrosion-resistant process equipment. Furan resins are resistant to solvents, most non-oxidizing acids, and inorganic acids, even at high temperatures (90°C [195°F]). They are highly resistant to alkalis and are unaffected by animal, vegetable, and mineral oils.

In addition to their chemical resistance, furan resin products also have good wetting properties and can be applied directly to porous surfaces such as wood.

Some disadvantages of furans include:

- Low adhesion to nonporous surfaces, such as steel
- Brittleness
- Shrinkage
- Offensive odor in the uncured state
- Expensive

Curing is activated by a co-reactive curing agent that is packaged separately from the resin solution. The curing agent is generally acidic, although alkaline-cure furan coatings are also available.

Nonporous materials, such as steel, should be blast cleaned and primed with a primer suitable for bonding with the furan product. As previously noted, acid-cure furans will not bond directly to concrete.

Furan resin products may be air-dried or baked, depending on the formulation and degree of chemical resistance required.

Monolithic Corrosion-Resistant Cements

There are a number of corrosion-resistant cementitious products, such as potassium silicate, sodium silicate, and calcium aluminates. These are produced in castable grades, gunite grades, and as mortars.

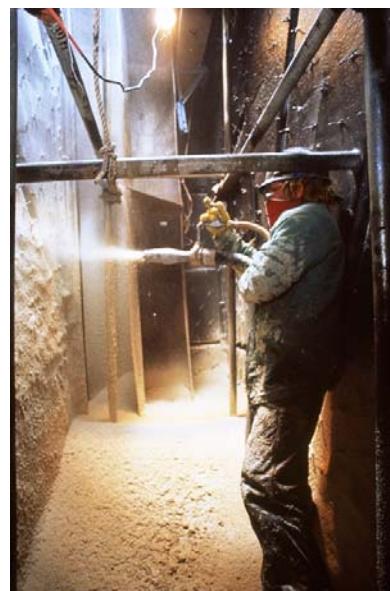


Figure 20.2: Guniting

These products have:

- Excellent acid resistance to a pH of 1.0

These silicates have good resistance to certain concentrations of bromic and hydrofluoric acids. The user should check with the manufacturer for corrosion-resistance data.

The maximum high-end pH is only slightly caustic (pH 8.0) for many of these products. Corrosion-resistant monolithics and mortars may become puddles of sand in just a matter of days in a high-caustic environment at a pH 9.0 and above.

- Excellent temperature resistance to 871°C (1,600°F)

Machinery Setting Grouts

In a typical production facility such as a food and beverage plant, pulp and paper mill, chemical plant, or power plant, various types of machinery—pumps, motors, tanks, etc., are installed or replaced.

If the potential for corrosion is low, these units may be installed, leveled, and stabilized with ordinary concrete. If the potential for corrosion is high, installation of these pumps, motors, etc., may require corrosion-resistant machinery grout.

These grouts, usually high-grade epoxy, may be some of the same materials used as mortars for the chemically resistant brick and tile. These high-grade grouts generally are 100% solids and exhibit almost no shrinkage upon curing.

Surface preparation may be critical and, in some cases, a membrane may be used on the concrete surface. The machinery is installed, and then the machinery setting grout is poured on top of the membrane around and under the machinery.

In these types of installations, the contractor should follow standard recommended construction practices for concrete, which may include the use of expansion joints for larger areas.

Polymer Concrete

Furan resins, along with certain vinyl esters polyester resins, novalac resins, or potassium silicates, frequently are used to manufacture polymer concrete, which has excellent chemical resistance.

The resins are blended with special aggregates and fillers, and the mixture is molded into specific structural shapes for use in grouting, in floor drains, conveyor troughs, drainage ducts, and pump and equipment foundations.

Polymer concrete may be useful in applications where conditions are highly aggressive to regular concrete, and a more resistant (and less porous) construction material is required.

Polymeric Sheet Materials

A wide variety of plastic sheet materials is available, such as:

- Polyvinyl chloride (PVC)
- Polyethylene
- Polypropylene
- Proprietary materials generally known by such brand names as Kynar®, Halar®, Penton (Aqualon®), etc.

The application procedures for most of these materials are similar, as follows:

- Surface preparation with abrasive blast cleaning to near-white to white metal
- Pre-cutting the material to fit the configuration
- Priming and/or application of a suitable adhesive to the substrate and/or to the material itself

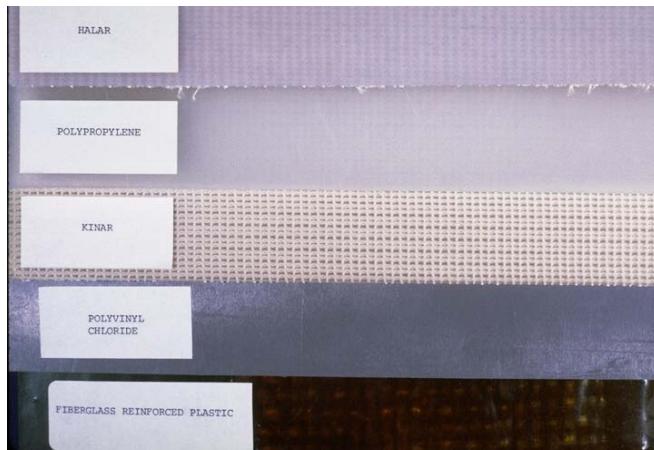


Figure 20.3: Various Mats

- Lay up of the sheet material (correct alignment is critical)
- Heat welding or other treatment of the seams to achieve a continuous lining. This joining process is critical to ensure there are no gaps and no contamination between sheet edges.

Inspection requires high-voltage spark testing for immersion service.

Rubber Sheet Linings

Rubber sheet linings are made in different types of natural and synthetic rubber. These linings are little noticed in the industrial coatings market, but they are widely used as protective barriers against corrosion. Also, they are used for the containment of certain chemicals and non-corrosive products and, where needed, they provide abrasion resistance.

Rubber linings are used in the storage and transportation of:

- Acids
- Certain alkalis
- Food chemicals and food products

- Selected solvents
- Specialty chemicals and other corrosive products
- Plastic pellets
- Clays, etc.

Rubber linings are used most commonly in:

- Railroad tank cars
- Truck tanks
- Barge tanks



Figure 20.4: Section of FGD Duct, Rubber Lined

Rubber linings are also recommended for:

- Reaction towers
- Process tanks, vessels, etc.
- Filters
- Flue gas desulphurization units
- Fume stacks
- Agitators
- Troughs

- Blowers and fans
- Crystallizers and sewers
- Pump shells and casings
- Rotors
- Chutes, hoppers, conveyors, screws, etc.

To be effective, rubber linings can be tailored to yield specific properties to handle particular materials.

Rubber Linings

Types of rubber can be divided into two major classes:

- Natural
- Synthetic

Natural rubber is derived from latex obtained from Hevea trees and is coagulated with acetic or formic acid. Chemically, it is an unsaturated hydrocarbon known as *polyisoprene*.

Synthetic rubber is any one of a group of manmade elastomers which approximate one or more of the properties of natural rubber.

Curing Rubber

Rubber is cured by vulcanization, a process discovered in 1846 by Charles Goodyear in the United States and simultaneously by Thomas Hancock in England. The overall effect of vulcanization is to convert rubber hydrocarbon from a soft, tacky thermoplastic material to a strong, temperature-stable thermoset having unique elastic modulus and tensile properties.

Vulcanization is a physicochemical (physical and chemical) change resulting from the cross-linking of the

unsaturated hydrocarbon chain of natural rubber (polyisoprene) with sulfur, and the application of heat.

Natural rubber is blended with 3% sulfur, 1% organic accelerator, 3% zinc oxide, certain fillers or reinforcing agents, and is cured in the presence of live steam at temperatures of 120 to 150°C (250 to 300°F).

All synthetic rubbers require vulcanization. In general, sulfur is used with the unsaturated polymers, while certain saturated polymers may be cross-linked with peroxides, metal oxides, or diisocyanates.

Three factors affect the properties of the vulcanizate (vulcanized product):

- Percentage of sulfur and accelerator used
- Temperature of the curing process
- Time of cure

The sulfur content is usually 1 to 3%, but in certain cases, it may range to 50% by weight. With strong acceleration, the cure time can be as short as three minutes at high temperatures of 150°C (300°F). Vulcanization also can occur at room temperature with specific formulations (self-curing cements).

There are five methods used to vulcanize sheet rubber lining onto substrates of piping, equipment, or vessels. Not all are appropriate for every rubber lining application. The specific method of vulcanization will depend on design of equipment, its overall dimensions, and facility on site.

Shielding or insulating the equipment during cure reduces the duration of cure. The thickness of rubber affects curing time; thicker rubber takes longer to cure.

The methods of cure are:

- Autoclave (vulcanizer) cure: The rubber-lined equipment is placed in an autoclave and subjected to controlled steam under pressure. This method is

preferred because of better heat transfer and shorter cure cycle. This method results in the highest rubber-to-metal adhesion and yields the highest lining density useful for more corrosive media.

- Internal steam cure: The pressure vessel is used as its own autoclave by closing off all openings and filling the vessel with steam under controlled temperature and pressure.
- Atmospheric steam cure (also called *exhaust steam cure*): This is vulcanization without pressure, using atmospheric steam. The temperature of the steam and the steel skin are closely monitored. To prevent collapse of a closed vessel, precautions should be taken against failure of steam supply or sudden cooling. This method is commonly used on vessels that are too large to transport and are therefore lined in the field.
- Hot-water cure: The equipment is filled with water, and steam is injected to boil the water. The temperature and water level are maintained for the required period of time.
- Chemical cure: Chemical cure is vulcanization at ambient temperatures by applying topically a liquid vulcanizing agent to the surface of the rubber. Supplementary heat may be used to reduce the cure time. Chemical cure takes place from the rubber surface downward. The adhesion obtained by this method is less than that obtained by other curing methods. This method commonly is used on tank repairs or large field-lined vessels.

Natural Rubber

Three categories of natural rubber are:

- Soft
- Semi-hard
- Hard



Soft Rubber

Of the three groups of rubbers (soft, semi-hard, and hard), soft rubber has the greatest flexibility, elongation, and accommodation to movement of the underlying surface.

Soft rubbers have:

- Good resistance to a number of corrosive chemicals
- Excellent abrasion resistance
- Good temperature resistance up to 60°C (140°F)

Soft rubber linings are standard for tanks containing hydrochloric (muriatic) acid. Soft rubber is unique in that it forms a surface film that toughens slightly and retards penetration by the acid. Washing the film with water tends to disturb that film and soften the rubber.

A “tri-ply” lining construction is often used to form a *sandwich* film, consisting of a hard or a semi-hard layer of rubber between two layers of soft rubber. Special lap seams separate the ends of the hard rubber and allow for expansion within the soft rubber. The steel substrate is coated with a special adhesive primer, and then a soft tie gum is applied over the primer. The rubber lining is applied over the tie gum. (Note: Tie gum is a soft backing layer of rubber used to promote bonding of two surfaces).

This sandwich film provides excellent corrosion and abrasion resistance, and can be compounded for steel pickling lines, halogen acids (HCl, HBr, etc.) and offer resistance to thermal shock and fatigue from flexing.

Soft rubber linings:

- Are very water resistant
- Provide the best in abrasion resistance
- Can be used with food-grade phosphoric acid

Hardness ranges from 35 to 70 Shore A durometer. The higher the sulfur content, the harder the rubber.

Semi-Hard Rubber

Semi-hard rubber is compounded with about 15%-by-weight of sulfur. This material may be mixed with acid-resisting fillers, rubber dust, accelerators, and a limited amount of plasticizers to produce a workable mass which can be kneaded, extruded, and/or calendered and then can be applied directly over tie gum or adhesive.

This type of rubber is resistant to the same chemicals as soft rubber, but may be used for stronger concentrations and at temperatures up to 82°C (180°F). Semi-hard rubber may be used for services that generally require hard rubber, but where the brittleness of the hard material cannot be tolerated.

Semi-hard rubber can be used in water conditioning equipment and for protection against wet chlorine gas, strong acids, and plating solutions.

Semi-hard rubber compounds:

- Are affected by temperature changes
- Become very brittle at freezing temperatures
- Are not suitable for some outdoor installations, or where there are wide temperature changes

The hardness range is generally from 70 to 75 Shore A durometer.

Hard Rubber

Hard rubber can handle highly corrosive solutions such as concentrated HCl and wet chlorine gas at 93 to 105°C (200 to 220°F). Generally, hard rubbers are used on rigid shapes of well-designed equipment that is not subject to rapid temperature changes. Because of their low permeability to moisture, hard rubbers often are used in

water treatment facilities. They also have good abrasion resistance.

Hardness range is from 60 to 80 Shore D durometer.

Synthetic Rubbers

The various types of synthetic rubber are:

Butyl Rubber

Butyl rubber is a very pliable and moldable material and is generally used in fittings, etc., where sheet lining is not feasible. It is easily vulcanized. Because of its cost, butyl rubber is not used as sheet lining; however, it can be easily reacted with chlorine to produce chlorobutyl rubber which is used as a sheet lining.

Butyl rubber is commonly used as a component of mastics, adhesives, sealants, etc.

Butyl rubber has excellent resistance to acid solutions such as sulfuric, dilute nitric, and dilute hydrofluoric acids at temperatures up to 93°C (200°F).

Chlorobutyl Rubber

Chlorobutyl has very low permeability and excellent chemical resistance. It is widely used in water boxes in the power generating industry. Generally, it can be applied as thickly as 12 mm (0.5 in.) over tie gum bonded to special adhesive primers. Chlorobutyl rubber also is used in flue gas desulfurization (FGD) scrubbers, and for such chemicals as sodium hypochlorite, superphosphoric acid, and sulfuric acid.

Neoprene Rubber

Neoprene is a general-purpose material that is resistant to a wide range of chemical and physical conditions and can resist:

- Lubricating oils
- Gasoline
- Sulfuric acid 50% at 80°C (180°F)
- Strong hydrochloric and hydrofluoric acids at room temperature
- Sodium hydroxide (50 to 70%) at 93 to 110°C (200 to 230°F)
- Acid slurries

Neoprene is very resistant to ozone and oxygen, both of which can cause deterioration of rubber, and these features make neoprene useful in outdoor applications.

Nitrile Rubber

Nitrile rubber has good resistance to aliphatic solvents, such as kerosene, naphtha, mineral spirits, etc., as well as animal, vegetable, and mineral oils. It has relatively poor resistance to acids.

Nitrile can be compounded and vulcanized to form soft, semi-hard, and hard rubber compositions. The soft form is most common for lining applications.

Hypalon

Hypalon is chlorosulfonated polyethylene, but is regarded by industry as a form of synthetic rubber.

The material is very resistant to weathering. It is resistant to oxygen, ozone, heat, flame, tear, abrasion, oil, and grease. Hypalon has gained wide recognition in handling chromic acid (10%), hydrogen peroxide (30%) and sulfuric acid (50 to 75%). It is resistant to temperatures to 93°C (200°F).

Application Process for Rubber

The prime requirement for equipment, vessels, piping, etc., to be rubber lined is that all vulnerable surfaces be accessible for lining installation. Generally, the surface conditions and surface preparation requirements are more strict than those required by many liquid dispersion materials.

The following are some typical surface preparation requirements for a rubber-lining project:

- The steel shall be new, full-weight steel, free from structural defects.
- The steel plate shall be flat, with no appreciable warp or buckle.
- The steel plate should have a minimum thickness and corresponding weight per square foot (6.3 mm [0.25 in.] thick steel plate should weigh 4.6 kg/m² [10.2 lbs/ft²] and 13 mm [0.5 in.] steel plate should weigh 9.2 kg/m² [20.4 lbs/ft²]).
- Vessel must be braced to avoid bulging.
- All welds should be solid and continuous, and should be peened to eliminate porosity, and should be ground to remove sharp edges and high spots.
- Edges and corners should be ground to a minimum radius of 3 mm (0.125 in.).
- All weld spatter should be removed.

Surface Preparation

In addition to the conditions described above, the surfaces to be lined should be free of all oil, grease, dirt, old coatings, etc., and then abrasive blast cleaned with steel grit to NACE No. 1/SSPC-SP 5 white metal blast with a surface profile of 38 to 64 µm (1.5 to 2.5 mils). After blasting, all surfaces shall be free of dust or debris before application of the adhesive (primer).



Lining Installation—Plant

The lining is cut to fit the geometrical shape of the vessel to be lined. When joined, the edges of the lining material must fit precisely unless an overlap is done.

A primer, tie coat, or adhesive, as required, is applied to the clean, dry, bare surface and the lining placed in position. After the lining is properly positioned, it must be rolled (generally, by hand) to remove any bubbles or wrinkles. When the installation is completed, the item is placed in an autoclave for curing.



**Figure 20.5: Beveled Edge of Rubber Sheet
After Cutting**

Curing—Plant

Curing generally is performed in an autoclave with live steam at about 345 kPa (50 psi) and a temperature of 125 to 150°C (250 to 300°F). Curing is a time-temperature relationship. The lower the temperature, the slower and longer the cure time. Conversely, the higher the temperature, the faster and shorter the cure time. As indicated previously, curing also may be done by internal steam cure or hot-water cure methods in the plant.

Lining Installation and Curing—Field

Field lining with rubber is performed when it is not possible to transport the item to an autoclave. A typical field installation of a closed-top tank may proceed as follows:

- After proper surface preparation, the tank walls, ceiling, and the floor area around the bottom corners of the tank are primed with the appropriate adhesive. The walls are lined first and the floor last.
- Sheet rubber is applied to the walls with enough material to overlap onto the tank bottom. The top end of the rubber is overlapped onto the roof just as at the bottom.
- The lined area is thoroughly rolled by hand to remove any bubbles or wrinkles. The joints at the top and the bottom are made away from the corners. When the walls and ceiling are finished, then the bottom is lined.
- Once the tank is lined and ready for cure, an exhaust steam line with a swivel elbow is placed in the tank and the tank shrouded to retain the heat. Live steam is introduced into the tank. Moving of the elbow circulates the steam. The field curing process is often called *exhaust* cure.
- In the curing cycle, it is possible to achieve at least 17°C (30°F) differential between the outside steel wall and the inside at the rubber interface. The cure process may require 24 to 36 hours in time.
- Pre-cure is optional. This is a method of interrupting the cure for the purpose of detecting defects, blisters, checking hardness, etc., before final vulcanization. During a pre-cure, steam should be introduced for approximately two hours. The time will vary according to the size of the vessel or the size of the steam line; however, the time should be long enough to expand any trapped air so that it will be found and repaired, and short enough so that the surface of the



lining will not be cured to the state where a repair cannot be made.

- After pre-cure repair, steam is introduced into the vessel for completion of cure.
- The operator may make hardness measurements with a durometer, especially in the potentially colder areas, such as the bottom, outlets, nozzles, and weldments where stiffener rings could create a heat sink.

Inspection

Inspection of the lining may include:

- Determining required hardness with a durometer
- Checking visually for bubbles, wrinkles, or any other unusual visible physical defect
- Checking for holidays with a high-voltage spark tester.

Spark testing will vary depending upon thickness and type of rubber. As a general guide, 15,000 V is adequate for 6.4-mm- (0.25-in.-) thick natural rubber. Generally, the probing electrode should be in light contact with the rubber and moved back and forth at the rate of approximately 30 cm/s (1 ft/s). The electrode should be kept moving without stopping in any one position; otherwise, dielectric breakdown of the rubber is likely.

When inspecting rubber linings the inspector should be knowledgeable of the total process. This is a specialty type application and the inspector should not undertake inspection of rubber linings without the required knowledge and experience.

The following is a sample acceptance criterion for a rail tank rubber lining installation, and would be cause for rejection:

- Pinholes in lining

- Blisters
- Loose lap seams
- Uncured lining (hardness)
- Mechanical defects (cuts, gouges, or other surface defects)
- Poor workmanship (excessive repairs)



Figure 20.6: Loose Lap Seam in a Rubber Lining



**Figure 20.7: Warning Label on
Rubber-Lined Tank Car**

Repairs

Repair procedures will vary. Generally, small repairs may be done with a chemically cured rubber such as chlorobutyl, when curing by vulcanization cannot be done.

Failures

Failures can occur with rubber linings. Some of the causes of failure may be:

- Incorrect product selected for the intended service
- Using rubber after the shelf life has expired
- Using rubber lining that was not properly stored. Rubber must be kept cool in storage because, with heat, it can vulcanize on the roll. If this occurs, the material should be discarded.
- Incorrect application process
- Inadequate cure

Other Sheet Linings

There are other polymers, such as polyethylene and chlorinated polyethers, which can be fashioned into sheet materials for linings. Their treatment and application is quite similar to that of rubber linings.

Chlorinated Polyether

Chlorinated polyether resins are available for application as a powder as dispersion or solution coatings or as sheets for linings.

Chlorinated polyether lends itself readily to dry powder application by sintering or by the fluidized-bed process.

When chlorinated polyether is applied as a coating, the surface should be cleaned as specified. Each coat should be fused after allowing the dispersion medium to evaporate to near dryness.

When chlorinated polyether is applied as a sheet:

- The bonding surfaces, both sheet and substrate, should be free of oil, grease, and dirt.
- Metal surfaces should be blast cleaned to white metal, vacuum cleaned, and given a single coat of primer. Chlorinated rubber primer is often used.
- The chlorinated polyether sheet should be cleaned with MEK and then given a light blast, or should be sanded by hand using fine-grade paper. The abraded sheet should be vacuum cleaned to remove dust or grit and should be given a coat of primer.
- Rubber-based adhesives are used for applying chlorinated polyether sheet. These may be applied by spray, roller, or brush.
- Optimum bond strengths may be obtained by reactivating the adhesive with heat. This is sometimes done by heating through the sheet to bring the adhesive layer to about 121°C (250°F) just prior to rolling in place on the substrate.

Polyethylene

In general, polyethylene polymers are high-temperature resistant and have excellent resistance to chemicals. They are resistant to creep, have high impact resistance, excellent tensile strength, and high electrical resistivity. They are insoluble in organic solvents and do not stress crack.

Basically, there are two forms: low-density and high-density. Essentially, the low-density materials have highly branched and widely spaced molecular chains, while the high-density materials have comparatively

straight and closely aligned chains. The physical properties are markedly affected by increasing density.

The high-density form has a higher melt point and greater tensile strength than the low-density form. The low-density materials are used generally for wire and cable coatings and liners for drums and other containers, etc. The high-density form is used for gasoline containers, piping, and film and sheet.

Three methods for applying polyethylene are in current use:

- Melting the resin and extruding it onto the article to be coated
- Heating the object to be coated to a temperature above the melting point of the polyethylene and immersing the object in a fluidized bed of powder
- Flame spraying the polyethylene directly onto a metal surface. This method of application requires special equipment and operator expertise.

Glass Linings

Glass linings are used to combat corrosive conditions in a number of situations and are widely used in the chemical processing and the pharmaceutical industry and in elevated-temperature environments.

There are three types of glass used in the chemical processing industry that possess the high corrosion resistance necessary for severe chemical applications:

- High silica (not bondable to a metal substrate)
- Alkali silicate (can be fused to a metal substrate and is most widely used in glass-lined steel chemical process equipment)
- Glass-ceramic or crystallized glass (can be fused to metal substrate and is gaining wider use in abrasive and other difficult applications)

Glass linings are very expensive. Generally, they are used in highly corrosive environments where organic coatings and polymeric sheet materials are unsuitable.



Figure 20.8: Examples of Items that May Be Glass Lined

Essentially, installation of a glass-lined vessel dictates that the vessel or equipment be situated on a stable foundation to eliminate or minimize the opportunity for movement, and hence, for the lining to crack. (Note: Special grades of low carbon-enamel quality steels are used for glass lining processes.)

When brick or tile is used as a lining, each is provided with a membrane between the substrate and the brick. Glass linings are heat-fused to the metal, and there is no secondary membrane.

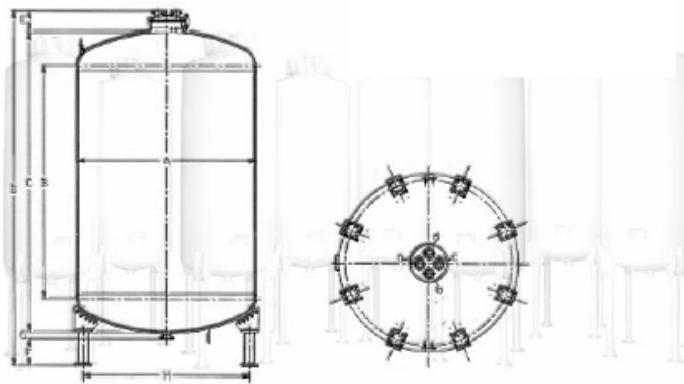


Figure 20.9: Drawing of Tank that will Receive a Glass Lining

Consequently, it is important to ensure the glass lining remains intact. If cracks were to occur, any corrosive material contained could course its way into the metal substrate and create a corrosion cell under the lining.

Application of Glass Lining

Surface Preparation

Fabrication of the item to be glass lined (called glassing) is critical. All welds should be complete with no voids or undercuts, etc. The welds should be peened shut and ground smooth. All edges should be ground to a radius of not less than 3 mm (0.125 in.).

After all fabrication defects have been corrected, the item to be glassed is placed in a furnace and brought to a temperature of about 840°C (1,550°F) and held for the required time. The item is removed and allowed to cool in the air.

This annealing (or normalizing) operation relieves stresses in the metal introduced by welding and fabrication, and also burns off any oil or grease.

Finally, the vessel or item is cleaned by abrasive blasting with grit. This removes all the furnace oxides and scale from the metal and produces the required surface profile. Although the bond of the glass to metal is believed to be largely a chemical bond, experience dictates that a roughened surface helps ensure a good glass-to-metal bond.

Application Process

The glass used to produce the lining is called *frit*.

Such compounds as oxides, carbonates, nitrates, and fluorides are thoroughly dry-mixed and then charged into a glass smelter where they are fused into a molten batch at a temperature of approximately 1,370°C (2,500°F). After a specific time, the molten batch of glass is charged

into a tank of cold water. This sudden chilling causes the glass to shatter into small pieces. Glass in this condition is called *frit*.

After the frit is dried, it is prepared for use in two forms, slip or dust. To produce slip, the frit is ground in a ball mill with specific amounts of water and clay. This process produces a slurry composed of finely ground glass held in suspension by the clay. Glass dust is prepared by dry grinding the frit in a ball mill to the required fineness.

There are four main methods of applying glass to metal:

- Spraying: Spraying is used to coat large vessels and accessories. The slip is sprayed onto the clean, prepared surface and allowed to dry. Then the item is placed in a furnace and heated to the desired temperature to fuse the glass to the metal. Subsequent coats, if required, may be sprayed over the fired glass surface and fused to each other.
- Spray dusting: With spray dusting, the item is first sprayed with the glass slip. While the slip is still wet, the glass dust is applied to the surface and the water in the slip is partly absorbed by the dry dust, causing the dust to adhere to the surface. In this manner, it is possible to apply coatings of about 5 mm (0.2 in.) thickness per coat.
- Slushing: The item to be coated is dipped into a container containing the slip (slurry), or the slip is poured onto the metal. By proper adjustment of the flow and specific gravity, the desired thickness of the wet glass mixture can be made to adhere to the metal and the excess drained off.

The dried coating is then fired in a furnace. This slushing method is most suited for piping and intricate shapes.

- Hot dusting: In this process the metal item must first receive a *ground coat*, which is defined as the first coat of glass applied to the metal surface. The purpose of this coat is to fuse the glass to the steel to form a strong bond between the glass and the metal substrate. The ground coat is produced by spraying or slushing the frit on the metal surface. The coating is allowed to dry and then placed in a furnace where the glass is fired at temperatures of 870 to 930°C (1,600 to 1,700°F).

Next, the frit is dusted onto the preheated metal, which has been ground-coated, and the item is returned to the furnace, where this coat is fired at the lower temperature of 815°C (1,500°F). Subsequent cover coats may be produced by dusting the frit onto the glass surface and heating the item to 815°C (1,500°F). Each cover coat applied must be fired at the lower temperature of 815°C (1,500°F).

In certain cases it is desirable to control the furnace atmosphere to prevent rapid oxidation of the base metal by introducing inert gases or products of combustion into the furnace. Between coats of glass, all radii and rough areas on the lining are ground before applying the next coat, which prevents an excessive glass build-up on areas that might tend to spall off.

Inspection

Glass lining is a very specialized factory process, and glass-lined vessels are usually thoroughly inspected prior to shipping.

Proper field inspection of glass-lined equipment is difficult due to the highly polished surface and the matte colors used in pigmentation. If a break in the glass lining can be detected when the flaw is very small, a repair may be possible.

Repairs usually consist of discs, plates, sleeves, caps, boots, etc., held on by means of studs and nuts and separated from the glass by a suitable gasket (usually

polytetrafluoroethylene [this is the chemical name for DuPont's product Teflon®]). A filler material is required to eliminate entrapped air behind the structural repair and to impart structural strength. It is necessary that the metal selected be satisfactory for the chemical conditions involved. Materials in current use include:

- Tantalum
- Stainless steel
- Nickel-base alloys
- Zirconium
- Nickel
- Titanium
- Molybdenum

An alternative repair method would be to use a pourable liquid resin. However, the very aggressive nature of the media may make resins unsuitable.

On the other hand, microscopic breaks do not usually occur under process conditions. Glass failure, whether by mechanical or other means, is usually decisive and of a size that can be seen by the naked eye.

Inspection of glass-lined equipment, therefore, becomes a scheduled routine operation. The frequency of inspection depends upon the severity of the chemicals being processed and the particular method of operation.

Visual inspection normally is acceptable, though electrostatic inspection may be required. It is critical that rubber-soled shoes be worn and no hard implements be allowed in the vessel.

The voltages used in field testing should be the minimum value necessary to determine the presence of defects in the glass lining. This ensures maximum life of the equipment and substantiates the fact that thin glass is better than no glass at all.



It should be borne in mind at all times that only glass-lined equipment made for severe chemical service should be subjected to field electrostatic tests. All other glasses, because of their minimum thickness requirements, might be severely damaged by such a procedure.

Stabilized 5,000 V AC of low frequency (60 cycle) is satisfactory for field testing glass-lined chemical equipment (such AC is judged to be dangerous and is not permitted under the Health and Safety At Work Act or other European safety legislation).

Unbonded Linings

Unbonded linings include what are frequently called *bag linings*.

Unbonded linings are often shop fabricated, but may be field fabricated to fit the service vessel. Generally, they are attached mechanically or adhesively to nozzles, manholes, and other vessel penetrations.

Unbonded lining operations should be inspected in accordance with the specification.

The inspector may be required to ensure that:

- All welds are ground smooth and flush.
- All edges are ground to a smooth radius.
- All spikes, protrusions, and sharp edges that could puncture the lining are removed.

The inspector also may be required to monitor pre-installation, which may include:

- Checking fabricator's drawings and instructions to determine:
 - Dimensions of liner and vessel
 - Which end goes in first

- How the liner should be inserted

At post-installation, the inspector may be required to:

- Check wrinkles
- Inspect to ensure the liner is attached to the vessel as specified

Rail Tank Car and Hopper Lining

The rail car industry defines a coating as a liquid dispersion whether used on the exterior or interior of a rail car and characterizes a lining as a polymeric sheet material, used on the interior.

For this discussion, the intended use—interior or exterior—will be used to distinguish between a coating or a lining, and any liquid or sheet material used on the interior of the car will be regarded as a lining.

Linings for rail tank cars and hopper cars must protect the steel substrate (and in some cases, aluminum) from corrosion, and from attack by the product contained. At the same time, the lining must not cause any contamination of the product being transported. Even though there may be no toxic effects to the cargo, discoloration itself may cause an entire cargo to be rejected.

Rail tank cars are used to transport:

- Acids (acetic, bromic, hydrochloric, sulfuric, etc.)
- Oils (castor, corn, fish, linseed, soybean, etc.)

Thick barrier lines:

- Fuels (gasoline, diesel oil, etc.)
- Caustics (sodium hydroxide [dry or liquid])
- Molten sulfur

- Foodstuffs or food ingredients, dry or liquid (corn syrup, palm oil, ethyl alcohol, food grade phosphoric acid, wine, fruit juices, vinegar, etc.)
- Various other finished chemical products or intermediates

Hopper cars (covered and uncovered) are used to transport dry bulk cargoes including:

- Food products
- Clays
- Fertilizers
- Corn
- Wheat
- Plastic pellets, such as PVC or high-density polyethylene
- Sand and gravel
- Coal, etc.

Protective materials used as linings in the rail tank cars and hopper cars include:

- Epoxy materials with amine, amine adducts, and polyamide curing agents
- High-solids urethanes
- Epoxy-novalac formulations
- High-bake phenolics
- Sheet rubber (generally for tank cars only)

Generally, except in the case of rubber lining, all welds, covers, edges, etc., are stripe coated prior to the application of a coating.

Coatings and linings used in the United States to transport some foods must meet U.S. Food and Drug Administration requirements.

Generally, surface preparation requirements for rail tank cars and hopper cars are more restrictive and detailed compared to requirements for surfaces exposed to the atmosphere only.

Depending upon the anticipated service, interior surfaces of new cars will be closely inspected for fabrication defects such as:

- Laminations, scabs, slivers, rollovers, etc.
- Rough welds
- Skip welds
- Weld spatter
- Sharp edges

All welds should be ground smooth or flush, all laminations, scabs, and rollovers should be properly ground flat, weld spatter should be ground down to the original substrate, skip welds should be welded solid, and all sharp edges should be rounded to a radius of 3 mm (0.125 in.).

The cleaned surfaces should be abrasive blast cleaned to specification, usually a NACE No. 1/SSPC-SP 5 white metal blast or NACE No. 2/SSPC-SP 10 near white metal blast with appropriate surface profile, usually 20 to 25% of the required DFT of the coating designated.

Epoxy materials, novolacs, polyurethanes, may be allowed to cure 5 to 7 days at 21°C (70°F), or they may be “force-cured” by heating. High-bake phenolics are baked after each application, and for food service these products receive a final bake at 202°C (400°F). United States health regulations require some coatings to be force cured with heating. In these cases, the materials are allowed to cure 16 to 24 hours at 21°C (70°F) before

force curing. The temperature and curing time will vary with the material used.

Rubber linings are cured (vulcanized) at 121 to 147°C (250 to 300°F) and at pressures of 345 kPa (50 psi).

Thick Barrier Linings

Rail cars previously coated, normally are exposed to a high bake (e.g., 202°C [400°F] prior to recoating). This bake cycle removes most contaminants and aids in coating removal. After the coating is removed, the substrate is inspected and abrasive blast cleaned as required.

Interior surfaces of some cars require special preparation; for example, a rail tank car previously used to transport molten sulfur is abrasive blast cleaned to NACE No. 1/SSPC-SP 5 white metal blast surface. The surfaces are then washed with a 3 to 5% solution of phosphoric acid, or a 3 to 5% solution of TSP (tri-sodium phosphate). The surfaces are washed with tap water allowed to rust bloom and dry overnight. The surface is then reblasted to NACE No. 1/SSPC-SP 5.

Inspection

The specification for coating/lining of new cars may require the coating inspector to:

- Check the interior of the car for any fabrication defects for correction and inspect those areas after correction and before cleaning
- Monitor solvent cleaning, steam cleaning, or high-pressure water washing
- Observe abrasive blast cleaning and check surface profile; this normally is 20 to 25% of the required DFT of the coating selected
- Measure surface profile with replica tape

- Check to see that all abrasive materials are removed and that no abrasive dust remains on the surface
- Monitor the stripe coating operation
- Observe coating operations
- Monitor force-cure operations (the inspector should closely monitor the rate of temperature increase, a process called *ramping*, and the intermediate and final bake temperatures)
- Check WFT and DFT as required
- Conduct holiday inspection as required

At appropriate intervals during the above operations, the inspector should take and record ambient conditions in the vicinity of the coating operations.

The inspector must carefully document each phase of the operation, since detailed and accurate inspection records are required by the Federal Railway Administration (FRA) (in the United States). These records remain with the owner of the lining and must be available on demand by the FRA or by the American Association of Railroads (AAR).



Level 2

Chapter 21

Maintenance Coatings

Operations

Maintenance Coatings Operations

Introduction

In this chapter, some of the important special conditions and items that may be encountered in maintenance coating inspection will be discussed.

For purposes of this discussion, maintenance coating operations are defined as:

- Applying coatings over a substrate that has been installed in its final environment and has been placed in service.

The maintenance operation may be for a substrate with an existing coating, or it could be the replacement of a section of the equipment or structure.

Often the structure or equipment to be recoated or repaired has been installed in a hostile environment and has been subjected to all types of contaminants, such as (but not limited to) oil, grease, chemicals, water, etc.

This discussion builds on material already covered, so a lot of time will not be spent restating practices already discussed.

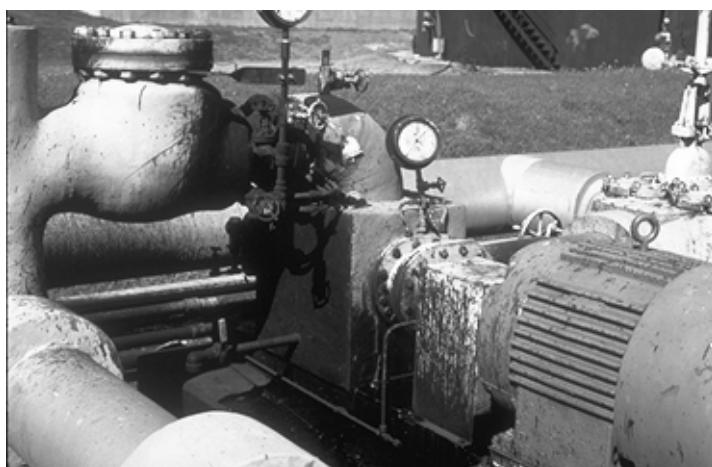


Figure 21.1: Typical Process Equipment to be Maintained

Reasons for Maintenance Coating

Generally, maintenance coating operations are performed to:

- Maintain a coating system so it will continue to provide the degree of protection originally intended
- Refresh the visual appearance of the coating system

Elements of Maintenance Coating Operation

A typical maintenance coating operation may range from a carefully programmed system of industrial maintenance to random hit-or-miss activities.

Good practice in maintenance coating operations follows the same general steps for coating new construction, namely:

- Coating selection
- Pre-job conference
- Pre-inspection of the structure to be coated
- Surface preparation
- Application
- Inspection and reporting

Coating Selection

Because of the many difficulties in maintenance coating situations, some additional constraints imposed on coating selection include:

- The coating chosen must be compatible with the existing coating system.

For example, if the existing coating is an alkyd, topcoating it with coatings containing hot solvents could degrade the alkyd unless a tie coat is used. There may not be enough time to add a tie coat or the additional cost of applying a tie coat may be prohibitive.

Often it is necessary to test the existing coating to determine its basic composition and a compatible topcoat. This could be done with a field-test kit or by more sophisticated instrumental analysis.

If the existing coating presents a hard, impervious surface, it may be necessary to use a solvent wipe to soften the surface, or abrasive-coated paper to roughen the surface. It may even be necessary, where allowed, to perform a light abrasive blast to create an anchor pattern to which the maintenance coating can adhere. The inspector should be diligent during the inspection of the light abrasive blasting (often referred to as brush-off), as blasting at too high a velocity, or the nozzle being held too close to the surface, could cause fracturing rather than just roughening of the existing coating.

Abrasive blasting may be prohibited in certain plant areas, or not be economically feasible. Surface preparation may be limited to hand or power tool cleaning. In this case, the owner may wish to select a coating that has good wetting properties or is formulated to be applied over a power tooled or hand cleaned surface.

The owner should check with the coating manufacturer regarding the appropriateness of the coating selected for use as a maintenance coating.

The coatings should be patch tested to determine their suitability for the specific service situation.

Pre-Job Conference

A pre-job conference to review and ensure a common understanding of the specification is a critical step in ensuring a successful coating job.

Specifications for maintenance coating operations may vary from job to job, depending on:

- The condition of the surface to be repaired, which may range from a perfectly intact coating system to a 100%-failed coating, and the surface is badly deteriorated
- Plant shutdown or inspection
- Effect on plant personnel in the area
- Budget constraints
- Use of in-house or contract labor
- Accessibility to area
- The result desired by the owner

Thus, a maintenance coating specification may call for anything from hand cleaning and spot recoating of failed areas to cleaning the entire surface to white metal and applying a total, new coating system.

As always, it is important that all parties involved have read and understand the coating specification, and also have a unified understanding of the intent of the specification and its expected results.

It also may be helpful for all parties to visit the job site to review points in the specification that may require judicious interpretation and common agreement, such as:

- Spot repair requirements
- Feathering
- Appearance of repaired areas

Pre-Inspection

Before any other work is performed, the surface should be inspected to locate and mark:

- Failed areas, including
 - Blistering
 - Loss of adhesion
 - Under-film corrosion
 - Chalking
- Areas that may have been contaminated by grease, chemical salts, dirt, or other substances

If the coating specification calls for spot repair, it is very important for the owner, contractor, and inspector to have a common understanding of the degree of failure that requires repair.

For example, if the specification calls for *spot repair of blistered areas*, does this mean that:

Every blister, no matter how small, regardless of location, be repaired?

or that

Any blister of a certain size or larger, or a cluster of some number of blisters in a certain area, be repaired?

A rather spirited discussion could result if the owner holds the former view and the contractor holds the latter.

Therefore, it is highly important that a common understanding of these points be clearly fixed in the minds of the owner's representative, contractor, and coating inspector.

Surface Preparation

Once the areas to be repaired have been located and marked, surface preparation operations may begin.

Many difficulties in obtaining the desired degree of surface cleanliness may be encountered, such as:

- Heavy build up of contaminants (grease, oil, dirt, chemical salts, corrosion products, etc.). These gross contaminants must be removed before final surface preparation by abrasive blasting or power tool cleaning may begin



Figure 21.2: Heavy Build Up of Contaminants

- Necessity of cleaning and coating while equipment is in service
 - Inability to remove the work piece to a clean and dry work area
 - Gauges, dial faces, and other sensitive equipment must be protected during the cleaning and coating operation

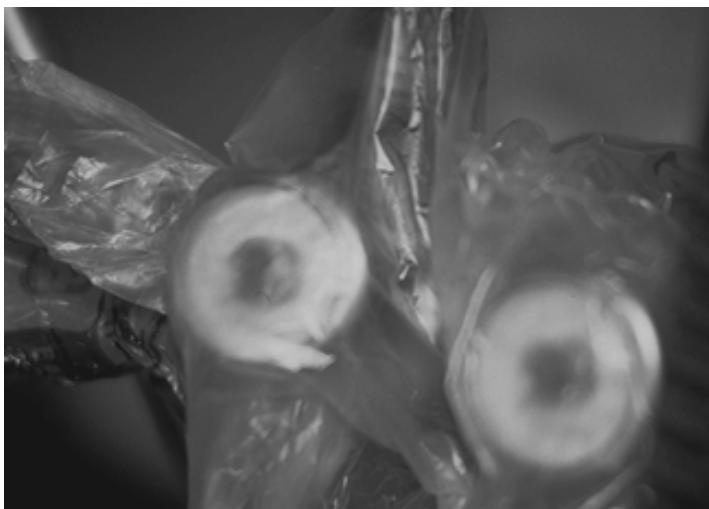


Figure 21.3: Protective Covers Over Dial Faces and Gauges

- Time constraints due to the need to perform cleaning and coating operations at the end of a turnaround or unit outage
- The extent to which the surface has deteriorated
- The type and thickness of coating currently on the surface

Generally, however, the same tools, equipment, and techniques used in surface preparation of new construction may be used in maintenance coating operations.

Solvent/emulsion cleaning and/or waterjetting or water blasting may be used to remove chalky, friable portions of the old coating system and grease, dirt, chemical salts, and other gross contaminants.

Hand or power tool cleaning and/or abrasive blasting may be used to open blisters, chip off cracked and peeling paint, remove tightly adhered mill scale, and provide an anchor pattern. One technique required in maintenance coating operations that is not generally encountered in new work is *feathering*.



Figure 21.4: Problem with Spot Blasting of Feathered Areas

Frequently, a maintenance coating specification will call for “spot” abrasive blast cleaning of areas with visible corrosion and light abrasion (feathering) of the adjacent coated areas.

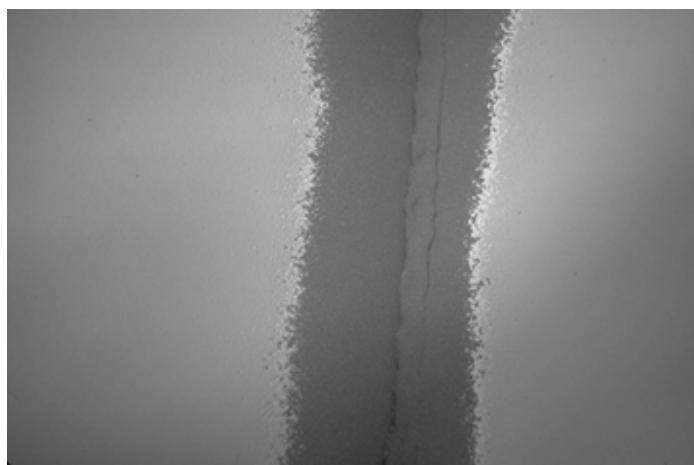


Figure 21.5: Abrasive Blast on Weld, Coating Feathered

This process of “spot” blast cleaning and feathering of the coating may damage the adjacent coating by causing unseen cracking of the coating, ultimately resulting in loss of adhesion, as illustrated by this slide.

Generally, if the applicator is to do spot blasting, he will use a straight-bore nozzle, rather than the typical venturi nozzle, in order to reduce the velocity of the abrasive and maintain better control of the blast pattern. He will also use reduced blast pressures to minimize the damaging effects of abrasive on the adjacent coating.

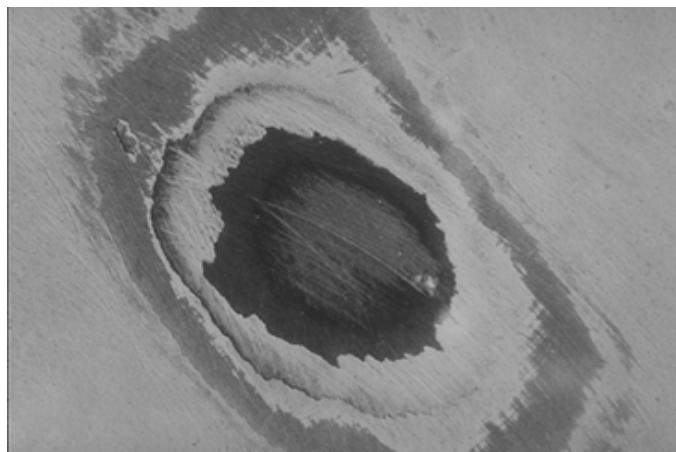


Figure 21.6: Spot Repair with Feathering of the Coating

Feathering is performed at the repaired area by working the edges of the repaired area back, so there is a fairly smooth transition from the repair area to the sound coating. Abrasive paper may be preferred for this so as to not fracture the adjacent coating.

Again, it can be very helpful if, during the pre-job conference, the owner’s representative, contractor, and inspector go to the job site where the contractor demonstrates his interpretation of how the feathering will be done.



Figure 21.7: Corner Cleaned, Feathered, Ready for Maintenance Coating

If this does not meet with the approval of the owner's representative, additional work should be done until an example is attained that is representative of the owner's and contractor's agreed-upon feathered repair. The coating inspector then refers to this example when evaluating repaired areas.

The coating to be applied may in some way be incompatible with part or all of the existing coating system. If so, *curling* may occur.

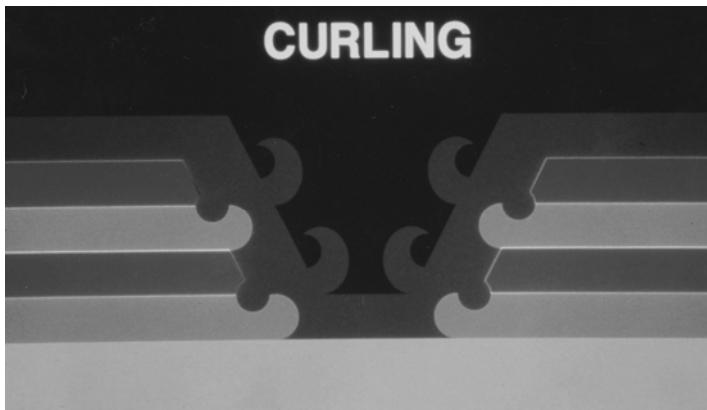


Figure 21.8: Spot Repair—Curling

Curling is the expansion, lifting, softening, or other deformation of the existing coating in reaction to the applied coating.

Hopefully, the specification will describe precisely what should be done to prevent or treat curling. If not, it may

be necessary for the owner's representative and the contractor to develop a procedure that meets the owner's approval.

Another area of maintenance coating surface preparation that requires sound judgment and a clear common understanding between the owner, contractor, and coating inspector involves standards of surface preparation cleanliness.

For example, the definitions of blast cleaning standards are the same, regardless of whether new work or maintenance work is being performed. The surface color of a maintenance surface that is abrasive blasted will vary according to the degree of rust.

The inspector should be familiar with SSPC-VIS 1 and VIS 3 pictorial standards, which are representations of different degrees of surface preparation performed on various steel surface conditions. These standards were thoroughly discussed in Level 1.

It may be extremely difficult to remove all traces of corrosion, etc., from severely pitted surfaces. Here again, it can be very helpful for the owner, contractor, and inspector to meet at the job site where the contractor prepares the surface to demonstrate his interpretation of the specified degree of surface preparation.

If this sample area does not meet the approval of the owner's representative, additional work should be done until an example is attained that is representative of an acceptable degree of surface preparation.

It should be kept in mind that certain factors, such as ambient conditions, may influence how long the surface will retain the desired standard appearance.

These factors include, but are not limited to, the same factors that may be encountered during new work coating operations, namely:

- Relative humidity

- Airborne contaminants
- Contaminants due to service

One additional factor which may be encountered in maintenance work is *permeation* of the steel by contaminants caused by the service conditions. Some service situations in which this may happen include, but are not necessarily limited to:

- Sour crude storage tanks
- Cooling towers
- Fertilizer plants

Evaluation of the surface at this point is essential.

Soluble chemical salts, sulfates, and chlorides of various descriptions actually permeate the steel and are not removed even by abrasive blast cleaning to bare metal. The surface then tends to *turn* much more quickly than it would otherwise.

With this condition, the owner may call tests to determine the presence of soluble chemical salts. This would be particularly useful in determining whether to use high-pressure waterjetting to remove the contamination prior to abrasive blast cleaning.

At any rate, once the surface has been prepared, it should be coated within the time period specified. If the surface turns from the specified condition, it may be unsuitable for application of the protective coating. In this case, it may be desirable for a conference between the contractor and the owner to determine the appropriate steps to proceed with the project.

Application

The general requirements of safety and workmanship for application and inspection and reporting are generally the same for maintenance coating as those for new work.

Inspection

The same general tools, techniques, and requirements for inspection apply in maintenance work as those in new work.

However, some variations in technique may prove useful.

To properly determine thickness of the newly applied coating using a nondestructive magnetic thickness gauge, it is necessary to:

- Take initial readings over the old coating after surface preparation has been performed.
- Take readings over the surface after the coating has been applied, taking care that these readings are taken in the same location as the first readings.
- Subtract the initial readings from the final readings to obtain an estimate of the thickness of the newly applied coating.

Another method to estimate the thickness of the newly applied coating is use of the wet-film gauge and performing WFT/DFT calculations as previously discussed.



Figure 21.9: WFT

- Adhesion tests (pull-off ASTM D 4541 and/or cross-hatch ASTM D 3359), if allowed, may be performed to determine the adhesive strength of the:

- Coating to be repaired to the substrate
- Bond between the new and old coatings



Figure 21.10: Pull-Off Adhesion Testing

Summary

While there are many similarities between maintenance and new coating work, some important additional considerations include:

- Coating selection
 - Compatible with existing coating (ASTM D 5064, Standard Practice for Conducting a Patch Test to Assess Coating Compatibility)
 - Patch testing may be desirable
- Surface preparation and application
 - Time constraints
 - Heavy contamination by service conditions
 - Feathering of spot repairs may be desirable
 - May have to work while facility is in operation

NACE technical committee reports that can be valuable to the owner, contractor, coating supplier, and the inspector include:

- 6H194, Combating Adhesion Problems When Applying New onto Existing Finish Coats of Paint
- 6H188, Coatings Over Non-Abrasive Cleaned Steel

SSPC: The Society for Protective Coatings has a publication devoted to maintenance paints.

- SSPC-PA 1, Part 10

NAME: _____ DATE: _____



CIP Level 2

PRACTICE PRACTICAL

STATION 1. PAINT INSPECTION GAUGE (Tooke Gauge)

Equipment:

- Tooke Gauge
- Test Panel

Activities

1. Show correct procedures for:
 - Turning instruments on/off
 - Checking/changing batteries
 - Setting focus adjustment
 - Checking/setting calibration for different tips/angles
 - Making cut with instruments
 - Viewing and evaluating cut made with instruments
2. After determining that the instrument is correctly calibrated, use the Tooke Gauge to evaluate the coating thickness of the sample panels provided. Record your evaluation of the coatings on the sample panels in the space below.

	Mils/Microns	
	Panel #1	Panel #2
1. Thickness of primer		
2. Thickness of intermediate coat		
3. Thickness of topcoat		
4. Total dry-film thickness		

NOTE: On the final practical examination, in addition using the instruments to evaluate coating thickness, there will be (8) questions that you will have to answer regarding use of the Tooke gauge.



STATION 2. COATING THICKNESS—MAGNETIC PULL-OFF GAUGE (TYPE I)

Equipment:

- Magnetic DFT (Pull-off) gauge
- Test panel
- Plastic calibration shims
- NIST calibration standard (range 0 to 1,000 μm [0 to 40 mils])

Assignment: Using the method defined by SSPC-PA 2, check your gauge to determine the DFT of the two coated areas of the panel in mils or μm and provide the four answers required.

	Mils	Microns
BMR		
PRIMER DFT		
Final (total) DFT		
Calibration standard used? Check only one.	NIST	Plastic Shims

Work areas for measurements and calculations are provided below. Adjusted readings must be marked in the table above.

SSPC-PA 2 Worksheets

1. Location: Primer Coat

mils / μm ?

Spots->	1	2	3	4	5	Overall Average DFT at this Location	Adjustments	
1							BMR	Deviation
2								
3						Before Adjustments	After Adjustments	
Avg.								

2. Location: Primer Coat + Finish Coat

mils / μm ?

Spots->	1	2	3	4	5	Overall Average DFT at this Location	Adjustments	
1							BMR	Deviation
2								
3						Before Adjustments	After Adjustments	
Avg.								

Spots->	1	2	3	4	5
BMR					
Average Value =					



STATION 3. PULL-OFF ADHESION TEST

Equipment:

- Elcometer 106 Adhesion Tester
- Aluminum Dollies (2)
- Photos of Dollies Pulled From Coated Surface (4) Numbered 1 through 4

Activities

1. Show correct procedures for:

- Pull-off adhesion test
- Cross hatch adhesion test
 - With cross hatch cutter
 - With knife
 - X-Cut adhesion test

2. Perform these tests on the sample panels provided and record your observations in the spaces below. Location of failure may be described using the key below:

A = Substrate
B = First Coat
C = Second Coat
D = Third Coat (etc.)
Y = Adhesive
Z = Dolly

Test	Panel:	Panel:
Cross hatch (with cutter)		
Cross hatch (with knife)		
X-cut		

PULL-OFF ADHESION TEST RESULTS

Location of Test	Test Type	Value (psi)	Adhesion % Failure	Cohesion % Failure	Glue % Failure	Location of Failure
Test Panel #1	Elc. 106					
Test Panel #2	Elc 106					

Note: On the final practical examination, you will evaluate photographs for failure and report the results and answer questions about the pull-off adhesion test.



STATION 4. COATING THICKNESS—ELECTROMAGNETIC GAUGE (TYPE II)

Equipment:

- Type II DFT Gauge (Positector 6000 F)
- Test panel E4
- NIST Calibration Standards (range 0 to 1,000 μm [0 to 40 mils])
- Plastic Shims

Assignment: Using the method defined by SSPC-PA 2, check your gauge to determine the DFT of the two coated areas of the panel in mils or μm and provide the four answers required.

	Mils	Microns
BMR		
PRIMER DFT		
Final (total) DFT		
Calibration standard used? Check only one.	NIST	Plastic Shims

Work areas for measurements and calculations are provided below. Adjusted readings must be marked in the table above.

SSPC-PA 2 Worksheets

1. Location: Primer Coat

mils / μm ?

Spots->	1	2	3	4	5	Overall Average DFT at this Location	Adjustments	
1							BMR	Deviation
2								
3							Before Adjustments	
Avg.						After Adjustments		

2. Location: Primer Coat + Finish Coat

mils / μm ?

Spots->	1	2	3	4	5	Overall Average DFT at this Location	Adjustments	
1							BMR	Deviation
2								
3							Before Adjustments	
Avg.						After Adjustments		

Spots->	1	2	3	4	5
BMR					
Average Value =					



Coating Inspector Program Level 2 Practice Practical

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STATION 5. BARCOL HARDNESS TEST

Equipment

- Barcol Hardness Tester Model No. 934
- 2 Aluminum Discs (1 No. 87 and 1 No. 89)
- Pencils

Activities

1. Show correct procedures for:
 - Pencil Hardness Test
 - Shaping pencil lead to smooth cylinder
 - Pushing pencil across surface
 - Interpreting results
 - Impressor Hardness Test
 - Changing point
 - Using instrument
 - Interpreting results
2. Evaluate the coated sample panels provided by means of both the pencil hardness and impressor hardness tests and record your observations in the space provided below.

	Panel:	Panel:
Pencil Hardness		
Impressor Hardness		

3. Evaluate the unknown test panels by means of the impressor hardness test only and record your observations in the space provided below.

PANEL NUMBER	HARDNESS	CREEP OBSERVED	
		YES	NO
1			
2			
3			
4			
5			
6			
7			
8			

Note: On the final practical examination, you will determine hardness using the Barcol Hardness tester and results and answer questions about the Barcol Hardness test.



STATION 6. COATING THICKNESS—EDDY-CURRENT DFT GAUGE

Equipment

- Eddy Current DFT Gauge (DeFelsko Positector No. 6000 N-1)
- Aluminum panel (1/3 bare metal) (1/3 Primer Only) (1/3 Prime & Topcoat)
- Package of Plastic Shims
- NIST Blocks
- Anvil Spring Micrometer

Calibrate the gauge and measure the thickness of the primer, then the thickness of the primer plus the topcoat on the panel provided. Record your answers in mils or microns.

	Mils	Microns
BMR (if required)		
Primer DFT		
Final (total) DFT		
Calibration Standard Used? Check one.	<input type="checkbox"/> NIST <input type="checkbox"/> Plastic Shims	

Work areas for measurements and calculation is provided below. Completion of the SSPC worksheet is mandatory. ON THE FINAL PRACTICAL EXAMINATION NO POINTS WILL BE AWARDED BELOW IF THE WORKSHEETS ARE NOT COMPLETED.

SSPC-PA 2 Worksheets

1. Location:

mils / microns?

Spots->	1	2	3	4	5	Overall Average DFT at this Location
1						
2						
3						
Avg.						

2. Location:

mils / microns?

Spots->	1	2	3	4	5	Overall Average DFT at this Location
1						
2						
3						
Avg.						



STATION 7. SOLUBLE SALTS TESTS

Equipment

- Potassium Ferricyanide Test Papers
- Chlorid CSN Kit
- Sleeve Test Kit
- Bresle Test Patch
- Set of Swab Test Materials
 - Graduated Cylinder
 - Beaker
 - DI Water
 - Pharmaceutical Grade Cotton Balls
 - Quantab strips
 - 6 x 6 panel (1 of the panels used in Level 2 class)
 - Swizzle Stick

Perform qualitative and semi-quantitative tests for soluble ferrous salts on the sample panel provided.

Test	Results
Qualitative	
Semi-Quantitative	

Note: On the final practical examination, you will answer questions about the following soluble salts tests:

- Potassium Ferricyanide
- Swab Test
- CSN Kit
- Sleeve Test
- Bresle Test



STATION 8. NACE VIS 7/SSPC-VIS 4

Equipment

- NACE VIS 7/SSPC-VIS 4, Guide Reference Photographs for Steel Surfaces Prepared by Waterjetting

Assignment

Using NACE VIS 7/SSPC-VIS 4 and the information provided in NACE No. 5/SSPC-SP 12 Waterjetting Standard, answer the questions in the table below.

	Answer (Record your answers in this column)
1. According to NACE No. 5/SSPC-SP 12 Waterjetting Standard, a steel surface cleaned to WJ-1 allows _____% of visible rust to be left on the surface.	
2. According to NACE No. 5/SSPC-SP 12 Waterjetting Standard, a steel surface cleaned to WJ-3 allows _____% of randomly dispersed stains of rust to be left on the surface.	
3. According to NACE No. 5/SSPC-SP 12 Waterjetting Standard, a steel surface cleaned to WJ-2 allows _____% of tightly adherent thin coatings to be left on the surface.	
4. According to NACE No. 5/SSPC-SP 12 Waterjetting Standard, a steel surface cleaned by waterjetting to NV-2 requires that less than _____ $\mu\text{g}/\text{cm}^2$ of chloride contaminants be left on the surface.	
5. According to NACE No. 5/SSPC-SP 12 Waterjetting Standard, a steel surface cleaned by waterjetting to NV-3 requires that less than _____ $\mu\text{g}/\text{cm}^2$ of chloride or sulfate contaminants be left on the surface.	





Level 2

Chapter 23

Self-Study Questions

Chapter 16—Linings and Special Coatings

1. A resistant _____ is a film of material applied to the _____ of _____, _____, conveyor lines, _____, process equipment, or other surfaces which is subject to _____, _____, _____, _____, _____, or _____, but is not necessarily subject to _____ in any _____ or _____.
2. A resistant _____ is a film of material applied to the _____ of _____, _____, _____, or _____ and is subject to _____ and _____ in _____, _____, or _____.
3. In the case of a _____, preventing _____ may be its _____ function.
4. The term _____, or sometimes _____, is used to describe a system made up of several _____ of _____ saturated with certain _____.
5. Gel coats for _____ and _____ usually contain a small amount of _____ that _____ to the _____ during _____. This _____ helps prevent _____ from _____ the _____ of the resins.
6. Specifications for the _____ may require the application of _____ and proper _____ of _____.
7. Since _____ take place in _____, _____ is extremely _____.
8. Powder coatings essentially are similar to _____ in their _____. Common formulations include _____, _____, _____, etc.
9. Powders fall into two broad categories:
 - _____: materials that _____ when _____ and retain their original _____ when _____.
 - _____: materials that _____ when _____ and retain their _____ when _____.

10. Powders applied to a heat source pass through ____ stages:
- _____
 - _____
 - _____
 - _____
11. The complete process from _____ to cure generally takes ____ than ____ minutes.
12. Powders are applied by one of the following methods:
- ____ spray
 - _____ spray
 - _____, dip method
 - ____-lining
 - ____ spray
 - ____ chamber

Chapter 17—Special Application Equipment

- ____ spraying is the automatic _____, _____ and _____ of _____ (usually two) _____ coatings such as polyesters, epoxies and urethanes.
- The major advantage of using plural-component spray systems is with materials such as the _____, which have a very short ____ life (usually less than _____) and cannot be mixed in an _____ prior to application.
- Plural-component spray equipment is either:
 - A ____-____ type, or
 - A ____-____ type

4. Most variable ratio units are equipped with a _____ that delivers _____ to _____ the mixing and delivery end of the system.
5. Plural-component spray guns are available for either _____ air spray or _____ applications.
6. In a _____ system, the coating components are drawn from their containers, brought together in a _____, mixed, and then delivered to the spray gun or spray head for spraying.
7. Static in-line mixers work by cutting the _____ in _____ and turning it _____.
8. _____ coatings formulated for _____ application also allows higher _____ and higher _____ materials to be sprayed more efficiently, permitting _____ coats of material to be applied without _____ or _____.
9. When _____ are used, the coating must not be _____ to a _____ than allowed by the specification or recommended by the manufacturer
10. The major disadvantage of heated spray is that the _____ may be _____ by _____.
11. In electrostatic spray operations a rather high charge (to _____ for _____ guns; to _____ for some _____ setups) is applied to the _____ as they pass _____ from the spray gun.
12. Centrifugal spray equipment uses a _____ disc, _____, or other device to _____ the coating.
13. In the _____ process, _____ mixtures of _____ are pre-dampened when they are first introduced into the system at the _____, and as they are propelled through the hose, a _____ (usually _____) is added to the dampened powder at the _____.
14. _____ spray systems use a high volume of _____ delivered at _____ psi (69 kPa) or less to atomize a fluid coating into a soft _____ pattern.
15. Air assisted _____ technology _____ the best features of _____ and _____ to create a new _____ capability.

Chapter 18—Concrete and Inspection

1. Concrete in itself is considered a _____ and is sometimes _____ to _____.
2. Concrete is _____. It is essentially a ___. It doesn't __ in the common sense of the term.
3. Concrete is formed by mixing _____, _____, and _____.
4. When _____ is added to the _____/_____ mixture, a process called _____ takes place. The _____ and the _____ combine _____, and the concrete _____ and _____.
5. Concrete has good _____ strength.
6. Concrete can _____ with age.
7. The pH of concrete may be as high as ____.
8. At least _____ have been identified as _____ in concrete as it _____.
9. In general, _____ concrete should be _____ for a _____ of _____ at temperatures above ____ (21°C) before _____, to help ensure that it has the desired surface __, _____, and _____, and for _____ of _____ water from the surface.
10. Finishing operations:
____ smoothes the surface. _____ is a procedure using a _____ trowel to smooth the poured concrete. _____ is the use of a stiff bristle _____ to provide a _____ surface to the concrete.
11. Laitance is a _____ of water-rich _____ on the surface of fresh concrete caused by the _____ of _____.
12. Efflorescence is caused by _____ passing _____ the concrete and carrying _____ concrete _____ with it to the surface. The salts _____ with _____ in the _____ creating a _____ deposit on the surface.

13. Sacking consists of _____ a mixture of _____ over the concrete surface using a _____ sack.
14. Stoning is similar to sacking, except that a _____ or other appropriate _____ is used to smooth the surface of the concrete.
15. Poured concrete may be affected by:
 - a. _____ conditions
 - b. _____
 - c. _____ operations
16. Abrasive blast cleaning concrete will provide a _____, _____ surface and will remove _____.
17. Many _____ and _____ tool techniques are used for _____ of concrete surfaces, and they _____ are _____ and _____.
18. When abrasive blast cleaning concrete:
 - a. The _____ is held _____ from the surface
 - b. _____ pressure is used
 - c. The nozzle is _____ across the surface _____
 - d. A _____ is used.
19. Acid etching is used on concrete to _____ and _____ the surface.
20. A _____ gauge may be used to verify coating DFT on concrete.

Chapter 19—Special Substrates

1. Some special metal substrates include:
 - a. _____
 - b. _____
 - c. _____

2. Other special substrates may include:
- _____
 - _____ (plastics)
3. Many metals and alloys _____ with the _____ to produce an _____.
4. Generally, the protective oxide films of _____, _____, _____, and _____ are tough and adherent.
5. One primer that may be used on these oxide films is a _____.
6. Aluminum may develop a _____ oxide film that exhibits _____ to the substrate.
7. Copper and copper alloys may be prepared by _____ and _____, followed by _____ with _____ or _____ abrasive coated paper.
8. Galvanized zinc surfaces react with the _____ and _____ in the atmosphere to form a _____ film of _____, zinc _____, and zinc _____.
9. Wood may be coated for the following reasons:
- _____
 - _____
 - _____
 - _____
 - _____
 - _____
10. The _____ general _____ for _____ and _____ apply to the _____ as well.

Chapter 20—Thick Barrier Linings

1. Brick and tile can be formulated to be _____ and/or _____ resistant.
2. Generally, a _____ is used when installing chemical-resistant brick. The membrane is installed on the _____ and is between the brick and the substrate.
3. Acid-cure _____ resin mortars are often used as a mortar and setting compound for brick flooring.
4. Acid-cure furan materials do not bond well to _____.
5. Some disadvantages of furans include:
 - a. Low _____ to non porous surfaces such as steel
 - b. _____
 - c. _____.
6. Usually some type of _____ is used to bond furan to steel.
7. The maximum pH for many of these products is pH _____ and they may become puddles of sand in just a few days if the pH goes above pH _____.
8. A _____ is usually used to seal a laminate (sometimes called laminant).
9. Generally _____ is used on vinyl ester and polyester gel coats. The wax floats on the surface and prevents _____ from retarding the cure of the resin.
10. _____ under pressure produces the highest rubber-to-metal adhesion.
11. Repairs to rubber are generally made by the _____ method.
12. Natural rubber can be:
 - a. _____
 - b. _____
 - c. Semi-_____.

13. Soft rubbers have:

- a. Good _____ resistance
- b. Excellent _____ resistance
- c. Temperature resistance to _____ F

Chapter 21—Maintenance Coatings

1. Maintenance coating operations involve applying coatings over a substrate that has been installed in its final environment and has been _____ in _____.
2. Maintenance coating operations are performed to:
 - a. Maintain a coating system so that it can continue to provide the _____ of _____ originally intended.
 - b. _____ visual appearance of the coating system.
3. The maintenance coating selected must be _____ with the existing coating.
4. In selecting coatings for maintenance:
 - a. It may be desirable to make a _____
 - b. _____ or _____ of the existing coating may be necessary
 - c. The coating may have to be applied over a _____ prepared surface.
5. Specifications for a maintenance coating operation may depend on:
 - a. _____ of surface to be repaired
 - b. Effect on plant _____
 - c. _____ to area
 - d. Plant _____
 - e. _____ desired by the owner.

6. All parties involved should visit the job site to review areas of the _____ that may require _____ and common agreement.
7. The surface to be maintained should first be inspected to locate and mark:
 - a. _____ areas
 - b. _____ due to oil, grease, and to chemical salts.
8. One technique used in maintenance coating but not generally used in new work is _____ of the coating.
9. If the new coating is not compatible with the old coating, _____ may occur.
10. Some chemical salts seem to _____ the steel surface and are not totally removed by abrasive blast cleaning.



Level 2

Chapter 24

Pipeline Coatings

Pipeline Coatings

Introduction

Pipelines of all types, sizes, and lengths—buried, submerged, or aboveground—can be found on each continent and in every country in the world.



Figure 24.1: Pipeline Before Being Buried



Figure 24.2: Pipeline Submerged



Figure 24.3: Pipeline Aboveground

This vast network of piping, estimated at over eight million kilometers (five million miles), is used to transport or convey the following materials:

- Crude oil
- Refined petroleum products
- Petrochemicals
- Slurries—coal, clays, wood chips, mine tailings, etc.
- Domestic and industrial wastes and treated effluents
- Water
 - Raw (untreated)
 - Domestic (potable)
 - Storm/rain (run-off)
 - Re-circulating (petrochemical and power-generating plants)

There are several areas of concern, such as corrosion, which are common to all facets of the pipeline industry.

Topics to be explored in this chapter include:

- Various terrains and environments
- Materials of pipeline construction
- Criteria for protection of pipelines
- Pipe linings
- Generic types of pipeline coatings
- Desirable properties of a good pipeline coating
- Methods of coating application
 - Mainline coating: A mainline coating is defined as the total coating on the body of the pipe, less any field-joint coating in a stationary coatings facility
 - Mainline coating in the field
- Field-joint coating
- Protecting pipeline coatings
- Inspection issues for specific materials and different application procedures

Pipeline Terrain

Pipelines may be:

- Buried in various types of soils
- Submerged in lakes, rivers, or waters offshore
- Laid in marshes or swampland
- Installed aboveground on supports or directly on top of the ground



Figure 24.4: Various Pipelines

Each location, type of terrain, and soil structure influences the materials of construction and the corrosion prevention mechanisms.

The selection of a generic coating for pipelines, its method of application, and its treatment in the field are likely to vary according to the region of the world and its terrain.

Materials of Construction

The selection of materials of construction for pipelines is generally governed by the in-service or operating conditions. Some of these materials of construction are:

- Carbon steel (mild steel)
- Glass-reinforced pipe
- Ductile iron
- Concrete
 - Pre-stressed
 - Steel cylinder
 - Asbestos cement (AC)

- Plastics
 - Polyvinyl chloride (PVC)
 - Polyethylene (PE) or polypropylene (PP)
- Alloy steel (stainless steel, titanium, Monel™, and Carpenter 20™ steel)

Carbon Steel

Carbon steel is probably the most widely used material of construction for pipe and is the natural choice for use with crude oil, natural gas, refined petroleum products, and, in many cases, for process slurry lines, raw water lines, and re-circulating water pipes in power plants.

Wall thickness may vary from 6 mm (0.25 in.) to over 25 mm (1 in.) for high-pressure gas service or for submerged service in deep offshore waters. Here, the extra weight of the heavy-wall pipe provides some measure of the negative buoyancy necessary to keep the pipe on the ocean floor.

Typical diameters for steel pipelines in various services are:

- Natural gas, to 1.42 m (56 in.)
- Crude oil, to 1.37 m (54 in.)
- Raw water, to 2.44 m (96 in.)
- Re-circulating water, to 4.3 m (168 in.)

Carbon steel pipe is fabricated by welding steel plate together by one of the following methods:

- Longitudinally with a butt weld
- Spirally with a butt weld
- Longitudinally with a lap weld



Figure 24.5: Pipe Joined by Bolted Flanges



Figure 24.6: Pipe Joined by Dresser™ Coupling



Figure 24.7: Large-Diameter Pipe Fabricated in a Bell-and-Spigot Arrangement

In most cases, the pipe is joined in the field by welding. In some instances, where special access is anticipated or surrounding construction makes it necessary, the pipe may be joined using flanges or mechanical couplings.

Some large-diameter water lines, made by spiral welding, have one end flared and the opposite end straight. These lines normally are lined with a protective coating that extends to each end of the pipe. The pipe then becomes a bell-and-spigot type and is installed in that manner with appropriate gaskets to provide a mechanical seal against fluid leakage.

The bell-and-spigot configuration allows flexibility at the joint and is not rigid like welded pipe, so the pipe can be installed to conform to its terrain without bending the body of the pipe. The coated ends join together to provide complete protection to the interior pipe.

Glass-Reinforced Plastic (GRP)

The overall chemical and abrasion resistance of glass-reinforced plastic (GRP) makes this an ideal material for pipe used to transport chemicals, acids, alkalis, and chemical wastes, and for use in and around petrochemical complexes. This type of pipe can vary in wall thickness from 9 to 50 mm (0.38 to 2 in.) and in diameters from 10 cm to 2.1 m (4 to 84 in.). Generally, GRP pipe is operated

at gravity flow or at low-fluid pressures, and at temperatures ranging from ambient to 121°C (250°F).

The sections of GRP piping are pre-cast, and the chemically resistant resins used in the manufacturing process provide not only the corrosion resistance, but also good mechanical strength.

Generally, the lengths of pipe are joined by chemical fusion using resins and/or by mechanical coupling devices such as bolted flanges. Larger-diameter pipe may be fabricated into a bell-and-spigot configuration—a bell on one end and a spigot on the other. The bell end is flared or rounded out to form an annular space larger in diameter than the spigot end, which is straight and the same diameter as the main portion of the pipe.

In the field, the smooth spigot is fitted with a rubber O-ring around its circumference, just off its terminus, and this end is forced into the annulus of the bell end. The O-ring fills this annular space, providing a tight seal against fluid leakage.

The coating inspector on a GRP project may be required to check the pipe for any mechanical flaws or defects, such as chipped ends, cracks in the pipe, etc., and may be required to observe mixing and application of resins used for pipe joining.

Ductile Iron

Ductile iron is used to transport water and/or sewage. Pipe diameters range up to 1.96 m (64 in.) with wall thickness from 13 to 38 mm (0.5 to 1.5 in.).

These materials are not weldable and are joined in the field with some type of mechanical coupler, such as a Victaulic™ coupling, a Dresser™ coupling, or a bell-and-spigot arrangement with rubber seal (usually some type of O-ring). Operating pressures range up to 2.41 MPa (350 psi).

Such coatings as coal-tar epoxy, coal-tar and asphalt cutbacks, and some epoxy materials may be used on the exterior of ductile iron (cast iron pipe). The primer coat should be followed by an appropriate topcoat.

In the United States, many users of ductile iron follow guidelines of the Ductile Iron Institute, which recommends that pipe for use in corrosive soils be encased in a loose-fitting sleeve of polyethylene. Polyethylene film is formed into a “sleeve” or “sock” about twice the pipe diameter and about 61 cm (2 ft) longer than the length of a joint of the pipe.

The prefabricated sleeve then is fitted over a pipe section. After joining the pipe in the field, this loose-fitting plastic sleeve is extended over the ends of the pipe so that by the time the pipe is laid in the open ditch and the ditch is backfilled, all bare areas of the ductile iron pipe are fully encased in the loose polyethylene sleeve. The polyethylene sleeve is sleeved by a wrap of tape or string every 60 to 90 cm (2 to 3 ft) along its length.

Because the plastic sleeve is loose around the pipe, it will be able to shift with the soil when the backfill moves due to moisture reversals, and it will not be dislodged from the pipe. Straight sections of ductile iron pipe also can be coated with a spiral wrap of a plastic tape, usually polyethylene, over a primed surface. Plastic tapes and inspection issues will be discussed later.

Concrete

- Asbestos cement (AC) pipe: Asbestos cement pipe consists of a combination of high-grade Portland cement fortified with appropriate asbestos fibers. The resulting pipe is very dense with a very smooth interior surface that permits good fluid flow through the pipe.

Notwithstanding the current regulations regarding asbestos removal from many structures, AC pipe has been approved in the United States for the transportation and distribution of domestic (potable) water.

- Pre-stressed concrete: Concrete is applied to a section of rotating thin-wall steel pipe, and as it rotates, steel wire under controlled tension is spirally wrapped tightly (embedded) into the concrete, which produces pipe of high unit strength. Additional concrete is used to encapsulate the wire in the concrete. The pipe is then cured in a steam kiln. Pre-stressed pipe diameters range to 1.2 m (48 in.), with typical wall thickness of 38 to 76 cm (1.5 to 3 in.).
- Steel-cylinder concrete pipe: Steel pipe sections of adequate thickness are lined and coated with a rich mixture of concrete to the desired thickness, which is related to the pipe diameter. The concrete can be air cured or cured in a steam kiln.

Pipe diameters usually vary from 41 cm to 3.66 m (16 to 144 in.). In the United States, a recent water “siphon” project in the mountains near Phoenix, Arizona, required the use of steel-cylinder pipe. Each section measured 7.3 m (24 ft) in diameter, some 15 m (50 ft) in length, and had a wall thickness of 46 cm (18 in.).

This pipe was constructed and allowed to cure in the field near the mountains at Phoenix, Arizona, and immediately transported by special machinery to the pipeline site to be buried.

Both pre-stressed and steel-cylinder pipe are used to transport water (untreated and treated), domestic and industrial wastes, and treated effluents. Concrete pipe used in collecting and transporting these wastes frequently is coated to provide chemical and/or corrosion resistance to the products being carried.

In service, the wastes being transported give off wet hydrogen sulfide gas, which collects in the top of the pipe interior, the vapor space.

This gas, along with certain bacteria, reacts with the concrete in this vapor space, progressively deteriorating the top interior of the pipe. It is this area that requires an adequate and durable protective coating. Concrete pipe, which may have a low flow of sewage or in which a



septic condition occurs, will be subject to attack by this collection of hydrogen sulfide gas in the vapor space.

Coal-tar epoxy commonly is used to coat the upper interior of pipe in this type of service. Due to concerns that coal-tar epoxy is a carcinogen many users have switched to 100%-solids elastomeric polyurethane and 100%-solids epoxy novalac resin-based coatings for this service.

Inspecting Concrete Pipe

In the coating operations for concrete pipe, the coating inspector may encounter inspection issues similar to those found in coating steel, and may be required to:

- Inspect the pipe prior to cleaning to ensure that it is dry, free of all visible contaminants, such as oil, grease, dirt, and other foreign matter, and that it is ready to accept coating
- Monitor the mixing and thinning of the coatings being used
- Observe application and check the WFT of the coating
- Observe the required recoat intervals
- Inspect to see that the coating has cured prior to pipe installation
- Conduct holiday inspection of the cured coating and monitor coating repairs, where needed
- Document, at appropriate points, each of the above activities

Plastic

Plastic pipe is used widely in the pipeline industry to convey natural gas, water wastes, and chemicals. Depending on the anticipated service and operating



conditions, polyethylene (PE), polypropylene (PP), or polyvinyl chloride (PVC) pipe may be used. This pipe is produced from materials having a low, medium, or high density, and a low or high molecular weight, depending upon the flexibility and ductility requirements.

For the transportation and distribution of natural gas, a medium density PE, pigmented yellow, is used. Pipe diameter ranges from 5 to 30 cm (2 to 12 in.) with maximum operating pressures of 690 kPa (100 psi).

This pipe is joined by heat fusing into a butt weld. The heat-fusion process and operating pressures, both must comply with government regulations.

In transporting water and wastes, high-density PE pipe, pigmented black, is used. Maximum pipe diameters can range to 137 cm (54 in.) with maximum operating pressures of 1,841 kPa (267 psi), again according to government standards.

In sizing pipe, certain standards regarding the ratio of pipe wall thickness to pipe diameter must be met. For example: An 20-cm (8-in.) diameter pipeline may require a wall thickness of 18 to 26 mm (0.784 to 1.039 in.), while a 30-cm (12-in.) diameter line may require a wall thickness from 24 to 39 mm (0.977 to 1.55 in.).

Generally, this larger-diameter heavy-wall pipe is joined by heat fusing to a butt weld, but it may be fitted with flanges to match ductile iron. In some instances, the pipe may be joined by a mechanical coupling such as a Victaulic™ or Dresser™ coupling, or it may be joined by the bell-and-spigot method. The pipe is constructed with one end flared and the opposite end straight. The bell end is filled with a gasket and the straight end is inserted into the gasketed end. This configuration allows the pipe to be installed, on grade, with minor deflection to follow the terrain.

Alloy Steels

Special alloy steels generally are limited to use in the oil industry or petrochemical plants for the transportation of corrosive liquids or special fluids. Because of their high cost, they generally are not used in transporting the commodities previously listed.

Criteria for the Protection of Pipelines

In 1964, the NACE International Technical Committee T-2 (now Specific Technology Group 35) on pipeline corrosion adopted basic criteria for the protection of pipelines as follows:

Pipeline protection shall consist of:

- An adequate protective coating, and
- Supplementary cathodic protection

These basic criteria became the foundation for NACE Standard SP0169, in 1969, which was later adopted in 1971 by the United States Department of Pipeline Safety (now the Department of Transportation) as the basis for regulations governing protection of pipelines against corrosion.

The primary purpose for pipe coating is to separate the pipe's base material from its environment. However, even today's most sophisticated coatings don't provide absolute barriers to moisture and electric (corrosion-inducing) current.

It is necessary to prevent the access of moisture because moisture is the electrolyte in the corrosion cell. High resistance to electric current is important because maintaining an electric potential constitutes cathodic protection, which is the secondary line of defense against corrosion.

Some coatings readily allow the passage of current, in which case more electrical energy will be needed to



maintain the potential necessary for protection. Most modern-day coatings bond well to the pipe and resist the passage of electric current. These coatings provide 99% of the protection needs of a buried pipe and the remaining 1% comes from cathodic protection. In time the coatings deteriorate and the need for cathodic protection becomes greater.

In addition to their use for corrosion control, pipe coatings are used to:

- Comply with government regulations (in the United States, Department of Transportation regulations)
- Enhance safety
- Reduce cathodic protection costs
- Reduce maintenance and replacement costs
- Provide resistance to soil bacteria and soil chemicals

Pipe Linings

As previously stated, pipelines are used to transport a variety of products ranging from water to slurries to solids. If the materials being transported are corrosive, then the pipe interior surfaces must be protected from the corrosive medium; and if the materials are abrasive, then the pipe interior must have good abrasion resistance.

When foodstuffs or chemicals which must retain a specified level of purity are being transported through a pipeline, the linings used must protect the pipe surface from that product. At the same time, the coating must not contaminate or discolor the product being carried.

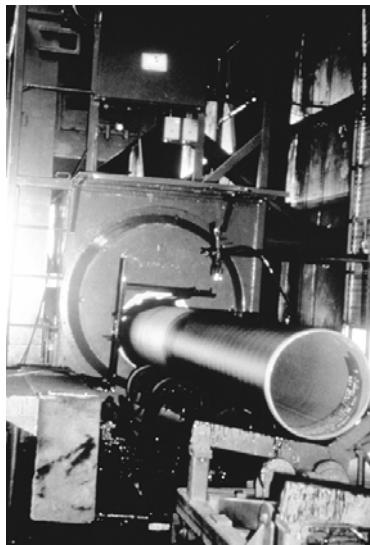


Figure 24.8: Machine-Applied Coal-Tar Enamel

The cost of transporting products by pipelines can be significant because the lift stations, compressor stations, and related pumping facilities consume large amounts of energy and require routine maintenance.

One way to reduce some of this energy consumption is to improve the flow rates in pipelines by applying a lining with a low coefficient of friction. This allows the product to move more freely through the line and thus reduce pumping costs.



Figure 24.9: Applying Coal-Tar Epoxy in 366-cm (144-in.) Water Re-Circulating Pipe

Injection Inhibitors

Another method of controlling corrosion in pipelines is by the use of inhibitors that are fed continuously into the product stream. The inhibitor “plates” out on the bare pipe and prevents the product being transported from contacting the pipe. Generally, inhibitors are used alone and the pipe is unlined.

Types of Pipe Coatings

There are several generic pipe coatings on today's market. Following is a list of commonly used pipe coatings and the approximate date each was first commercially available in the United States:

Coal-tar enamel narrow range (un-plasticized)	1920
Asphalt mastic	1923
Fabric-reinforced petrolatum tape	1927
Coal-tar enamel wide range (plasticized)	1941
Fabric-reinforced coal-tar pitch tape	1943
Epoxy	1948
Polyethylene tape wrap	1952
Cross-head extruded polyethylene	1956
Coal-tar epoxy	1957
Fusion-bonded epoxy (FBE)	1961
Hard adhesive-bonded extruded polyethylene	1965
Coal-tar urethane	1970
Side-extruded polyethylene	1973
Co-extruded polyethylene tape	1979

Desirable Properties of a Pipe Coating

The selection of a pipe coating may depend on such considerations as:

- Anticipated in-service conditions
- The user's previous experience with pipe coatings
- Budget constraints
- Anticipated climatic conditions at the time of installation

A good pipe coating should:

- Exhibit a strong, durable bond to the pipe
- Be waterproof, highly resistant to moisture penetration and absorption
- Have good mechanical strength, be resistant to handling and soil stress
- Have good dielectric strength
- Resist cathodic disbondment
- Be resistant to soil bacteria and soil chemicals
- Be economical over the life of the job
- Resist physical and chemical changes over the design life of the pipeline
- Durable bond to the pipe

One of the most important attributes of a good pipe coating is the durability of its bond to the pipe surface. A well-bonded coating will prevent creep under film and will resist cathodic disbondment. Pipe coatings such as coal-tar epoxy, hot-applied coal-tar enamel, and fusion-bonded epoxy (FBE) exhibit a strong durable bond to the pipe.

- Moisture resistance

Coated pipelines frequently are submerged offshore; they may be partially or totally immersed in lakes, rivers, or swamplands, or they may be buried in wet soil. The coating, in order to isolate the pipe from water, must be resistant to moisture absorption and moisture migration through the coating. A pipe coating that exhibits both a high resistance to moisture and a durable bond generally will be a long-lasting coating and well suited as a pipe coating. Coal-tar enamel, coal-tar epoxy, and some polyethylene tapes are very resistant to moisture.

- Mechanical strength

Currently, most pipe coating is done in a stationary coatings plant, and because the coated pipe is handled at least twice after coating and before installation, the coating must be able to resist mechanical damage from the handling operations.

Once installed, the pipe coating must be able to resist soil stress, which results from movement of soils due to settling and the alternate wetting and drying of soils. As rains fall, the wetted soil has a tendency to expand and press against the coating. Often this stress can dislodge portions of the coating, especially softer thermoplastic materials.

In some instances, the soil sticks to the coating or to its bonded outer wrap. When the soil dries it shrinks, and any portion of the soil that has bonded to the coating may pull sections of the coating away from the pipe.

In areas of known high soil stress, the user may apply an extra layer of an outer wrap to provide additional mechanical strength to the coating and to provide better resistance to the soil stress.

- Dielectric strength

A good pipe coating should resist the passage of electrons to avoid loss of electrical potential in developing an optimum level of cathodic protection.

- Cathodic disbondment

Cathodic protection is used for most buried and submerged pipelines to aid in corrosion control. However, cathodic protection systems may adversely affect the coating at a pinhole or holiday in the coating, or at any other defect such as those created by impact during backfill.

In Level 1, it was shown that a corrosion cell at a pinhole could develop into an area of concentrated corrosion. The cathodic protection system may accelerate the corrosion process and cause premature failure.

In the electrochemical corrosion process, excess hydroxyl ions (OH^-) collect at the cathode, creating an alkaline environment under the coating. Any coating affected by the excess alkalinity may disbond from the pipe. Ideally, the pipe coating should be able to resist the effects of an alkaline environment.

Most coatings are tested for cathodic disbondment according to the test procedures described in ASTM Standard G 8 or ASTM Standard G 42 (*Cathodic Disbondment at Elevated Temperatures*).

There are a number of pipeline companies that make the tests more severe than the recognized standards. Some coatings manufacturers challenge the more severe tests, saying that they are unrealistic and do not prove a coating is more resistant to cathodic disbondment. However, the fact is that the more severe tests are used, and still provide a relative measure of performance.

This test procedure was discussed earlier in this course.

Cathodic disbondment is at least partially influenced by the:

- Nature of the coating
- Primer in the coating system
- Voltages for the cathodic protection system
- Temperature of the electrolyte
- Surface profile on the pipe

Since there are many variables and conditions that may influence cathodic disbondment testing, it is wise to run such tests side by side with a coatings system of known performance, at the same time and in the same electrolyte solution. This will give a more direct and objective comparison of results.

- Economy

Economics can be determined only by the users according to their own accounting schemes. The anticipated installed cost must match the expected life of the structure. Generally, the lowest initial cost is not always the optimum cost. Frequently, a more expensive coating properly installed, that holds up well over a long period, can result in the optimum coating cost for the life of the pipeline.

- Resistance to soil chemicals and soil bacteria

Certain soils may be acidic or alkaline in nature, which could be a factor in selecting a coating best suited for a specific geographical location. Some soils can be contaminated by leaching of chemicals from toxic waste disposal sites or by crude oil or other petroleum products from nearby production and refining sites.

If contamination is known to exist, the user may want to select a more chemically resistant coating, such as a high-solids epoxy, coal-tar epoxy, or epoxy novolac, to obtain optimum chemical and oil resistance at a reasonable cost.

Microbiologically influenced corrosion (MIC) is the result of certain bacteria attacking either the coating or the bare pipe surface. The coating used should have

optimum resistance to the action of bacteria and, by bonding well to the pipe, should be able to prevent bacteria from reaching the pipe surface.

- Resistance to aging

The design life of some pipelines may extend to 75 years. A good coating must be able to resist physical and chemical changes over the life of the line, and an ideal coating would be one that exhibits all of the characteristics just described and appears to be new after the design life has been reached.

Methods of Application

Some coatings are applied only in a stationary coatings facility; some may be applied either in a plant or in the field, while others are applied only in the field. The following table illustrates how various pipe coatings usually are applied.

Table 24.1

Pipe coating	Plant application	Field Application
FBE	Yes	Yes (Field joints only)
Extruded polyethylene: Crosshead extruded Side-extruded Hard adhesive-bonded	Yes	No
	Yes	No
	Yes	No
Hot asphalt mastic	Yes	Yes (Field joints only)
Coal-tar enamel	Yes	Yes (Mainline/joints or re-hab)
Coal-tar epoxy	Yes	Yes (Mainline/joints or re-hab)
Epoxy	Yes	Yes (Mainline/joints or re-hab)
Coal-tar urethane	Yes	Yes (Mainline/joints or re-hab)
Polyethylene tape wrap	Yes	Yes (Mainline/joints or re-hab)
Concrete weight coating	Yes	Yes
Coal-tar pitch tapes	No	Yes (Field joint/rehab)
Petrolatum tapes	No	Yes (Field joint/rehab)
Shrink-fit sleeves	No	Yes (Field joint/rehab)

Plant Coating Application—General Sequence

The pipe coating operation in a stationary coatings plant, **with noted exceptions**, follows a basic sequence, and the plant lay out is much the same for different generic coating types. Generally, the operation, which allows for inspection hold points, is approximately as follows:

- Pipe to storage
 - Log in pipe sections, pre-inspection for damage
- Pipe delivery to start of coating operation
 - Pre-inspection
- Pre-cleaning
- Abrasive blast cleaning
 - Inspection
 - Mechanical repairs
- Priming (if required by the specifications)
- Coating and wrapping
- Inspection
 - Visual
 - Holiday inspection
 - DFT measurements
- Coating rework or loading for storage or for delivery to pipeline right-of-way

Plant Coating Operation by Generic Coating Types

Coal-Tar Enamel

The starting point for the manufacture of coal-tar enamel is coal-tar pitch, which is the stable residue from the coking process in a steel mill. In this process, coal undergoes controlled destructive distillation at 1,100°C (2,000°F) to produce high-purity coke (carbon) for use in the reduction of iron ore. By products of the coking ovens are coal-tar pitch, a semi-solid of high density, and lighter fractions such as benzene, xylol, toluol, etc.

Coatings derived from coal-tar pitch—such as coal-tar cutbacks, coal-tar epoxy, and coal-tar enamel—contain a high ratio of aromatic compounds, characterized by the stable diamond-shaped (hexagonal) ring structure.

Coatings based on this aromatic ring structure usually:

- Are very waterproof; they exhibit excellent resistance to moisture absorption and moisture vapor transmission
- Exhibit relatively poor resistance to aromatic solvents (toluol, xylol, etc.)
- Exhibit poor resistance to sunlight; with time, they crack
- Exhibit excellent bond to steel

The coating, coal-tar enamel, is a thermoplastic, semi-solid material, which is manufactured by digesting (cooking) a mixture of coal-tar pitch, selected pulverized coal, and coal-tar oils, and then adding inert fillers. These fillers or bulking agents, such as talc or powdered slate, provide mechanical strength and heat resistance to the enamel.

- Enamel coating operations

In the coating plant, coal-tar enamel is heated to 230 to 245°C (450 to 490°F), and applied in molten form to a DFT of about 2,500 µm (100 mils) over a thin primer, less than 25 µm (1 mil) thick. As the pipe rotates through the coating station, a 500 µm (20 mils) inner layer of inert porous glass fiber mat is simultaneously wrapped over the coating. This glass wrap reinforces the enamel much as steel does in concrete.



Figure 24.10: Coal-Tar Enamel with Glass Layer

To be effective, the glass should be positioned in the outer one-third of the enamel. It should not be exposed to the air nor be allowed to contact the bare surface of the pipe.

Any moisture that contacts the glass can wick moisture to the pipe surface under the coating. If this occurs, a corrosion cell could be established at that location, and under-film corrosion could occur.

A heavier, more dense layer of glass-fiber mat, saturated with a coal-tar cutback solution, is applied to the outer surface of the hot coal-tar-enamel coated pipe. This outer wrap provides additional strength to the coating and, once installed, offers resistance to soil stress.

A final outer wrap of Kraft paper or whitewash is applied to the coated and wrapped pipe. This wrap provides a light background to spot obvious mechanical damage and

provides heat reflection while the pipe is in outside storage.

As a typical thermoplastic coating, coal-tar enamel is affected by changes in ambient temperature. At higher temperatures, the enamel will soften and flow and eventually may disbond from the pipe, while at lower temperatures the material may become brittle, crack, and disbond.

- Coating process

In the plant coating process, in the order shown, the pipe is:

- Delivered to a holding rack, identified according to shipping papers, and inspected for mechanical damage
- Conveyed through an open gas flame ring which removes moisture, mill lacquer (a temporary protective coating), loose rust, etc., and heats the pipe to about 38°C (100°F)

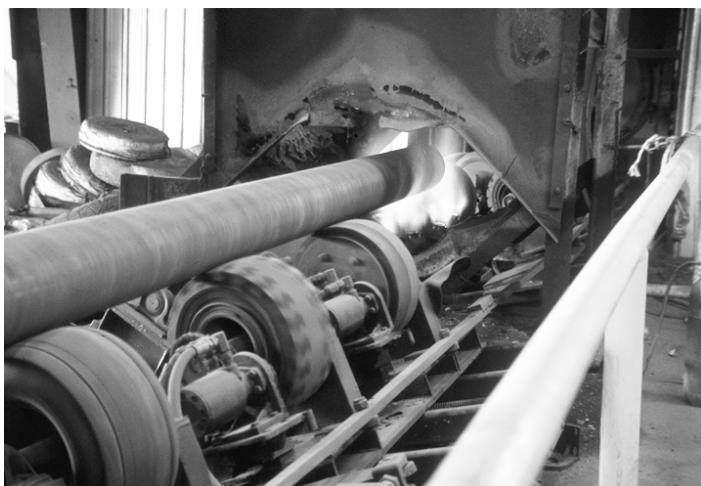


Figure 24.11: Flame Cleaning before Blasting

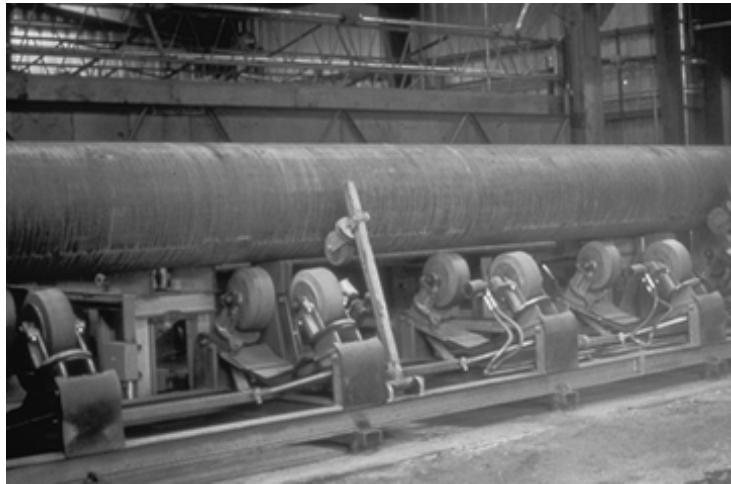


Figure 24.12: Rusty Pipe Pre-Blast

- Conveyed to a centrifugal wheel blast station where the pipe is blast cleaned with steel shot or grit, or a combination of both, to achieve the specified surface cleanliness (usually NACE No. 3/SSPC-SP 6 or better) and the required surface profile

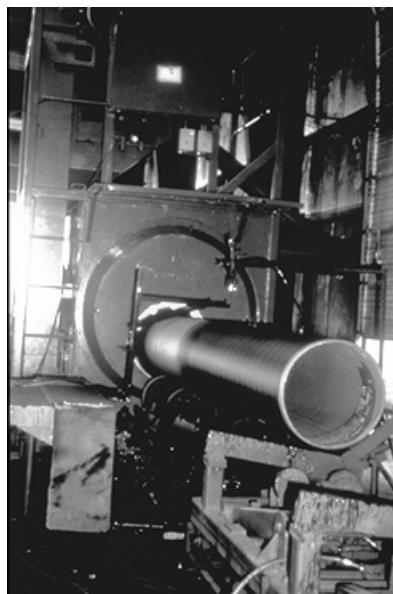


Figure 24.13: Post-Blast Pipe Primed

- Primed as it exits the wheel blast unit
- Coated by a flood coat of molten coal-tar enamel, with simultaneous wraps of a:
 - * inner glass wrap

- * outer glass wrap
- * final outer wrap of Kraft paper
- Exposed to a water quench to cool and re-solidify the enamel
- Conveyed to a cooling and storage rack where the coated and wrapped pipe is further cooled, and the coating ends are beveled to expose the enamel for later field-joint coating as the pipe is installed
- Inspected for holidays with a high-voltage DC holiday detector; the holidays are marked and repaired
- Inspected for any obvious mechanical damage and repairs are made
- Transported to storage or to the pipeline right-of-way for installation

Once the pipe leaves the entry-holding rack, it rotates as it is conveyed through the various stations—cleaning, coating, wrapping, and quenching—until it reaches the final holding and inspection racks. Both the speed of rotation and the speed of travel can be varied, which permits adjustment of the cleaning process as well as the coating process.

At the enamel coating station, the hot coal tar emits volatile coal-tar oils and some white smoke, which intensifies with excess heating. With continued excess heating, the coal tar will emit copious yellowish-white fumes, which is a sign of degradation of the enamel coating, until finally the product becomes carbonized, brittle, and unsuitable as a protective coating.

Coal-tar epoxies and cutbacks are self-priming. However, coal-tar enamel requires a primer in order to develop a reliable bond to the pipe. Here, the purpose of the primer is to insulate the pipe long enough to prevent chilling of the enamel and to allow the primer and enamel to fuse together to develop the bond.

Extruded Polyethylene

Polyethylene materials may be extruded into pipe coatings by one of the following methods:

- Cross-head extrusion

After the pipe has been blast cleaned, it passes through an annular extrusion head (die) where a hot mastic (120°C [250°F]) is applied. This mastic is a butyl rubber/asphalt blend extruded uniformly on the pipe to a DFT of about 250 µm (10 mils).

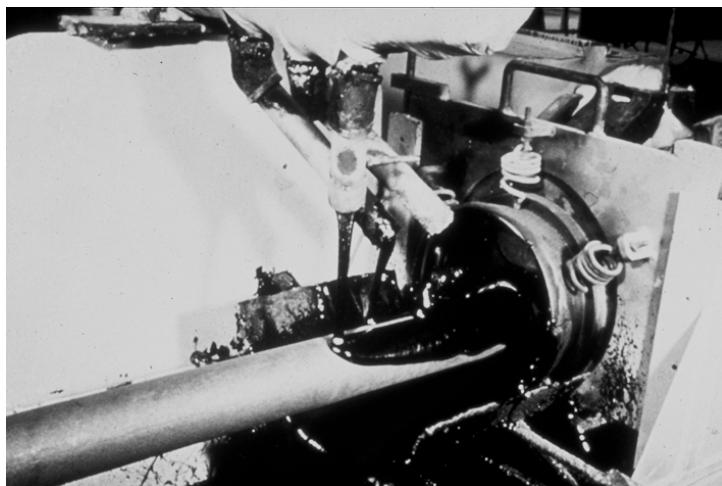


Figure 24.14: Applying Mastic Primer

The primed pipe enters a second annular extrusion head where a seamless sleeve of polyethylene is extruded around the pipe to a DFT of 1,000 µm (40 mils). The sleeve is larger in diameter than the pipe being coated. Just beyond the extrusion head, the pipe enters a water spray that cools the polyethylene and causes it to shrink onto the primed surface in somewhat of a “compression” fit.



Figure 24.15: Extruded Sleeve of Polyethylene, Water Quenching, and Holiday Testing

During the cleaning, coating, and extrusion process, the pipe travels longitudinally, but does not rotate.

Pipe up to 76 cm (30 in.) can be coated by this process.

Extruded polyethylene has some memory and can shrink from the ends. The polyethylene does not bond to the mastic primer.

The inspector may be required to inspect the polyethylene pellets used in the extrusion process for any sign of moisture. The inspector also may be required to check:

- The temperature of the asphalt/rubber mastic
- The WFT of the primer
- The DFT of the extruded coating
- That the holiday detector is connected and in proper working order
- For any mechanical damage to the coating

- Side extrusion of polyethylene coatings



Figure 24.16: Coated Pipe Film Shrinkage/Memory

Steel pipe may be made using a lap weld. This type of weld leaves a void that must be filled in with an adhesive layer of polyethylene-type refined coating.

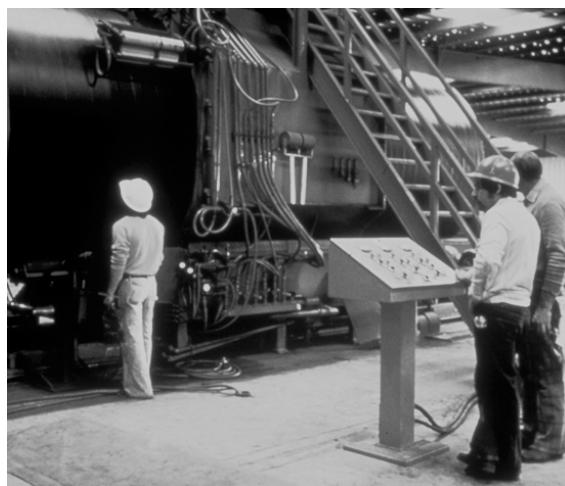


Figure 24.17: Side Extrusion Head

After large-diameter pipe (to 2.44 m [96 in.]) is abrasive blast cleaned, it rotates as it travels forward under a side-extruder head. Polyethylene beads under high temperature and pressure are forced through the side extruder into a hot film about 1,000 μm (40 mils) thick.



Figure 24.18: Trimming Cutback

This hot film is attached to the pipe at an angle to its longitudinal axis. As the pipe rotates and travels forward, the hot film is wrapped onto the asphalt/butyl mastic primed pipe surface. The finished coating resembles a spiral wrap of tape. The polyethylene film fuses together at the overlap due to the latent heat of the hot extruded plastic.

The coated pipe is tested for holidays with a high-voltage DC holiday detector, using a conductive rubber electrode.

Hard-Adhesive Extruded Polyethylene

In this process, a material such as epoxy is applied to the bare pipe and is then over coated with one or more layers of polyethylene applied by the side-extrusion process.

Fittings, bends, valves, etc., may be coated with polyethylene by the *sintering process*. Sintering is a method of applying polyethylene powder directly to a heated surface in much the same way as FBE, except at a lower temperature.

Weight Coatings

The wall thickness of pipelines installed onshore may vary with the product transported. A high-pressure natural gas line may require a greater wall thickness than

a line transporting a petroleum product. For onshore installation, pipelines with a wall thickness as low as 6.2 mm (0.25 in.) may be used. For offshore installation, especially in deep waters, pipelines may require a greater wall thickness sometimes exceeding 25 mm (1.0 in.):

- For greater strength
- To provide negative buoyancy to prevent the pipe from floating, especially pipe diameters larger than 20 cm (8 in.).

Frequently, this heavy wall pipe is coated with a weight coating such as:

- Asphalt mastic, which is a combination of protective and weight coating, fortified with heavy aggregate
- Concrete reinforced with metal wire mesh

Asphalt Mastic

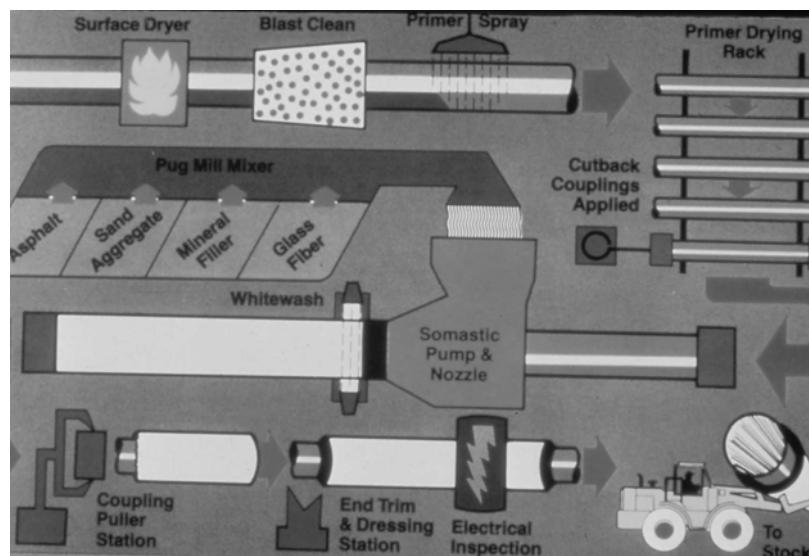


Figure 24.19: Asphalt Mastic Coating Operation

Asphalt mastic is produced only in the United States under the trade name SomaticTM. Use of this material has declined in recent years, such that its future is in some doubt.

This is a combination protective coating and weight coating commonly used for offshore operations.

The asphalt mastic is made by adding mineral fibers (formerly asbestos fibers, now glass), inert fillers, and very dense, very heavy aggregate to molten asphalt enamel (260°C [500°F]). The resulting mixture, which contains about 15% asphalt and 85% inert materials, is applied at about 155°C (300°F).

The hot mixture is extruded over the pipe surface that has been primed with an asphalt primer. Minimum coating thickness is 1.25 cm (0.5 in.). The coating often is over coated with whitewash, then supported on its bare ends and stored out doors in a spider-like formation until the coating cools and sets.

The whitewash reflects some of the rays of the sun and thus provides heat reflectance for the coating. This treatment is common with many thermoplastic coatings that have a tendency to soften and slump if not protected during storage.

The asphalt-mastic-coated pipe may be fitted with bracelet anodes (usually zinc) bonded directly to the pipe. In effect, the lay-contractor installs the “sacrificial” cathodic protection system as the pipe is being installed.

Bracelet anodes can be installed in this manner on pipelines with any type coating.

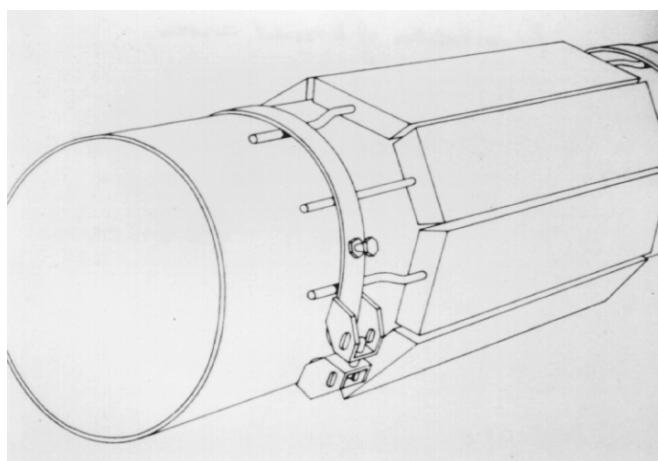


Figure 24.20: Bracelet Anode

Concrete Weight Coating

Concrete may be applied over asphalt-mastic-coated pipe to provide additional negative buoyancy or it may be applied over other pipeline coatings.

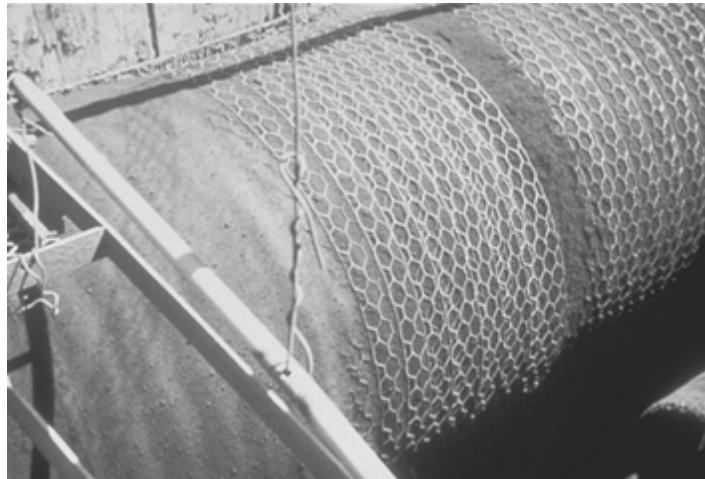


Figure 24.21: Application of Concrete Weight Coating with Steel Wire Screen

Concrete weight coating may be applied:

- By the gunite method
- As a compression coat (extruded)



Figure 24.22: Typical Somatic/Concrete Field Joint

Thickness of the concrete coating may vary from 5 to 30 cm (2 to 12 in.) depending on the weight requirements.

The annular space at the field joint must be filled to the diameter of the coating plus any concrete weight coating added. Quick-setting cement, asphalt mastic, or high-density polyurethane foam may be used to fill this space.

Field Application of Pipeline Coatings

As shown in Table 24.1, several mainline coatings can be applied both in the field and in a stationary plant. Polyethylene tape is the most commonly used material for mainline (i.e., pipe coating less field-joint coating) coating in field applications. These materials are widely used for coating rehabilitation work in the field. To a lesser extent, coal-tar epoxy, epoxy polymer, concrete epoxy, coal-tar urethane, and 100%-solids elastomeric polyurethanes also are applied in the field.

A number of the products mentioned may be used in the field to coat the bare, welded field joints of plant-coated pipe; these materials will be discussed later today.

Polyethylene Tapes

There are two types of polyethylene tapes:

- Laminated
- Co-extruded

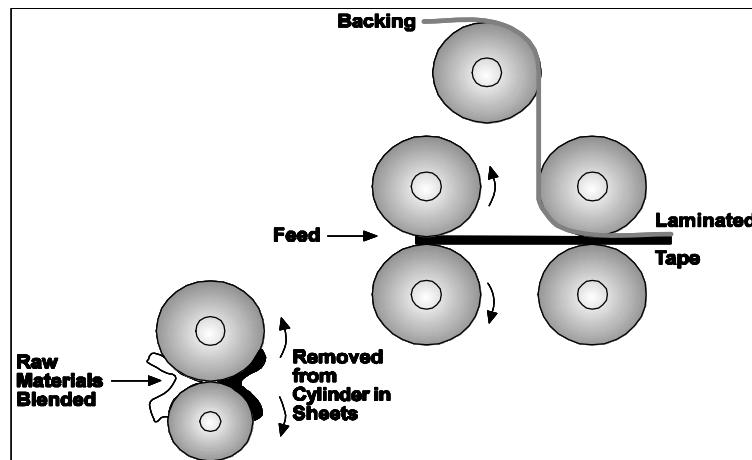


Figure 24.23: Laminated Tape Process

The laminated tapes are manufactured by applying a compatible adhesive to one side of a pre-fabricated film of plastic (polyethylene). The film usually is of medium density and molecular weight designed to provide optimum strength, flexibility, and ductility for application under tension.

The tape can vary in total thickness from 375 to 1,250 μm (15 to 50 mils). The typical adhesive portion can vary in thickness from 125 to 500 μm (5 to 20 mils).

The adhesive is prepared by introducing certain raw materials into a calender that consists of two rollers of different diameters placed close together, and rotating at different speeds. The raw materials fed into the calender are chewed and blended together at reasonably high pressure, with heat being generated in the process. The hot adhesive is removed and fed through another series of rollers that carry the plastic film backing. Here, the hot adhesive and film backing are laminated together, slit to size and put on rolls.

Co-extruded tape is manufactured in an entirely different manner from the laminated tapes. The co-extrusion apparatus consists of three separate feeders, each of which carries a different raw material connected to a single extruder or die.

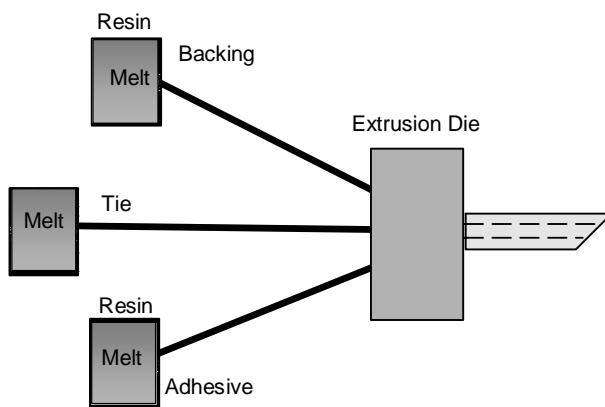


Figure 24.24: Co-Extruded Process

From three separate feeders, melted or heated materials are funneled through an extrusion die, and the materials

exit into a homogeneous tape rather than a laminated tape.

With laminated tape, the adhesive can be separated from the backing. One side of the co-extruded tape exhibits a smooth and dense film, and the opposite side resembles an adhesive surface. It is virtually impossible to pull the co-extruded tape apart into separate, identifiable layers.

Both materials are applied cold—no heat is needed—under controlled tension over specially primed surfaces.

Tape Application

- Stationary Plant

Pipe coated in a stationary coating plant follows the same coating sequence as that used for the application of polyethylene by the side-extrusion process:

- Pre-inspection
 - Pre-cleaning
 - Blast cleaning and priming
 - Tape application
 - Inspection and loading out
- Field Application

These tapes are used as a:

- Mainline coating
- Rehabilitation coating
- Field-joint coating

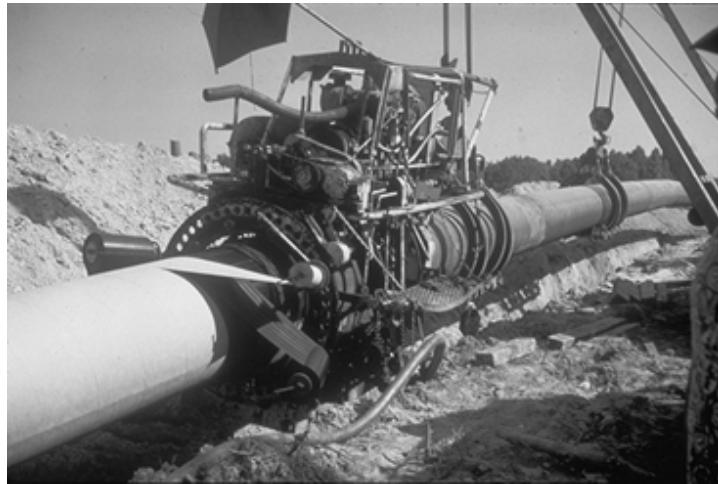


Figure 24.25: Field Tape Application

For mainline construction, the pipe is welded into a continuous length, and bent to conform to the contour of the ditch. Frequently, two side-boom tractors, which travel about 15 m (50 ft) apart along the open ditch, are used in the application of the tape.

The front side boom carries a cleaning and priming machine that fits around the pipe and is adjusted for its diameter, while the rear side boom carries the tape-wrapping machine that also fits around the pipe.

The two side booms, working in tandem, lift the pipe, and as they travel forward, the pipe is cleaned, primed, and wrapped with the tape.

Alternatively, a combination cleaning/priming/wrapping machine may be used. These specially built units are equipped to clean and prime the pipe with a fast-drying primer, then simultaneously wrap the tape over the primed surface.

In rehab work, a combination machine is used and the application procedure is similar. Because the pipe is still in service and still in its original ditch, there are some exceptions in the process:

- Only short sections can be cleaned and wrapped
- The machine is on the pipe in the ditch

- The machine must frequently be taken on and off the pipe to bypass the necessary pipe supports



Figure 24.26: Rehab Coating with Plastic Tape

Some Problems with Pipeline Tape Coatings

Each generic pipe coating has its own unique set of problems, and those often associated with plastic tapes include:

- Cathodic disbondment due to the CP system
- Spiral corrosion due to poor seal at the tape overlap
- Soil stress, which may displace portions of the tape
- Attack by bacteria, generally on the adhesive
- Undercut corrosion at the pipe/coating interface

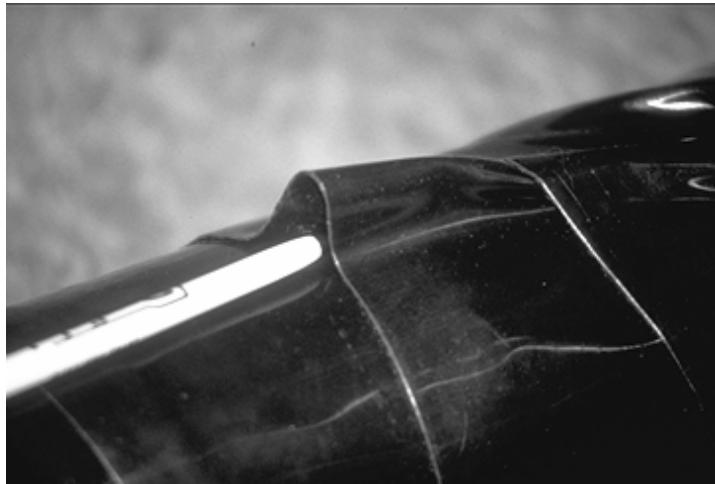


Figure 24.27: Fish Mouth, Poor Overlap Seal

Liquid Coatings

Liquid coatings on pipelines may be solvent-based, coatings such as coal-tar cutbacks, vinyls; or chemically cured, such as inorganic zinc, coal-tar epoxies, high-solids epoxies, vinyl esters, 100%-solids epoxy coal tars, coal-tar polyurethanes, and 100%-solids elastomeric polyurethanes.

Either type of coating must be applied over properly cleaned (minimum near-white blast), dry surfaces, according to the manufacturer's specific recommendation. Application equipment can consist of a simple conventional air spray rig with coal-tar cutbacks and vinyls, high-ratio (30:1 or 45:1) airless spray units with coal-tar epoxies, epoxies, etc., or finally, with more sophisticated plural-component spray units for coal-tar polyurethane and 100%-solids elastomeric polyurethanes.

Coating selection, number of coats, recoat times, total thickness, etc., all vary with the generic material, service conditions, and customer demand.

Coal-Tar Epoxies

Epoxies and coal-tar epoxies have been used for years both in plant and field applications.

The coal-tar epoxies have the advantages of high-bond strength, better chemical resistance, and higher temperature resistance than the solvent cutback coatings. Combined with its resistance to moisture, coal-tar epoxy coatings give excellent service for many years and are still used extensively.

Field-Joint Coatings

Introduction

When pipe is coated in the plant, each end must be left uncoated (called *coating cutback*) to allow joining by welding in the field. The amount of coating cutback is determined by the type of coating and the pipe diameter.

The cutback may vary from as little as 5 cm (2 in.) in the case of FBE and side-extruded polyethylene, to as much as 30 cm (12 in.) in the case of coal-tar enamel and asphalt mastic.

Commonly used field-joint coatings include some of the mainline coatings just described:

- Fusion-bonded epoxy
- Coal-tar enamel
- Asphalt mastic
- Polyethylene tapes

Other coatings for field joints may include:

- Hot-applied coal-tar pitch tapes
- Petrolatum tapes

- Shrink-fit sleeves

Coal-Tar Pitch Tapes

Coal-tar pitch tapes are described as *fabric-reinforced* coal-tar pitch tapes. They consist of a cotton fabric saturated with a low-softening-point (or melt-point) of 120°C (250°F) coal-tar pitch that has no inert filler. A thin (7.5 μm [0.3 mil]) film of polyester is overlaid on one side to serve as a separator.

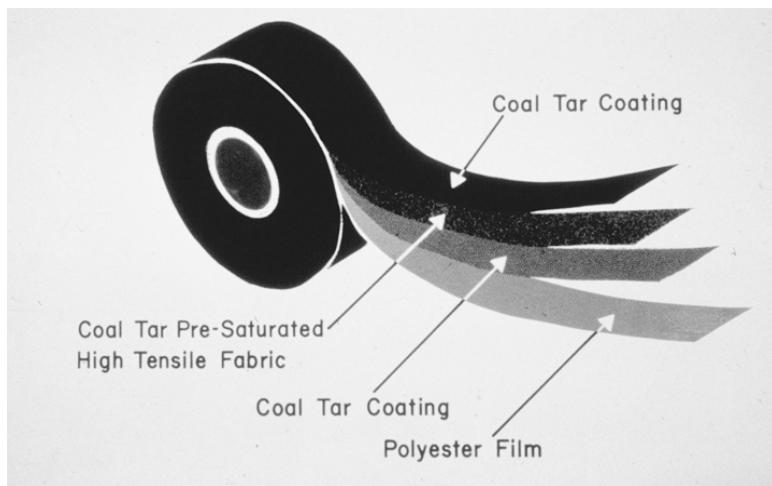


Figure 24.28: Coal-Tar Tape Construction

In application, the welded field joint is:

- cleaned, most often by wire brushing
- primed, generally using coal-tar cutback or special chlorinated rubber primer
- wrapped with hot tape

The tape is heated with a portable low-pressure gas (usually propane) torch enough to soften the tape.

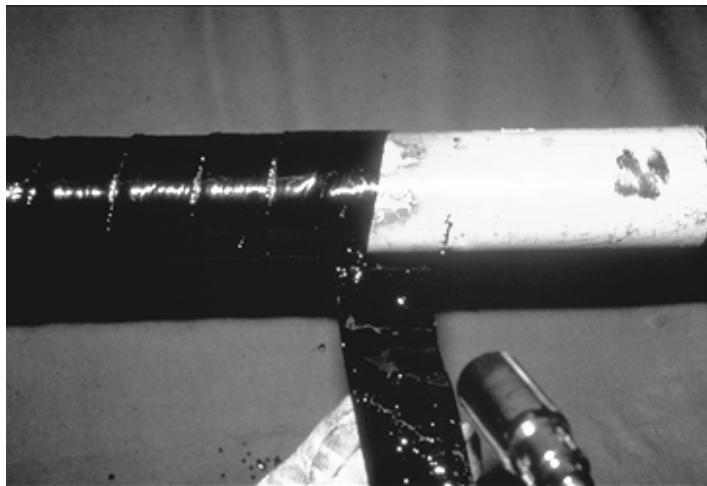


Figure 24.29: Torch Applying Coal-Tar Tape

Once attached to the pipe, the tape is heated to soften the tar and make it fluid enough to be spirally wrapped around the pipe. The tape is alternately heated and wrapped around the pipe. Only a short section of the tape is heated at a time.

Caution should be taken to avoid overheating the pitch; too much heat causes the pitch to flow off the fabric. Excessive heating will cause the pitch to burn and become useless. Only enough heat should be applied to melt the tar yet retain it on the fabric as the tape is applied.



Figure 24.30: Cigarette Wrap of Tar Tape

The tape is pulled firmly and tightly onto the pipe surface. The softened tar is squeezed into all the pipe surface irregularities and at the tape step-down. The tape can be wrapped (with overlap) spirally, or in a cigarette fashion (like a sheet material).

Generally, this type of tape is used only for field joints or for short sections of pipe, not as a mainline coating, and is applied by hand, although it may be applied by a specially built machine.

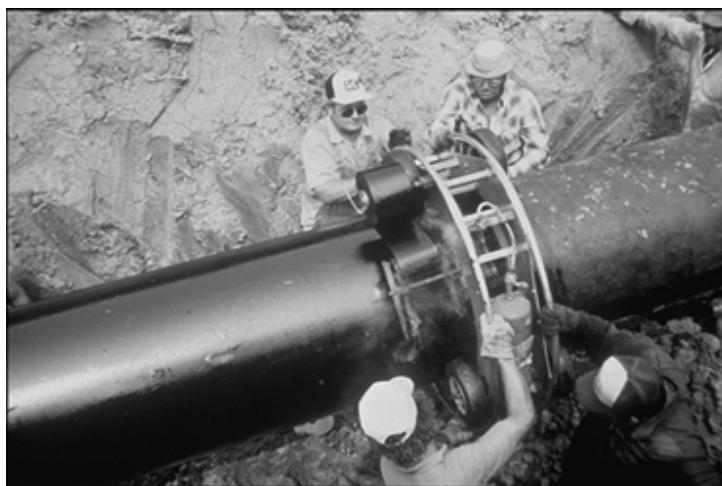


Figure 24.31: Special Machine Applying Tar Tape

Petrolatum Tapes

Petrolatum tape consists of a fabric saturated with petrolatum made from the residue of processed paraffin-based hydrocarbons.

The tape is applied cold (no heat needed), by hand over a compatible primer. This material can be applied over a damp surface.

Polyethylene Tapes

Polyethylene tapes may be applied in a spiral or a cigarette wrap either by hand or by a portable wrapster. The pipe is cleaned as with hot pitch coal-tar types, primed with compatible primer, and then wrapped.



Figure 24.32: Plastic Tape Hand Wrapster

Shrink-Fit Sleeves

Shrink-fit sleeves are similar to tapes made in sheet form from the same composites. The plastic backing is chemically treated or is irradiated to cause it to expand somewhat. When the material is heated, it shrinks into a tighter and more dense film as it tries to return to its normal dimension.

Some of these materials are tubular and must be slipped over one end of the pipe. Most sleeves, however, are wraparound lengths of polyethylene backing, overlaid with a special adhesive.

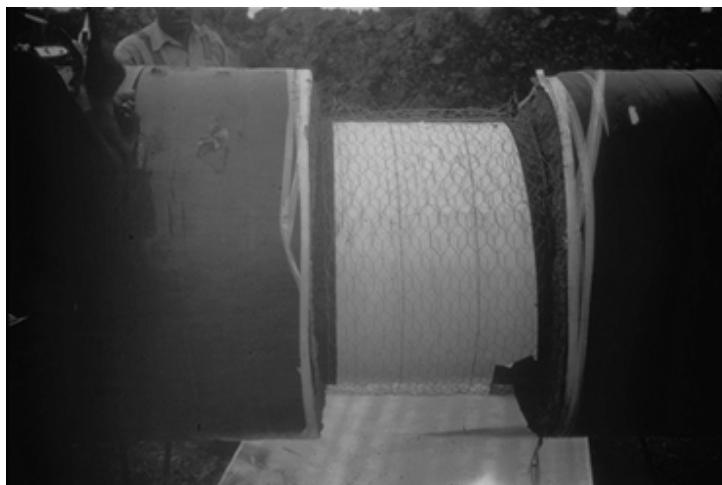


Figure 24.33: Weight Coated Field Joint Coated with Polyethylene Tape—Wire Mesh in Place

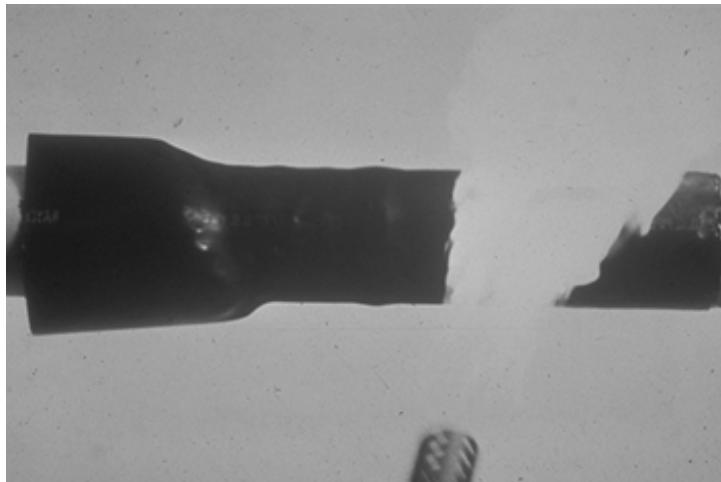


Figure 24.34: Heating Tubular Sleeve

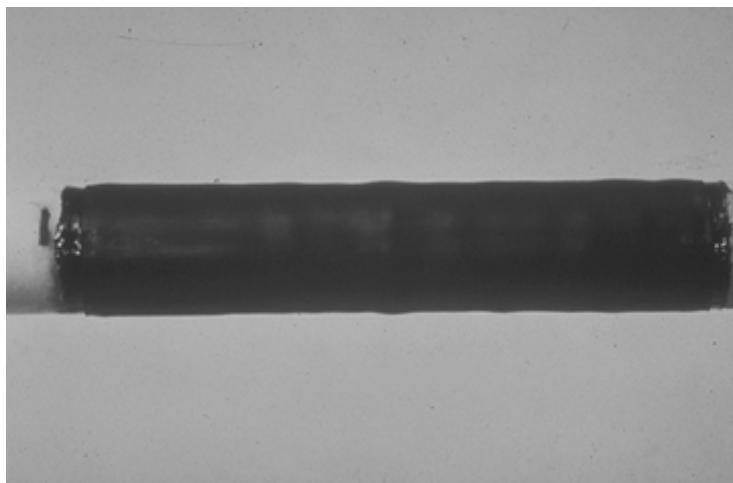


Figure 24.35: Tubular Sleeve Heat-Shrunk



Figure 24.36: Weight-Coated Pipe with Wraparound Sleeve

The sleeves are sized to match the pipe diameter plus an allowance for overlap, and are wide enough to cover the bare field joint and extend over the coating at each cutback. The sleeve may be applied over a special adhesive primer, usually epoxy-type.

The wraparound sleeve is then placed around the pipe circumference with the overlap facing the ditch bottom. The sleeve is heated with an LPG torch and, as it is heated, the sleeve shrinks to a tight fit over the joint.



Figure 24.37: Heating Wraparound Sleeve



Figure 24.38: Folding Sleeve Over

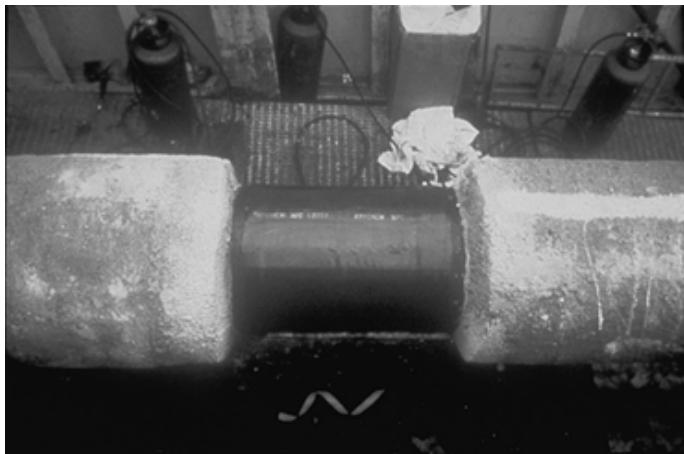


Figure 24.39: Finished Joint with Wraparound Sleeve Annular Space to Be Filled

Fusion-Bonded Epoxy

Tapes, sleeves, etc., may be used on fusion-bonded epoxy coated pipe. Generally, however, FBE is the material of choice for pipe coated with FBE in the plant.

The bare welded field joint area and about 2 to 5 cm (1 to 2 in.) of the coating at the cutback are abrasive blast cleaned and heated to the proper application temperature (up to 250°C [450°F]) by a portable induction heater.



Figure 24.40: Field Joint to be Blast Cleaned Before FBE Coating

After heating, a sprayer rotates around the pipe and sprays FBE powder onto the heated surfaces. The powder coating fuses together just as it does in the plant operation.



Figure 24.41: Induction Coil Mobile FBE Heater



Figure 24.42: Mobile FBE Heater

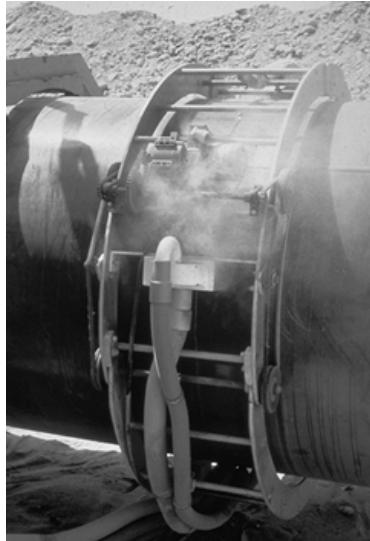


Figure 24.43: FBE Mobile Heater Applying FBE Powder

Coal-Tar Enamel

Molten coal-tar enamel is poured over the primed field joint and is caught by a hand-held wrapper. The hot enamel is applied to the bottom and sides of the pipe when the wrapper is moved upward in a see-saw fashion.



Figure 24.44: Pouring Hot Enamel



Figure 24.45: Finished Field Joint

To complete the joint, the wrapper is folded over the top of the pipe with its end facing down. This prevents entry of any water that migrates through the soil.

Asphalt Mastic

Generally, hot asphalt mastic is applied only to a field joint of asphalt-mastic-coated pipe to fill the annular space formed by the mastic and any concrete weight coating.



Figure 24.46: Asphalt Mastic in Mold on Pipe



Figure 24.47: Asphalt Mastic Field Joint—Complete

Protecting Pipeline Coatings

Coatings are often damaged during installation of the pipeline or by soil (backfill) movement in service.

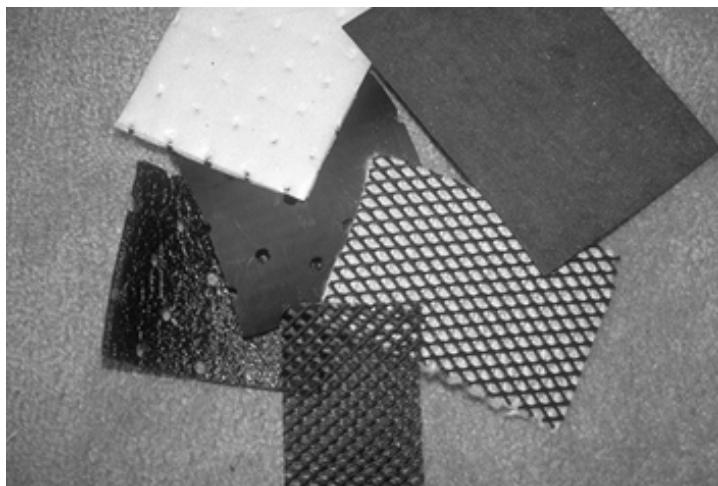


Figure 24.48: Various Types of Rock Shield



Figure 24.49: Foam Rock Shield—Close-Up

The coating system may be protected by the use of some type of rock shield that is made in various forms:

- Foam-backed polyethylene
- Heavy-duty plastic mesh
- Cloth-backed mesh
- Polyethylene sheeting
- Tar- or mineral-filled sheet

This outer wrap of protection may be bonded to or merely wrapped around the coating system. When it is used as an overcoat, it usually is held in place with some type of filament tape until the line is backfilled.

The rock shield should be applied so that the overlap is pointed down. This prevents the backfill from being caught in the overlap and tearing off the rock shield.



Figure 24.50: Line with Rock Shield



Figure 24.51: Close-Up of Rock-Shield Overlap

Cathodic shielding is a point of debate with some engineers when using rock shield. It is argued that if the rock shield is too solid, it will inhibit the transmission of moisture around the pipe, a necessary condition for the electrolyte, which allows the cathodic protection system to function properly. Even when the rock shield is perforated, some argue that shielding will occur.

The inspector may be required to determine that the rock shield is properly installed.

Pipeline Coatings and the Inspector

Some of the inspection steps, as well as the different types of products and coatings, have been discussed.

In summary, the pipeline coating inspector may required to:

- Verify certain lab tests
- Inspect incoming pipe
- Ensure proper coating application procedures at the pipe coating plant or in the field
- Inspect for damage caused by shipping to site and/or installation
- Monitor holiday detection and inspect repairs
- Verify proper cleaning and coating of welded field joints
- Inspect field-joint coating process
- Ensure proper application of rock shield
- Monitor the backfill operation





Level 2

Chapter 25

Fusion-Bonded Epoxy

Pipeline Coatings

Fusion-Bonded Epoxy Pipeline Coatings

Introduction

Fusion-bonded epoxy (FBE) resins are the most widely used materials for pipe coating today. These coatings are usually applied in a stationary coatings facility, although they are often applied in the field to coat the girth welds (field joints) of plant-coated pipe or, occasionally, for very short sections of pipe.

FBEs are powder mixtures containing pigments, plasticizers, anti-foaming agents, epoxy resins, curing agents, etc.

These materials are heated to partially react and then chilled to prevent further reaction; they are reduced to a very fine powder by grinding and are stored in weatherproof containers. The particle size of a typical FBE powder is expressed as “2% maximum retained on a 100 mesh (150 μm) sieve and 0.1% maximum retained on a 60 mesh (250 μm) sieve.”

FBE powders are applied to heated pipe (approximately 232°C [450°F]) under carefully controlled conditions to produce a hard, tough, durable pipe coating. (Note: Application temperatures should not exceed 275°C (527°F).

Many of the newer formulations of FBE require lower temperatures for application and curing.

The basic sequences for plant application of such pipe coatings as coal-tar enamel, extruded plastics, asphalt mastic, and FBE are quite similar. However, the coating process for FBE is much more complex than the processes for other pipe coatings, and the inspection procedure and inspection criteria are more critical for FBE than those for any of the pipeline coatings described in previous chapters.



Because FBE plays such a key role in the pipe coatings industry, a separate discussion of these materials is important. The following discussion and illustrations may be considered a summary of the plant application and inspection process for all other pipeline coatings.

Application Process for FBE

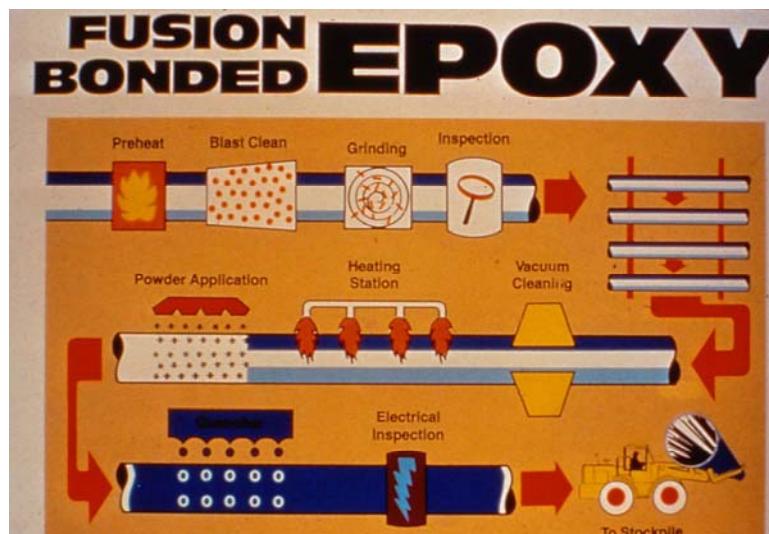


Figure 25.1: Schematic of FBE Coating Plant

Plant Layout

The layout of an FBE coating plant typically includes the following stations:

- Pre-heating
- Blast cleaning
- Grinding
- Inspection (post grinding)
- Vacuum cleaning
- Heating

- Powder application
- Water quenching or air cooling
- Inspection
- Loading out

Other stations may include:

- Pre-cleaning (before pre-heating)
- Pre-blast (after pre-heat and before blast cleaning)
- Chemical pre-treatment (after vacuum cleaning and before heating)
- Laboratory testing of FBE powder and coated pipe specimens

Pre-Inspection Station

Generally, pipe scheduled for an FBE coating plant first is closely inspected for quality at the steel mill and again at the coating plant before being coated. On arrival at the coating plant, the pipe is stored in the yard on skids or on earth or sand berms.

The inspector may be required to check the following:

- Pipe identification (ID) numbers
- Uniformity of roundness
- Beveled edges
- Overall steel quality
- Temporary protective coatings (mill lacquer), if any. Excessive coating thickness may require removal by mechanical means or by burning off prior to any blasting operations.
- Surface contaminants (visible and/or invisible soluble chemical salts)



Inspection for soluble salts may be necessary, particularly if the pipe has been shipped by sea where chloride (sea salt) contamination is likely. (Note: 2 $\mu\text{g}/\text{cm}^2$ of ferrous salt can adversely affect coating performance.)

Pre-Clean Station



Figure 25.2: Open-Flame Cleaning

Pipe is transported from storage to the first station (generally) in the coating process, which is the pre-clean station. The objective at this station is to remove any transportation debris and contamination. Several methods of cleaning may be used, including:

- Soaking in a hot-water bath
- Steam cleaning
- Chemical cleaning
- Open-flame cleaning

The cleaned, wetted pipe may be force dried by passing it through an open flame prior to pre-blast or blast cleaning operations. If no wet cleaning is done, the pipe may be heated with an open flame to remove light rust, moisture, temporary protective coatings, old coatings, etc., prior to abrasive blast cleaning.

The inspector may be required to:

- Check water quality and temperature of the bath water
- Monitor force-drying operation
- Monitor open-flame cleaning
- Look for defects such as laminations, slivers, etc., in the steel

Pre-Blast Station



Figure 25.3: Pre-Blasting

A pre-blast cleaning station may be incorporated in the coating production line. The main objective of the pre-blast operation is to “stress relieve” the external surfaces of the pipe when it is to be used for high-pressure service, such as high-pressure natural gas transmission.

The pipe is conveyed through a centrifugal blast unit that contains blast media of steel shot only, or a blend of 80% steel shot and 20% steel grit. The shot “peens” the surface, which relieves the stresses in the pipe and cleans the surface so the inspector can check for such defects as laminations, slivers, hard spots, etc. Surface profile is not a critical factor at this stage of the operation.

At the pre-blast station the inspector may be required to:

- Monitor the grade of abrasives to ensure correct size and shape or the proper mix of shot and grit
- Locate and mark defects exposed by the blasting that would require correction at the grinding station

Abrasive Blast Cleaning Station



Figure 25.4: Various Pipe Couplings

Generally, before abrasive blast cleaning, the pipe is coupled with internal couplings sized to fit its internal diameter. The coupling may be constructed of short sections of angle iron welded to opposite sides of a circular separator plate or disc equal in size to the outside diameter of the pipe to be coupled. The opposite ends of each angle iron are attached to a disc smaller than the pipe diameter. The separator disc is located in the center of the coupling.

One end of the coupling is inserted into a pipe end, and the other end is inserted in the end of the trailing pipe. As the pipe is conveyed, the beveled end of each coupled pipe is made to fit snugly against the circular separator disc. This arrangement helps prevent abrasive particles from entering the pipe. Any loose abrasive found inside the pipe must be removed prior to coating.



Figure 25.5: Centrifugal Blast Stations

The exterior surface of the pipe is prepared for coating by abrasive blast cleaning, usually with steel grit or a mixture of steel grit and steel shot. The pipe is conveyed through a centrifugal blast (wheel blast) unit, which is designed to produce the required degree of surface cleanliness.

Most specifications require a surface cleaned to NACE No. 1/SSPC-SP 5, *White Metal Blast* (or sometimes, NACE No. 2/SSPC-SP 10 *Near-White Metal Blast*) with a required surface profile of 40 to 100 μm (1.5 to 4 mils).



Figure 25.6: Couple Pipe After Blast Station

Abrasive blast cleaning may be accomplished by using a single centrifugal blast unit, though some plants use two such units arranged in tandem.

Modern centrifugal blast units are capable of cleaning pipe up to 3 m (96 in.) in diameter at a rate close to 6 m

(20 ft) per minute while achieving a NACE No. 1/SSPC-SP 5, *White Metal Blast*.

The coating inspector usually will monitor the surface cleanliness at least hourly and will measure the surface profile at least once every four hours using replica tape, according to NACE Standard RP0287, *Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape*.

Vacuum Cleaning Station

Incidental to the abrasive blast cleaning operations is the development of abrasive dust residue and a certain amount of minute steel slivers held on the pipe surface by electrostatic forces.

Some coating facilities use a combination of high-speed wire brushes and vacuum cleaning to remove both the slivers and the abrasive dust, while other facilities may use vacuum cleaning only.

The inspector may be required to check for abrasive residue.

Pipe Grinding Station

The pipe is rotated so workers may grind and remove any laminations, slivers, etc., that the coating inspector may have located.



Figure 25.7: Pipe Grinding Station

Some coating plants may have other inspectors (ultrasonic or magnetic particle) available at this station with which the coating inspector may interface as necessary.

Generally, the maximum grind is 0.09 m^2 (0.1 ft^2) per location and 0.2 m^2 (2 ft^2) per pipe joint, or 2% of the total pipe surface.

Pipe with serious defects may be sent to a reject area for further inspection.

Rejected pipe may be used for casing or carrier pipe.

When deep laminations are found, the pipe is “kicked out” to a reject area and is suitably marked to ensure that it is not used for product service, but it can be used as a casing or carrier pipe.

Maximum depth criteria for grinding may be determined by government regulations or may be detailed in the user’s specifications. Some users set their own maximum percentage, for example 12% of wall thickness, as the criterion for rejection.

Inspection criteria for the grinding station may include:

- Laminations and other defects (quality and size)
- Definition of the methods of removal
- Limits for allowable depth of grind



Figure 25.8: Results After Removal of Steel Defects

Chemical Pre-Treatment Station



Figure 25.9: Chemical Pre-Treatment

Chemical pre-treatment may be used in some plants to enhance adhesion of the FBE. Phosphate- or chromate-based proprietary solutions, formulated to comply with minimum government regulations, are used to treat the pipe, which is then dried using a blower or heater prior to the heating process.

The inspector may be required to monitor this station to ensure the chemicals are uniformly applied and properly dried before the pipe enters the heat station.

Heating Station

Prior to powder application, the pipe must be heated to the required temperature. Generally, the recommended application temperature range is from 225 to 246°C (438 to 475°F). High-frequency induction coils are commonly used to heat the pipe, and in some plants, more than one series of induction coils may be used.

The high-frequency alternating current generates an expanding and contracting magnetic field. As this alternating magnetic field expands and collapses, it causes the molecules that make up the steel pipe to oscillate. This creates internal friction and generates a high degree of heat.

If the pipe is allowed to remain too long in the magnetic field, the temperature of the pipe may rise above 290°C (554°F) and the steel can be oxidized and “bluing” takes place.

Bluing of the steel can impair the adhesion of the FBE, and if bluing occurs, the pipe must be re-blasted before it can be coated.

Other heating methods include direct gas flame, indirect gas-fired ovens, and infrared heaters.

Direct Heat Oven



Direct Open Flame



Figure 25.10: Direct Heating



Figure 25.11: Temperature Monitoring Using Tempilstiks



Figure 25.12: High-Frequency Induction Coils Used to Heat Pipe

At the induction coil heating station, the inspector may be required to monitor such conditions as:

- Electric conditions
 - Voltage
 - Amperage
 - Frequency
 - Conductance
- Pipe temperature
 - Time in induction field
 - Bluing effects

If other methods of heating are used, the inspector may be required to monitor only the pipe temperature to ensure it is within the recommended range and no bluing occurs.

Powder Application Station

FBE powder is applied to the heated pipe usually by a flocking gun or by electrostatic spray heads located in a closed or semi-closed powder chamber. In some plants, the pipe may be powder-coated as it passes through a cloud chamber.



Figure 25.13: Alternative Method of Powder Application: Individual Joints of Pipe Pass Through a Cloud Chamber

This series of slides illustrates the powder application process.

In some FBE powder systems, there may be a post-heating stage known as *reduction heating*. Some powders may require post-heating to ensure proper curing and/or to reduce thermal shock, which can occur as the coated pipe is cooled suddenly at the water quench station. Some coating facilities cool the coated pipe only by fans or blowers directed at the pipe.

The key to the curing mechanism of FBE is the transitional heating stage. Once the powder is applied to the heated pipe, either in a pre-heat or post-heat situation, the powder changes its state and temporarily resembles a liquid coating; once cooled, it forms a homogeneous film over the steel surface.

FBE powders applied to the heated pipe pass through four distinct stages:

- The flow stage, which occurs when the particles of powder begin to flow but are not fully liquid
- The wetting stage, which occurs when the particles of powder absorb more heat, fully liquefy and wet the surface
- The gel stage, which occurs when the particles of the liquefied material begin to gel, converting to a solid
- The curing stage, during which further changes take place, allowing the FBE powder to cure fully

The complete process, from flow stage to cure, generally takes less than two or three minutes, which makes this an ideal process for production-line application. For most FBE resins that do not require post heating, the cure time—the minimum time to quench—is about 45 seconds at 232°C (450°F).

The application process for FBE is critical and the coating inspector may be required to monitor the operation to ensure that:

- The specified powder is used and batch numbers are recorded
- The powder is dry and has not picked up moisture in transit or storage
- The powder mix, *original-to-recycled powder ratio*, is properly maintained
- Voltage settings are correctly maintained
- The number of powder guns are matched to the pipe diameter and the proper powder delivery ratio is maintained

Water Quenching or Air Cooling Station

Immediately after the coated pipe leaves the coating chamber, it may pass under a water spray that is designed to suddenly cool the heated pipe to about 80°C (175°F), or it may be conveyed to a cooling rack where the pipe is

cooled more slowly by fans or blowers. The cooled pipe is conveyed to the final cooling and holding rack for a final inspection.

The powder manufacturer usually specifies the limits of the water quench process and the coating inspector should be aware of the recommended processing (dwell) times, temperature drop, etc.

Final Inspection Station

- The final stage of the quality control process of the FBE coating operations occurs at the final inspection station where the:
- Pipe ID number is recorded.
- DFT of the FBE coating is measured and recorded. Typically, the DFT range is 254 to 457 μm (10 to 18 mils).
- Pipe is tested for holidays with a high-voltage DC holiday detector, and holidays, if any, are marked and repaired.
- Pipe is visually inspected for any mechanical damage to the coating.

DFT Measurements



Figure 25.14: Making DFT Measurements

The inspector should measure DFT at three locations on each pipe joint. At least once per eight-hour shift he/she should use a coating thickness gauge calibrated to specified calibration standards to ensure DFT is within 20% of the specified coating thickness.

If any individual DFT measurement is less than the specified minimum value, then the coating thickness should be measured at 1-m (3-ft) intervals along the pipe length. The average of these measurements must exceed the specified minimum value and no individual value may be more than 50 μm (2 mils) less than the specified minimum value.

Holiday Inspection



Figure 25.15: Holiday Inspection

The coating inspector may be required to perform or monitor holiday inspection, however, the coated pipe must be cooled to a temperature below 90°C (194°F) before such testing can proceed.

A high-voltage DC holiday detector is used to check for holidays in accordance with NACE Standard RP0490, *Holiday Detection of Fusion-Bonded Epoxy External Pipeline Coatings of 10 to 30 mils (0.25 to 0.76 mm)*.

According to this standard recommended practice, the minimum testing voltage should be within 10% of the value determined from the formula:

$$\text{Testing voltage} = V = K\sqrt{T}$$

V= Voltage in volts

T= Nominal coating thickness in mils

K= Constant =525

For example, based on this formula, the testing voltage for a 0.25-mm (10-mil) coating would be 1,650 V, and for a 0.41-mm (16-mil) coating the voltage would be 2,100 V.

Repairs to Holidays

Pipe coatings containing holidays must be repaired or recoated in accordance with NACE Standard RP0394, *Application, Performance, and Quality Control of Plant-Applied, Fusion-Bonded Epoxy External Pipe Coating*.

The inspector may be required to monitor the repairs to holidays.

Generally, holidays can be repaired by using hot-melt sticks or a two-part liquid epoxy or equivalent. These repair materials must be furnished by or approved by the powder supplier. The hot-melt stick method requires the use of a hand-held liquid propane gas (LPG) torch to melt a stick of partially reacted FBE resin to the holiday in a process similar to soldering.



Figure 25.16: Hot-Melt Stick Repairs

The surface to be repaired should be suitably prepared to ensure adhesion of the patch material; usually this can be done by sanding around the holiday.

Patched areas should overlap the parent coating a minimum of 13 mm (0.5 in.). Areas 25 mm (1 in.) in diameter usually are patched with the suppliers' recommended hot-melt patch stick or a two-part epoxy or equivalent.

Areas larger than 6.4 mm (0.25 in.) in diameter and smaller than 130 cm² (20 in.²) should be patched with the powder suppliers' recommended two-part epoxy or equivalent. The total maximum repaired areas for each pipe should not exceed 520 cm² (80 in.²).

Any pipe that must be recoated because of excessive holidays, mechanical damage, etc., must first be stripped of the coating by heating the pipe to a temperature not exceeding 270°C (527°F) in order to soften the coating, which is then removed by scraping, then abrasive blasting.

Pipe Identification Markings

After this inspection process has been completed, protective or masking covers on the pipe ends, if used, are removed, and a pipe control number is stenciled on the interior of each pipe end.

Some users specify identification markings to be placed on the coating at the pipe ends. These markings may include:

- Applicator's name or mark (work order number)
- Markings required by the applicable pipe specification or standard (grade, weight, manufacturer, etc.)
- Date of coating
- Coating material identification
- Additional markings as desired by the applicator or requested by the user (purchase order number)

Preparation of Pipe for Storage or Loading Out

The pipe is fitted with full-encirclement separators. These separators should be located within 0.9 m (3 ft) of the pipe ends and at one or more equidistant intermediate location(s) less than 5.5 m (18 ft) apart. The separators near the pipe end should not interfere with the readability of identification markings.

These separators, which are made of polypropylene rope, are slightly larger than the pipe's outside diameter. When placed on the coated pipe, they support and separate the sections of coated pipe as it is nested for storage or transportation to the installation site.

Laboratory Testing

In addition to the inspection steps conducted in the plant and the field, other quality-control procedures may be performed in a testing laboratory often located in the coating facility. The coating inspector may be required to monitor or even perform some of the tests.

Generally, laboratory testing is performed on the powder coating materials and on selected coated pipe specimens.

The specimens are smaller sections obtained from production test rings taken from each pipe size (distinct combination of diameter and wall thickness). The minimum frequency for obtaining test rings is determined by the user.

Some of the more frequently performed tests include:

- Gel time, a determination of the time required for the heated powder to transform from a liquid to a gel or semi-solid; usually 15 to 20 seconds. This particular test is used by the powder manufacturer on stock-stored materials prior to shipment, and again by the coating plant laboratory. The gel time, in seconds, must meet the supplier's specification, plus or minus 20%.

- Cure characteristics of the FBE. This test is usually conducted using an instrument known as a *differential scanning calorimeter* (DSC), which measures the degree or completeness of cure of the resin by measuring its heat distortion resistance.
- Impact resistance (ASTM G 14).
- Bending or flexibility (Modified ASTM G 10). This test may be used to determine the bond strength.
- Hardness (usually determined by the ASTM D 2583 [*Barcol Hardness Test*] or ASTM D 2240 [*Shore Hardness Test*])
- Cathodic disbondment. One of the most commonly performed tests on production-run FBE-coated pipe is a 24-hour cathodic disbondment test. Because most users specify that the coated pipe pass this test as a condition of its acceptance, it is shown here in some detail. Retained samples may be tested for longer periods after the pipe has been accepted.

Generally, this test is a modification to ASTM G 95, *Standard Test Method for Cathodic Disbondment of Pipeline Coatings (Attached Cell Method)*.

In this test, a plastic cylinder is cemented to the surface of the coated pipe specimen. The cylinder is centered over an intentional holiday (3-mm [0.13-in.] in diameter) in the coating and sealed to the test sample surface with a waterproof sealing material.

The cylinder is filled with an electrolyte, impressed-current anode, reference electrode, and other necessary equipment. The test is conducted for 24 hours at -3.5 V, with the temperature of the electrolyte maintained at 66°C (±3°) (150°F [±5°]).

After 24 hours, the sample is removed, rinsed, and air-cooled to room temperature. Evaluation should be made within one hour of removal from the heat source.

Using a utility knife, radial cuts at about 45° are made from the edge of the holiday outward through the coating

to the substrate. The radial cuts must be at least 20 mm (0.8 in.) in length.

The blade of the knife is inserted under the coating, and a prying action is applied to chip off the coating. This procedure is continued until the coating demonstrates a definite resistance to the prying action.

The radius of the disbonded area from the holiday edge along each radial cut is measured and the results are averaged. The maximum radius of the disbonded area should not exceed 8 mm (0.3 in.).

Disbondment radii greater than 8 mm (0.3 in.) generally indicate that problems exist in either process control or in powder quality. Some users specify a maximum cathodic disbondment test radius of less than 12 mm (0.48 in.).

Next, a new reference holiday is drilled in an area that was not immersed; radial cuts are made as before; and efforts to chip off the coating are made with the utility knife.

The two test areas are compared and the following information is recorded:

- Manufacturer, product code, batch number, and date tested
- Pipe identification, if applicable
- Average disbonded radius

Other laboratory tests may include:

- Porosity, a determination of the porosity or voids in the applied coating
- Hot-water soak, an accelerated assessment of the coating's adhesion to the substrate in a hot, wet environment
- Miscellaneous tests such as abrasion resistance, shear resistance, penetration, etc.

The inspector may check the samples of the powder materials to determine:

- Storage conditions, including temperature and moisture control
- Particle size
- Mix ratio of the original-to-recycled powder

FBE coating operations may vary slightly, depending on the specific plant, and the inspector should be aware of the impact that different coating sequences may have on the quality of the plant coating process.

The inspector also should become thoroughly familiar with the various test procedures that may be required during FBE-coating operations.

Installation of FBE-Coated Pipe

The following slides relate to the storage, handling, and installation of FBE-coated pipe onshore and offshore. In most cases, these operations are similar to the storage, handling, and installation of pipelines coated with other types of materials.

In the field, the coating inspector may be required to monitor the overall installation process, and the inspector may:

- Look for any mechanical damage to the coating caused by handling operations
- Observe application of field-joint (girth-weld) coating
- Monitor holiday inspection process
- Observe pipe bending process, looking for damage to the coating



Figure 25.17: Storage of Coated Pipe Fitted with Full-Encirclement Separators



Figure 25.18: Lifting Pipe With Electromagnets in Lieu of Padded Slings or End Hooks



Figure 25.19: Bending Pipe Using Internal Mandrel and External Bending Shoe
Maximum Allowable Bend is One Degree Per Diameter Inch of Pipe



Figure 25.20: Burying Coated Pipe in Rocky Soil



Figure 25.21: Burying Coated Pipe in Sandy Loam Soil



Figure 25.22: Burying Coated Pipe in Hills and Mountains



Figure 25.23: Coated Pipe Spooled onto Storage Reel for Offshore Lay



Figure 25.24: Lay Reel with Connecting Lay Reel Containing Pipe Straightener

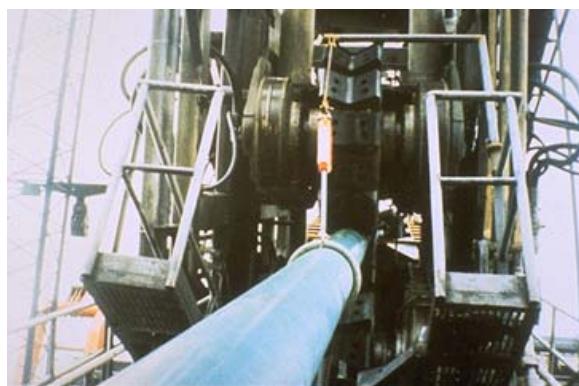


Figure 25.25: Pipe Exiting Straightener With Holiday Detector in Operation



Figure 25.26: Typical Offshore Lay Barge Installing FBE-Coated Pipe Overcoated with Weight Coating



Level 2

Chapter 26

Inspection and Reporting

Inspection and Reporting Procedures

Introduction

In CIP Level 1, some of the procedures a coating inspector may follow were discussed. Also, an outline of a typical work day for a coating inspector on an offshore platform was presented.

The discussion today will focus on many of the details of an inspector's working procedures and the day-to-day role of a coating inspector in a normal work environment.

It is important to realize that almost every user of third-party coating inspection has his/her own concept of what the duties of the inspector should be. There is no general agreement within industry on the day-to-day activities of coating inspection. The inspector often will find that the job will vary with the client.

Some clients regard the inspector as a project supervisor and, in addition to normal quality control testing, may expect him to:

- Supervise the labor force
- Control material stocks and order materials
- Organize transportation and material deliveries to the job site (for example, offshore).
- Check safety

Other clients may specifically instruct the inspector to focus only on quality-control issues, such as:

- Observe the work
- Make inspection tests
- Take measurements

- Document the work
- Issue nonconformance reports
- Report directly to the client
- Avoid any direct communication with the contractor and workers

These are two distinctly different viewpoints; the inspector, on occasion, may be called on to represent either extreme, or some other viewpoint in between.

For the purpose of the CIP, NACE has defined the inspector's role as that of a quality-control technician:

The inspector is responsible primarily for observing and reporting the technical aspects of a coatings project. Supervision of labor is not considered to be part of the role of the inspector.

In the real world, the inspector's most important task is to determine what the client expects. Sometimes that can be a difficult task, because the role may not have been defined by the client.

Mostly through a process of reading and discussing the specification with the client, the inspector should be able to match the job requirement with the client's expectations. Good inspectors often find they form a working relationship with the client such that the client begins to rely on the inspector for more than a coating inspection role.

While this may be good for all concerned, it is important that the inspector not become involved in any disciplines and activities that essentially are outside his field of expertise.

Inspection Procedures

An ideal specification would contain a procedure for the inspector to follow in performing inspection duties. Such an inspection procedure would define the inspector's task and could contain such items as:

- A comprehensive statement of the inspector's authority and responsibilities
- When, where, and how many measurements to take
- Which instruments to use
- Guidelines for preparation and submission of inspection reports, including NCRs (nonconformance reports)
- An organizational chart showing the chain of command and the inspector's position

If such procedural guidelines do not exist, then it should be the inspector's prime responsibility to establish his own procedure. A well-prepared procedure should contain all the same elements.

Pre-Job Conference

The pre-job conference provides an opportunity to analyze and discuss the procedures and processes to be used on a project. The major purpose of a pre-job conference is to ensure that all parties, including the contractor, his site supervisor, the engineer, the coating supplier, and the inspector, know what is required by the client's specification and what restrictions, if any, apply.

The meeting provides an opportunity for the personalities involved to meet and get to know each other and to understand some of the concerns of others. It also can help prevent problems.

The inspector's duties at the pre-job conference may include:

- Contribute an understanding of the specified inspection criteria and the tools and methods that will be used.
- Ensure that every clause of the specification is understood.
- Highlight areas of the specification that may create conflict (e.g., differences between the specification and the coatings technical data sheets) and promote discussion to try to achieve resolution.
- Highlight potential problems based on past experiences and discuss proposed solutions. This should be a positive contribution.
- See that an accurate written account of the discussion is prepared. (With luck, a professional secretary will be on hand to keep minutes; if not, someone needs to do it.) If at all possible, the inspector should concentrate on the discussions and should not be required to keep minutes.

The inspector provides a crucial element of the team undertaking a protective coatings project. The inspector's presence at the pre-job conference should be considered mandatory.

Specification Documents

The specification document should contain references to other documents, including national standards, safety regulations, and company requirements. In addition, there should be references (which may be implied) to coating material technical data sheets and to material safety data sheets (MSDS).

The inspector's duties with respect to this documentation are:

- Read and understand the meaning of every word of these documents.
- Anticipate problems that may arise from conflicts about documents and attempt to establish a resolution.
- Understand the requirements and the spirit of the specification documents. This should help ensure that the specification is fully and fairly implemented during the project.

As with many other aspects of the inspector's duties, it may be wise to communicate any concerns in writing to the parties involved and to try to get answers or resolutions in writing.

Work Schedules

Many specifications require a coating applicator to prepare and submit a schedule showing the planned program of work for the project. The only involvement here for an inspector would be if the client asks for an opinion regarding the quality of the schedule planning.

However, the inspector should review the work schedule. If any conflicts occur or if the schedule is unrealistic, the inspector should bring this to the attention of the owner.

Typical scheduling errors may include:

- Coating operations intervals which are too short or too long
- Blast cleaning operations adjacent to painting operations
- Scaffold being dismantled without allowance for touch-up coating work

Progress Records

The work schedule depends on the day-to-day performance of the applicator. If the applicator does not follow the plan, or if no plan exists the project may fall behind schedule. This may result in the disruption of the owner's long-term planning.

Most inspectors realize that delays can cost money; as much as \$1 million per day is quoted for an oil platform's lost production, or \$50,000 per day for a ship out of service.

Many owners require the inspector to maintain a record of progress, either for planning purposes, or perhaps to allow the owner to make stage payments for work completed to date.

The client may require the inspector to:

- Estimate the square meters (feet) of surface completed each day.
- Maintain a record of work completed, estimated in terms of percentage of the total project.
- Compare progress with the work schedule and try to find the reason for any delays.

If this kind of recordkeeping is not required, it is still a good idea for the inspector to monitor progress. The inspector should discuss with the supervisor the daily action plan and suggest modifications, if necessary. Often the inspector will be aware of technical matters, (e.g., over-coating intervals) which may affect the applicator's planning.

Application Preparation

Most specifications require the applicator to take action to prepare a site for coating operations prior to work commencing. Most applicators want to "get on with it."

The inspector is the observer who can see best whether the site is ready for work to commence and request necessary additional preparation before work begins.

The inspector should:

- Check the masking of sensitive areas of the site, including instrument glasses, identity plates, breather holes, electric components, etc.
- Note the presence of drainage inlets that could be blocked or otherwise affected by site operations.
- Ensure that existing coatings or partially coated surfaces are protected from over blast or overspray.
- Check containment screens.
- Ensure that required hazard warning signs are in place.
- Check level of contaminated steelwork requiring pre-treatment, also sources of contamination, e.g., vents or dirty scaffolding.

Equipment

The equipment used for surface preparation and coating application is essentially the responsibility of the applicator. The owner may not consider inspection of the equipment to be a major concern of the inspector. A prudent inspector should at least look over the equipment because:

- Dirty or defective equipment can be one of the first signs of a disorganized applicator.
- Missing or defective items of equipment may impede progress on the project.
- Wrong equipment may show that the applicator, or his site supervisor, may not understand the nature of the project.

- Defective equipment may be unsafe.

For all these reasons, the inspector should check over the applicator's equipment, checking general cleanliness and determining if all the required equipment is present.

Operators

Some owners now require that the site operators (blasters and sprayers) be qualified to perform their duties in much the same way that welders may be certified on a job-by-job basis.

Programs are in place in the United States and Europe and some are being planned in other countries to train and certify blasters and sprayers.

The inspector should:

- Be aware of the contract requirements for certified personnel and know which operators are certified and for which skills.

Even in cases where there is no formal requirement, the inspector, through experience, will discover which operators are skilled and which are not. Unskilled operators may be detrimental to the overall quality of the project. In extreme cases, the inspector should:

- Note which operators are not adequately skilled and inform the client through proper channels.

Ambient Conditions

One of the more familiar requirements for the coating inspector is to monitor the ambient conditions at the time of blast cleaning, coating application, and during curing of coatings.

The principal restrictions on temperature, relative humidity, dew point, etc., normally are defined by the specification. Experience quickly will show the inspector

when to make measurements and how often. As a minimum, the inspector should:

- Measure and record air temperature, relative humidity, dew-point temperature, and substrate temperature at least four times during a working day.

The most important times to make these measurements are:

- Prior to commencement of work to determine whether work may start
- When weather conditions appear to be changing or unstable
- At commencement of a new activity (i.e., when ready to begin painting)

Normal restrictions on ambient conditions include:

- No rain, snow, fog, or mist
- No water on the substrate
- Air temperature above 10°C (50°F)
- Relative humidity below 85%
- Substrate temperature more than 3°C (5°F) above dew-point temperature

There are times when these conditions seem to be comfortably exceeded. It is important that the inspector maintain accurate and timely records. This allows the owner to reexamine the information on ambient conditions at some future date and determine that the specification was met.

Surface Preparation

Surface preparation is considered the most critical aspect of a coating project. It follows that the inspector can be of most value by carefully implementing the specification at this stage of the contract.

While projects vary, some inspection activities are almost universal, including:

- Visually examining the substrate prior to blast cleaning or power tool cleaning to ensure there are no inherent defects (such as laminations or cracks) or detrimental contamination such as mud, oil, or construction debris.
- Checking blast cleaning air to ensure it is free of oil and water. This is particularly important at the start of the work day, although air should be run through the lines for a few minutes before checking. Condensation probably will be in the pipes from the previous day and not until the equipment has reached operating temperature will the condensation disappear.
- Checking to see that in-line oil and water traps are functioning and empty of unwanted material
- Observing the surface preparation operations for the appearance of any unusual surface coloration which may indicate water or oil in the blasting air
- Visually checking the abrasive being used to see if it appears the same as previous supplies. If it does not, the inspector may:
 - Throw abrasive in the air to see if any dust floats out
 - Conduct a vial test to check for contaminants
 - Conduct a sieve analysis to check the size
- Measuring anchor profile at specified intervals.

- Visually inspecting the blast cleaned surface to determine:
 - Surface cleanliness to see if it meets the standard
 - Surface profile pattern to see if it is angular or rounded and what was expected
 - Cleanliness of surface and any color irregularities
 - If all surfaces have been blast cleaned
 - All areas, including under edges, close to the ground, and behind the flanges, meet the standard (Note: an inspection mirror can be useful at this stage)
- Marking all areas that may have been inadequately blasted for subsequent reworking, using a grease-free marker such as school chalk
- Checking edges to ensure sound coatings and necessary feathering
- Observing rework and checking those areas again
- Ensuring applicator removes abrasive (blows down) and makes final visual check. In enclosed spaces, a vacuum-cleaning device may be required.
- Making clear tape test to ensure dust has been removed

Coating Application

Coating application begins with a basic knowledge of the coating materials and their principal characteristics. As part of the inspector's review of the project documentation, some knowledge of the coating materials should have been gained.

Practical experience with the specified products may be an advantage. But the inspector should be able to rely upon the past performance of the generic coating type. The inspector should be able to rely on the technical data

sheets and the manufacturer's technical support group to provide technical advice and guidance.

Inspection at a relatively early phase of the project would require the inspector to:

- See that the coatings delivered to the site are those specified.
- Check the date of manufacture through the batch numbers to ensure coatings are within their shelf-life. The inspector should note that many different batch numbers may indicate poor stock control and/or storage procedures.
- Determine that multi-component materials have matching components in the required quantities.
- Check material storage conditions such as temperatures to ensure compliance with manufacturer's or pacifier's guidelines.
- Check the condition of the unopened containers to see that they are not rusty or leaking.
- Ensure applicator has the necessary equipment to apply coatings specified.

Prior to completion of surface preparation, the applicator may have his personnel mix the coating materials and set up the equipment in preparation for the next phase of the operation. The inspector should:

- Check the condition of the coating material as the cans are opened. If the material looks strange, has gelled, or is the wrong color, the inspector should see that it is set aside and open some more containers. If the material condition appears to be the same when more containers are opened, the inspector should alert the client, the contractor, and material supplier.

- Observe the mixing process. Check both the method of mixing and the effectiveness, looking for signs of ineffective mixing, such as swirls of different liquids, or lumps.
- Check the empty cans to ensure that all pigments and all components have been mixed.
- Count the empty cans to see how much material was mixed and determine if an equal number of component cans have been used.
- Observe contractor in mixing partial quantities to ensure accurate measurement of each component.

Partial mixing proportions may be maintained by careful measurement in graduated containers, or by dipstick measurement in parallel-sided containers.

A common mistaken assumption made by many applicators is that all coatings require the addition of solvent prior to application, particularly for spray applications.

In fact, most industrial protective coatings might be more reliably applied if solvents were not added.

The inspector should:

- Observe the addition and mixing of solvent, if any.
- Record the quantity and type of solvent added.
- Ensure that the quantity and type of solvent meets the requirements of the specification.

When surface preparation has been completed successfully, application of coatings should begin. At the time of application, the inspector should:

- Measure and record ambient conditions to ensure compliance with the specification.
- Record the type of application equipment used, including details of spray tips and pressures.

- Check equipment, including oil and water traps in air supply lines to conventional spray equipment, to ensure no contamination reaches the paint.
- Observe the application operation, looking for:
 - Even coverage, with no observable boundaries between spray passes, brush overlaps, etc.
 - Evidence of poor adjustment of spray equipment, such as dry spray, uneven spray pattern, spray fog, clogging of the spray gun, etc.
 - Consistent color
 - Runs, sags, misses, etc.
 - WFT measurements by painter
- Check WFT using his own gauge, notifying the contractor if the WFT does not comply with the specification.
- Look for signs of poor workmanship, such as improper cleaning of equipment.



Figure 26.1: Runs and Sags

Inspect Coating Film

The finished coating film should provide the appearance and protection that are the purposes of the project. Many paint film defects are a result of the application process and may be seen and even remedied at the application stage.

Therefore, the inspector should be constantly observing the quality of the coating film, both during the application phase and during the drying and curing phase.

Many coating defects were described in CIP Level 1.

In particular, the inspector may watch for:

- Pinholes and blisters, which may indicate film formation problems due to solvent imbalance or substrate temperature
- Fisheyes, which may indicate a contaminated surface
- Dirt in the film, which indicates poor housekeeping during application
- Dry spray, which indicates poor management of the spray operation
- Runs, sags, and misses, which indicate poor spray technique
- Overspray on adjacent surfaces, which indicates a need for better containment

One of the most recognized coating inspection tasks is the measurement of dry-film thickness. The inspector should:

- Ensure that his DFT gauge is properly calibrated, frequently calibrating his gauge to the contractor's gauge. Any deviation should be recorded and factored in the reported results.
- Measure DFT with the specified instrument and at the specified frequency. If no frequency is specified, 15

measurements per 9.3 m^2 (100 ft 2) (SSPC-PA 2) is a reasonable figure to use.

- Ensure the measured DFT falls within the requirements of the specification.

Daily Reports

A principal duty of the inspector is to record the technical details of the project. It has been said previously that projects are likely to vary in their requirements of the inspector and the reports.

Most clients have either their own report form or are happy to use the reporting format of their chosen third-party inspection company. If necessary, the inspector can devise a standard report form acceptable to the client.

Whichever reporting format is chosen, the inspector should:

- Fill out the report form as completely and accurately as possible. It is good practice to write *Not Applicable* or *None* in spaces where no report is required. This can be more informative to the client than simply leaving blank spaces. If a report form has space for five DFT measurements, the inspector should try to record five DFT measurements.
- Make the report neat and legible, using a dictionary or spell checker as needed.
- Fill out the report as the day progresses. The longer a report is delayed, the less likely it is to be complete and accurate.
- Get reports in on time.

Site Clean-Up

Like the care of application equipment, it has been said that site clean up is the concern of the applicator, not the inspector. However, a site that is not kept tidy throughout

a project or is not cleaned at the end of a project may constitute a safety hazard. It could reflect badly on the applicator and the inspector.

At the very least, the inspector should:

- Bring poor housekeeping and clean-up practices to the attention of the applicator. If this fails, he should report to the client in writing.

In the current climate of legal restrictions on hazardous waste, site clean-up in general and waste disposal in particular are a matter of concern to all parties. The inspector should:

- Be aware of the nature of the waste materials and of any restrictions in their collection, handling, or disposal.
- Keep the client informed of the practices for handling hazardous waste materials.
- Ensure that waste material handling complies with the requirements of the specification, or report any noncompliance in writing.

Safety

The safety regulations that govern a project should be detailed in the specification. The inspector has a *duty of care* to himself, primarily, but to other personnel on the job site and to the client, as well.

The *duty of care* requires that the inspector take all reasonable steps to protect herself/himself and fellow workers and to use experience and knowledge to prevent the occurrence of accidents.

As an example:

The inspector should:

- Familiarize herself/himself with the location of medical facilities, telephone, hazard warning systems, escape practices, etc.
- Comply with all safety requirements that apply to the job site or work facility.
- Report any unsafe working practices to the proper authority (usually the client).

All the above duties are stated as examples of the inspection process, and may be modified to suit a particular project. Coating inspection is a variable occupation, and the inspector will probably always encounter new situations and new demands on his expertise.

The inspector should try to apply the best principles of quality control while maintaining the integrity for which his client employs him.



NACE Standard RP0490-2001
Item No. 21045

Standard Recommended Practice

Holiday Detection of Fusion-Bonded Epoxy External Pipeline Coatings of 250 to 760 μm (10 to 30 mils)

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Foreword

Detection and correction of defects in protective coatings are important factors in an effective corrosion control program. High-voltage electrical inspection of pipeline coatings prior to installation is one method in general use. Prior to issuance of this NACE International standard, there had been no U.S. standard for electrical inspection of fusion-bonded epoxy pipeline coatings. Although several specifications have been written by operating companies for high-voltage electrical inspection of protective coatings, they apply only to specific coatings. This standard is intended to serve the needs of pipeline owners, coating applicators, coating inspectors, and other interested parties in the electrical inspection of fusion-bonded epoxy pipe coatings.

This standard recommended practice was originally prepared by NACE International Work Group T-10D-9c on Electrical Inspection and its parent, Task Group T-10D-9 on Coating Inspection, a component of Unit Committee T-10D on Protective Coating Systems. Unit Committee T-10D reaffirmed the standard in 1995. This standard, now issued by NACE International under the auspices of Specific Technology Group (STG) 03 on Protective Coatings and Linings – Immersion/Buried, was developed through the joint efforts of representatives of coating manufacturers and applicators, holiday detector equipment manufacturers, corrosion specialists, and others concerned with the construction of underground pipeline facilities, as represented in STG 03. This standard was reaffirmed in 2001.

These recommendations apply only to fusion-bonded epoxy pipeline coatings, which are generally applied at a dry-film thickness of 250 to 760 μm (10 to 30 mils). For other types of patching materials and joint wrap, the manufacturer of the material should be consulted for holiday detection voltages. Conformance to the principles of this standard improves methods of holiday detection and, therefore, the effectiveness of the coating.

In NACE standard, the terms *shall*, *must*, *should* and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. *Should* is used to state something considered good and is recommended but is not mandatory. *May* is used to state something considered optional.

**NACE International
Standard
Recommended Practice**

**Holiday Detection of Fusion-Bonded Epoxy External Pipeline
Coatings of 250 to 760 μm (10 to 30 mils)**

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Section 1: General

1.1 This standard presents recommended techniques in the operation of holiday detector equipment currently used on fusion-bonded epoxy (FBE) pipeline coatings prior to on-site installation of the pipeline. It also presents recommended voltages for various coating thicknesses. Guidelines for establishing minimum requirements to ensure proper application and performance of plant-applied, fusion-bonded epoxy coatings are presented in NACE Standard RP0394.¹

1.2 Electrical inspection (holiday detection) is a test of the continuity of a protective coating. This type of inspection is not intended to provide information on coating resistivity, bond, physical characteristics, or the overall quality of the coating. It detects voids, cracks, foreign inclusions, or contaminants in the coating that are

of such size, number, or conductivity to significantly lower the electrical resistance or dielectric strength of the coating.

1.3 Use of a holiday detector shall be under the direction of a qualified coating inspector, such as a NACE-certified coating inspector. An initial holiday detector inspection, performed as soon as practical after the application of the coating, assists in verifying conformance to specifications for the materials and the application procedures. Before the coated pipe is placed in the ground, a final electrical coating inspection discloses coating discontinuities or damage that may have occurred during the shipping, storage, or construction period.

Section 2: Definitions

Continuous Direct Current (DC) Voltage Holiday Detector: A holiday detector that supplies a continuous DC test voltage. The continuous DC-type holiday detector is often used in very arid, sandy, or rocky areas and in coating plants where moisture and contamination conditions are controlled. The continuous DC test voltage holiday detector cannot be used where continuous moisture is present on the surface of the coating. For proper inspection using continuous DC-output test voltage, other than in coating plant operations, the fusion-bonded epoxy coating surface must be dry.

Generated Test Voltages: With two types of commercially available detectors, generated-output test voltages are used for the electrical inspection of fusion-bonded epoxy pipeline coatings. They are commonly described as *pulse-DC* and *continuous-DC* test voltages.

Holiday: A discontinuity in a protective coating that exposes unprotected surface to the environment. For the purpose of this standard, the term is used interchangeably with *discontinuity*.

Holiday Detector: An electrical device that locates discontinuities in the protective coating.

Pulse-DC Voltage Holiday Detector: A holiday detector that supplies a high-DC voltage pulse of a very short duration (such as 0.0002 seconds at a rate of 30 pulses or more per second). The pulse-type holiday detector is the most common type used in the industry, and it can be used on damp or dry coatings.

Section 3: Testing Voltages

3.1 All holiday detector output test voltages in this standard refer to pulse-DC and continuous-DC values.

3.2 The minimum effective applied output test voltage is dependent on coating thickness, atmospheric conditions, electrode configuration, and grounding conditions. Therefore, the applied test voltage varies from case to case.

3.3 To determine the minimum effective applied test voltage for a given set of field conditions, the following field calibration should be performed daily:

3.3.1 Make a holiday 790 μm (0.031 in.) in diameter through the fusion-bonded epoxy coating. Ensure that the hole extends completely through the coating to the metal substrate.

3.3.2 Start with the lowest test voltage setting of the holiday detector and slowly increase the test voltage until the manufactured holiday can be positively detected at normal operating speeds (see Paragraphs 5.3 and 9.2 and Section 6).

3.3.3 This method of test-voltage adjustment shall be performed while the exploring electrode and grounding are in the expected operating positions. If the above conditions change, it may be necessary to readjust the test-voltage setting.

3.4 Alternatively, the pipe-to-electrode test voltage can be adjusted to the minimum test voltages described in Paragraph 3.5, which are commonly used in the pipeline industry. Output test voltages may be somewhat higher than these test-voltage settings; the differential depends on grounding conditions and detector type.

3.5 The minimum testing voltage for a particular coating thickness shall be within 10% of the value determined by Equation (1):

$$\text{Testing Voltage} = V = K\sqrt{T} \quad (1)$$

where V = peak voltage in volts, T = nominal coating thickness in μm , and $K = 104$ (constant).⁽¹⁾

Table 1 gives calculated voltages for coating thicknesses of 250 to 760 μm (10 to 30 mils).

TABLE 1
Recommended Test Voltages for Various FBE Coating Thicknesses

Coating Thickness	Test Voltage ^(A)
250 μm (10 mils)	1,650 V
280 μm (11 mils)	1,750 V
300 μm (12 mils)	1,800 V
330 μm (13 mils)	1,900 V
360 μm (14 mils)	1,950 V
380 μm (15 mils)	2,050 V
410 μm (16 mils)	2,100 V
510 μm (20 mils)	2,350 V
640 μm (25 mils)	2,650 V
760 μm (30 mils)	2,900 V

^(A) Rounded to the nearest 50 V.

3.5.1 The test voltage should be verified periodically (see Paragraph 3.3.3).

3.5.2 If an outerwrap is applied over the primary coating, the thickness and dielectric strength of the outerwrap material must be considered when determining or specifying the test voltage. Certain

outerwrap materials may have electrical insulating properties equal to or greater than the coating.

3.5.3 Consumer-specified test voltages used at the coating site at the time of coating application shall not be exceeded during the on-site electrical inspection of the coating.

Section 4: Grounding

4.1 Proper electrical grounding of the holiday detector to the coated pipe under inspection is necessary to complete the electrical circuit.

4.1.1 The coated pipe metal must have electrical contact to earth at one or more points. An electrical ground of the pipe can be effected by electrically connecting the pipe metal to a metal grounding rod

driven into the earth to a depth of 60 to 90 cm (2 to 3 ft).

4.1.2 The holiday detector can, in most cases, be effectively grounded electrically by the use of a flexible ground wire of approximately 9 m (30 ft) in length that is connected to the ground terminal of the holiday detector and trailed along the surface of the

⁽¹⁾ For coating thickness in mils, use $K = 525$.

earth. The first 1 to 1.5 m (4 to 5 ft) of the ground wire extending from the ground terminal of the holiday detector must be adequately insulated to prevent possible electrical shock to the operator. In some instances the bare end of the ground wire must be attached to an independent driven earth rod to ensure adequate electrical grounding.

4.1.3 In arid, sandy, or rocky areas where earth resistivity prevents effective holiday detection by creating high circuit resistivity, a direct wire connection between the pipe metal and holiday detector ground terminal shall be maintained. Additional ground wire (0.324 mm² [22 AWG] minimum) of any length may be used in making connections between the holiday detector ground terminal and the pipe metal.

Section 5: Exploring Electrode

5.1 The exploring electrode is the means by which the electrical potential is applied to the surface of the coating.

5.1.1 Typically, electrical holiday detector exploring electrodes are manufactured in two basic forms. The most common electrode is the full-circle wire spring type, which, when placed around the coated pipe in operating position, allows for complete circumference inspection with one pass by rolling the spring electrode over the coated surface. The second type is in the form of a brush made of conductive rubber or brass bristles.

5.2 The construction of the exploring electrode shall be such that there is no more than 250 µm (10 mils) lateral distance between the spring coils or brass bristles at the area where the electrode contacts the coated surface.

5.3 The exploring electrode shall maintain contact with the coated surface at all times.

5.4 The exploring electrode shall be kept clean and free of coating material and rough surfaces that might damage the coating.

Section 6: Travel Speed of Exploring Electrode

6.1 Pulse-type holiday detector: The output test voltage pulse rate must be considered in determining the travel speed of the exploring electrode over the coated surface. Faster pulse rates allow a higher speed of travel of the exploring electrode over the coated surface.

6.2 The proper travel speed for a particular set of conditions shall be determined by making holidays in the coating and attempting to detect the holidays at various electrode travel speeds (see Section 3, particularly Paragraph 3.3.2).

Section 7: Test Voltage Measurements

7.1 Test voltage measurements of pulse-type holiday detectors shall be made with a peak-reading kilovoltmeter or with a capacitance or resistance voltage divider and suitable indicator such as an oscilloscope or voltmeter.

7.2 Test voltage measurements of continuous DC-type detectors shall be made with a high-resistance DC voltmeter.

7.3 The exploring electrode must be in the normal operating position on the coated surface in a holiday-free area.

7.4 The holiday detector and the coated pipe must be electrically grounded (see Section 4).

7.5 The test voltage shall be measured between the electrode and the pipe metal.

Section 8: Condition of Coating Surface

8.1 Electrically conductive material, such as contaminating moisture, in or on the surface of the coating system can cause appreciable DC leakage

through the holiday detector circuit, producing false signals. This may lower the effective test voltage or

falsely indicate holidays. The contamination must be removed or dried prior to electrical inspection.

8.2 All foreign materials that cause an increase in the distance between the exploring electrode and the coated surface must be removed prior to electrical inspection (see Section 5).

8.3 The maximum temperature at which fusion-bonded epoxy coatings shall be electrically inspected is 90°C (195°F).

Section 9: Care of Equipment

9.1 All parts of the holiday detector shall be kept clean at all times.

9.1.1 The electrode shall be kept free of coating material and in suitable mechanical condition to maintain contact with the coated surface at all times.

9.1.2 All electrical contacts and connectors on the holiday detector shall be kept clean and free of corrosion.

9.1.3 The trailing ground wire shall be kept free of coating material and kinks and shall be in suitable condition to maintain electrical grounding with the earth. The ground wire shall be of sufficient length to ensure proper grounding (see Paragraph 4.1).

9.2 Batteries should be in full charge condition at the start of the inspection day. Batteries shall be maintained in accordance with the manufacturer's recommendations.

References

1. NACE Standard RP0394 (latest revision), "Application, Performance, and Quality Control of

Plant-Applied, Fusion-Bonded Epoxy External Pipe Coating" (Houston, TX: NACE).



Level 2

Chapter 27

Case Study D

Case Study

You are the inspector (the only inspector) on a crude storage tank coating job. The specification calls for a thickness of 100 to 150 μm (about 4 to 6 mils) per coat, with a total of three coats to be applied. The contractor is on a fixed-price contract, and is required to supply the paint as part of the contract. For some reason, attaining the specified thickness has been difficult, although after the first coat you are pleased that the contractor has become less difficult to deal with on this point. You have been very carefully taking and recording thickness measurements, as per the specification, after the first and second coat. There have been a number of areas where the minimum thickness was just barely attained. You have recorded a number of areas where the thickness is just 200 μm (about 8 mils). The gauge you are using is the latest microprocessor DFT gauge, which records readings in memory and can perform a variety of statistical functions, etc.

Retiring to your room for the night, you are making good use of your evening hours by organizing your field notes. This done, you have taken out your DFT gauge to check the calibration, and find that you have been using the gauge incorrectly and that your readings have all been off by at least 50 μm (2 mils) on the high side. You calculate that the thinnest spots on the tank are not 200 μm (about 8 mils), but only about 150 μm (about 6 mils).

You know that the contractor, who has been making the painters be quite careful to check their work frequently with a WFT gauge, is going to want to apply the coating at a WFT which will give as close to 100 μm (about 4 mils) for the third pass, which will result in a total thickness of 250 μm (about 10 mils) in most places, instead of the 12 required by the specification.

How would you deal with the situation?



Level 2

Chapter 28

Hot-Dip Galvanizing

Hot-Dip Galvanizing

Introduction

In CIP Level 1, we discussed a variety of ways to apply coatings to steel and concrete. Many of these methods were portable or field methods (operations) that also could be used in a manufacturing plant or a shop setup.

Now we will discuss some methods of applying metal coatings, both in the shop and the field.

Our objectives are to become familiar with the

- Application of coatings by:
 - Hot-dip galvanizing in the shop
 - Sherardizing
 - Aluminizing

Later we will look at other shop-coating techniques, such as:

- Dip
- Flow
- Flood
- Roller
- Electro-coating

Hot Dipping

Hot dipping consists of immersing the object to be coated into a bath of molten metal for a short period of time.

While metals other than zinc may be used, we will primarily discuss hot dipping in zinc, which is called *hot-dip galvanizing*.

In this section we will briefly discuss:

- Hot-dip safety
- Hot-dip process
- Hot-dip effect
- Faying surfaces
- Hot-dip galvanizing quality

Hot-Dip Safety

The hot-dip process involves the use of molten metal, and the coating inspector should exercise special safety precautions when working around the hot-dip kettle.

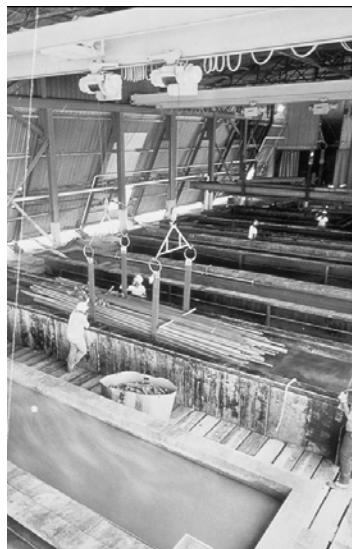


Figure 28.1: Hot-Dip Galvanizing Kettle

The inspector should learn and observe all plant safety rules and abide by all government regulations pertaining to the hot-dip process. The inspector should be aware of the following:

- Hot-dipped articles stay hot for some time. The article should be cooled thoroughly before touching or putting a gauge on it.
- Molten metal can splash quite far from the kettle. Sometimes when pipe is being galvanized, and is dipped too quickly, water vapor in the pipe expands rapidly, causing molten zinc to shoot out the end of the pipe and travel for some distance.
- Nascent hydrogen, picked up by steel during pickling (if the galvanized surface area is large enough, such as with grating), may be released fast enough and in great enough quantity to burn in the air above the kettle.

Hot-Dip Process

There are several major stages in the hot-dipping process.

- Surface preparation

The material to be hot-dip galvanized should be free of welding slag, rolled-in mill scale, paints, varnishes, oil, and grease.

Overlapping surfaces should be cleaned before fabricating, because any residual oil and grease may trap moisture, which creates a safety hazard during the hot-dipping process. Immersion in the molten zinc changes this moisture into steam, which causes miniature explosions in the zinc bath, producing uncoated areas adjacent to the unsealed areas, as well as creating a potentially hazardous condition.

Cleaning the fabricated pieces is generally a two-step operation. The work piece is dipped into a hot caustic

bath, or a similar solution, to remove oil, grease, and other organic contaminants.

Next, the work piece is thoroughly rinsed with clean water and immersed in a mineral acid bath (usually sulfuric or hydrochloric acid) to remove rust, mill scale, and other inorganic contaminants. After rinsing, the work piece is ready for the next step—fluxing.

Occasionally, after the degreasing operation, the steel may be cleaned by dry abrasive blasting. Sand castings must be abrasive blast cleaned to remove the burned-on sand from the casting operations.



Figure 28.2: Acid Pickling Tank

- Fluxing

The purpose of fluxing is

- To remove oxides that may have formed during the cleaning and handling process just prior to the actual galvanizing;
- To improve the *wetting* of the molten zinc onto the steel substrate, providing good adhesion and build up of the different alloys (see Figure 28.8).

Fluxing may be conducted as a *dry* or *wet* process.

- In the *dry* process, the items are immersed in a heated aqueous 20 to 40% solution of zinc ammonium chloride

called a *pre-flux solution*. The items are then thoroughly dried in an oven before being dipped in the molten zinc.

- In the *wet* process, the items are passed through a layer of molten zinc ammonium chloride which rests on top of the molten zinc.
- Dipping

All types of plain carbon and alloy steels as well as iron and steel castings can be galvanized. This includes materials ranging from bolts and nuts to large fabricated pieces.

The largest kettle in the United States can galvanize objects up to 25 m (82 ft) long, in a single dip. Objects larger than the kettle can be galvanized by a procedure referred to as *double dipping* (first dipping one end and then the other end).



Figure 28.3: Fabricated Piece Being Dipped into Zinc Bath

Small fabricated pieces can be mounted on jigs and dipped in batches. Larger pieces are dipped individually.

Small articles, including nuts and bolts can be placed in perforated baskets and then dipped.

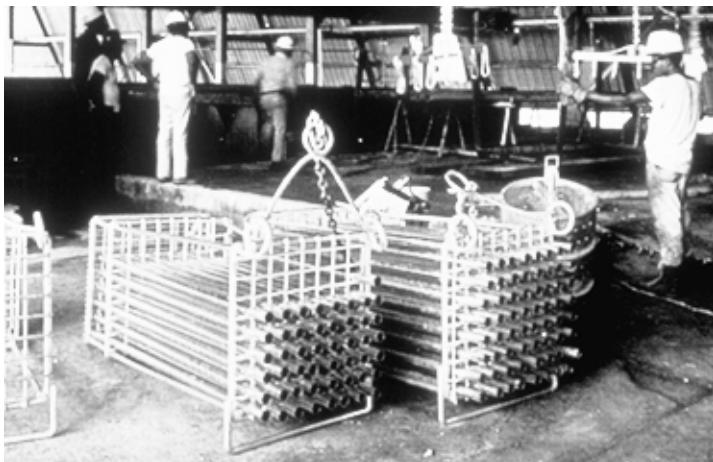


Figure 28.4: Perforated Baskets Used for Dipping Small Parts

Strip steel (sheet) can be continuously galvanized at a rapid speed.

Sheet steel can be dipped singly in rapid sequence.

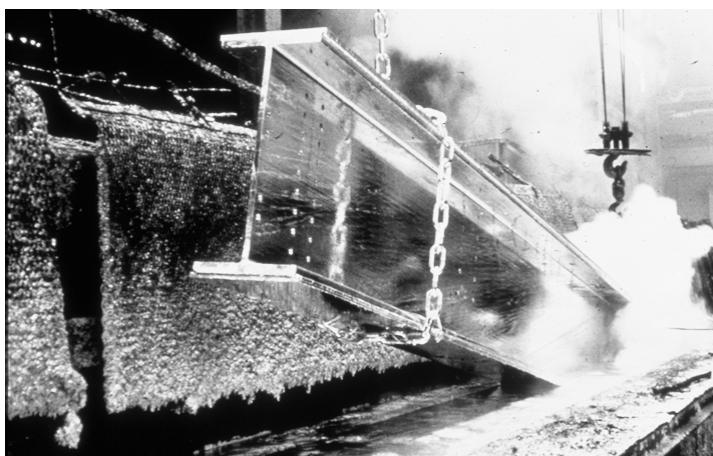


Figure 28.5: Steel Beam Leaving Bath

The work piece remains in the molten zinc until the alloying reaction is complete. Depending on the chemical composition of the steel and the configuration and mass of material being coated, this process can take from 30 seconds to eight hours. Generally the work piece must attain the temperature of the zinc bath, which may vary from 450 to 475°C (840 to 885°F).

Most galvanizers prefer to keep the temperatures of their kettles on the cooler side to prolong the life of the kettle. The galvanizing kettle is essentially a high-grade steel

plate firebox, 30 to 35 mm (1 to 1.5 in.) thick that usually lasts from two to five years.

When the alloying action is complete, the steel is removed from the kettle to air cool or it may be immersed in a water quench tank. The quench operation *freezes* any further reaction (alloying) between the steel and the zinc coating.

- Post treatments



Figure 28.6: Fabricated Steel Leaving Galvanizing Bath

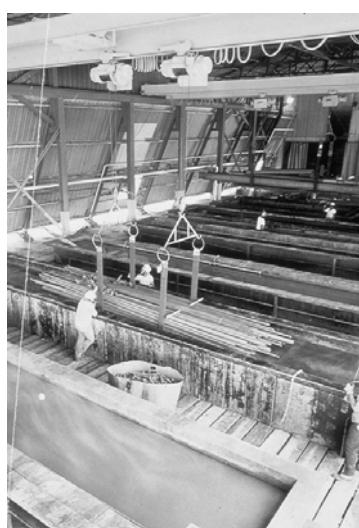


Figure 28.7: Galvanizing Small-Diameter Pipe

Post treatments are performed to produce one or more of the following results:

- Reduction of coating thickness by reducing the amount of molten metal adhering to the article as it leaves the bath. This may be done by rolling, wiping, centrifuging, or air blasting. These operations must be done while the coating is still molten.
- Improvement of the properties or the appearance of the coating may be accomplished by such treatments as chromating, phosphating, light rolling, and roller leveling.
- Change in the character of the coating. Hot-dipped zinc coatings are sometimes annealed to convert the whole of the coating into an alloy. Aluminum coatings intended for heat resistance may be converted into an alloy in the same way. Aluminum can be anodized and dyed attractive colors.

All these post treatments, except anodizing, immediately follow the hot-dipping process and are considered as part of the coating process.

- **Inspection**

At each step in the hot-dip process and after the entire operation, the work piece should be inspected to ensure compliance with the specification.

Hot-Dip Galvanizing Effect

When the steel work piece is dipped in the molten zinc bath, the alloying (coating) process between the steel and zinc begins immediately. The type and thickness of the coating is influenced primarily by the reaction between the base metal and the molten zinc.

The usual galvanized coating consists of three distinct iron-zinc alloy compounds:

- Gamma (next to the steel) 75% zinc and 25% iron
- Delta 90% zinc and 10% iron
- Zeta 94% zinc and 6% iron

The outer layer, Eta, has the same composition as the bath—100% zinc.

This slide illustrates a microscopic cross section of a hot-dip coating.

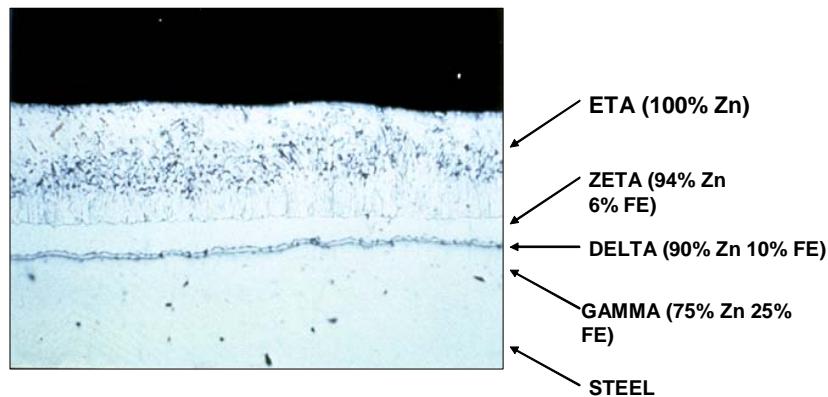


Figure 28.8: Alloy Compounds of Galvanizing Coating

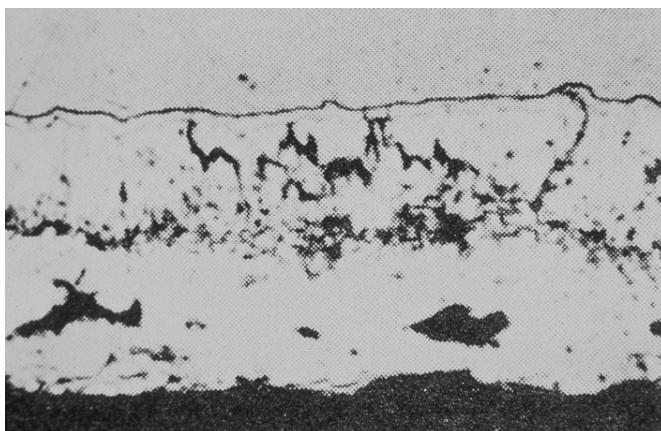


Figure 28.9: Microscopic Cross-Section of Hot-Dip Galvanized Coating

Faying Surfaces

Surfaces that depend on friction to hold the structural elements in place should not be hot-dip galvanized, because this treatment greatly reduces the possible coefficient of friction between the surfaces.



Figure 28.10: Faying Surface

This schematic of a faying surface shows two pieces of steel bolted together. A force is pulling on one piece. The bolts hold the pieces in tight contact, not to resist the shear force. The friction between the two tightly bolted pieces of steel keeps the pieces in place.

If these surfaces were galvanized, the friction could be lowered considerably, placing more shear force on the bolts and possibly leading to mechanical failure of the joint.

Hot-Dip Galvanizing Quality

Some quality issues relating to hot-dip galvanizing include:

- Alteration of the properties of the substrate
- Design of the work piece
- Coating thickness and service life

- Adhesion
- Appearance

Alteration of Substrate Properties

Alteration of the properties of certain types of steel may be affected by certain processes incidental to the hot-dip galvanizing process, such as quenching after hot dipping.

Work Piece Design and Fabrication

Design and fabrication of the work piece can affect quality in a variety of ways, including:

- Skip welds, crevices, and/or other areas where pickling acid may be trapped. This trapped acid may
 - Vaporize rapidly during hot dipping, possibly causing damage to the work piece
 - Leak out, causing staining or other deterioration of the coating
- Areas where pockets or air bubbles may form, preventing the molten zinc from contacting those areas.
- Pieces too large for the dip tank. These pieces may be dipped one section after the other. It is important to be sure that the overlap area is properly coated.
- Warping of the work piece may occur due to unequal thicknesses or nonsymmetrical design.
- Dissimilar metals. Ideally, a work piece to be hot-dip galvanized should be made of the same alloy of steel throughout; different alloys of steel have different galvanizing characteristics.

Coating Thickness and Service Life

The purpose of hot-dip galvanizing is to protect steel from corrosion; the length of time this protection can reasonably be expected to last sometimes is called the *service life*.

Service life usually is directly related to the thickness of the protective zinc coating and generally is governed by the amount of zinc deposited where the coating is thinnest, rather than by the average thickness of the coating.

Average thickness can be determined by weight.

The articles to be galvanized are weighed after pickling and drying, then weighed again after galvanizing. Or, a sample of known weight and area and of the same composition as the article to be galvanized may be attached to that article. Zinc coating weight is then determined by dividing the weight gain by the total area of the pieces galvanized.

Thus, a total weight gain of 680 g (24 oz) over a total area of approximately 1 m^2 (10 ft^2) = 680 g/m^2 of coating (2.4 oz/ft^2).

ASTM specifications for coating weight requirements for some hot-dip galvanized products are listed in Table 28.1.

TABLE 28.1
Comparison of Coating Weight Requirements for Hot-Dip Galvanized Products
(ASTM Specifications)

Class of Material	ASTM	Minimum Weight of Zinc Coating, oz/ft² of surface (a)	
		Avg. of Specimens Tested (b)	Any Individual Specimen
Products fabricated from rolled, pressed, and forged steel shapes, plates, bars, and strips: 1/8 in. - 3/16 in. thick 1/4 in. and heavier	A123	2.0 2.3	1.8 2.0
HARDWARE: Class A—Castings: gray iron, malleable iron, steel Class B—Rolled, pressed, and forged articles (except those included under Classes C and D) B-1-1/16 in. and over in thickness and over 15 in. in length B-2-under 3/16 in. in thickness and over 15 in. in length B-3-15 in. and under in length and any thickness		2.00 2.00 1.50 1.30	1.80 1.80 1.25 1.10
Class C—Fasteners (over 3/8 in. in diameter) and similar articles. Washers 3/16 in. and 1/4 in. thick	A153	1.25	1.00
Class D—Fasteners (over 3/8 in. and under in diameter), rivets, nails, and similar articles. Washers under 3/16 in. thick		1.00	0.85

- (a) In the case of long pieces, such as anchor rods and similar articles over 5 ft in length, the weight of coating and uniformity shall be the average of the determination made at each end and the middle of the article. In no case shall individual measurements be below the minimum shown in the "Any Individual Specimen" column.
- (b) The number of specimens to be tested per order shall be as specified in ASTM B602 or as specified by the purchaser.

TABLE 28.1
Comparison Of Coating Weight Requirements For Hot-Dip Galvanized Products
(ASTM Specifications)
(continued)

Class of Material	ASTM Specification	Minimum Weight of Zinc Coating, oz/ft ² of surface (a)	
		Avg. of Specimens Tested (b)	Any Individual Specimen
ASSEMBLIES: Class A-Castings: gray iron, malleable iron, steel	A386	2.00	1.80
		2.00	1.80
		1.50	1.25
		1.25	1.00
		1.00	0.85
High Strength Bolts	A325	1.25	1.00
Tower Bolts	A394	1.25	1.00
Class C	A153		

Inspection of Products Hot Dip Galvanized After Fabrication, American Hot Dip Galvanizers Association, Inc., 1000 Vermont Avenue, N.W., Washington D.C. 20005. Reproduced by permission.

Weight of zinc coating may be converted to an estimated average thickness measurement by multiplying the weight of the coating by a conversion factor.

The conversion factor is 1.7 to obtain an estimated average thickness measurement in mils when the weight is given in ounces per square foot, and 0.14 to obtain an estimated average thickness in microns when the weight is given in grams per square meter.

Thus, if the coating weight is determined to be 1 oz/ft² (305.2 g/m²), the estimated average thickness will be 1.7 mils (43 µm).

Table 28.2 in your notebooks shows conversions of some typical coating weights to thickness.

It must be stressed that this is an estimated average thickness measurement. Theoretically, there could be bare spots in some places and triple thicknesses in others, affecting average weights.

TABLE 28.2
Conversion from Zinc Coating Weight to Estimated Average Coating Thickness
Conversion Factors

1 mil = 25.4 μm

1 oz. = 28.35 g

1 oz/ ft^2 x 1.7 = 1.70 mil

1,000 g/ m^2 x 0.14 = 140 μm

Sample Conversions

Imperial Surface (oz/ ft^2)	Estimated Thickness (mils)	Metric Surface (g/ m^2)	Estimated Thickness (μm)
1.00	1.7	305.2	42.7
1.25	2.1	381.5	53.4
1.50	2.6	457.8	64.1
1.75	3.0	534.1	74.8
2.00	3.4	610.3	85.4
2.25	3.8	686.7	96.1
2.50	4.3	762.9	106.8
2.75	4.7	839.3	117.5
3.00	5.1	915.5	128.2

- Determining coating thickness by chemical stripping (ASTM Standard Test Method A 90 [Vol. 01.06])

A properly prepared sample article, or a sample coupon, which was attached to a larger piece of work is hot dipped.

The coated sample is then cleaned with a suitable solvent to remove grease; it is dried, weighed, and then immersed in a chemical solution that dissolves the zinc coating.

The stripped article is then rinsed, dried, and weighed again. This weight is subtracted from the original weight, giving the weight of the zinc coating from which a predicted average coating thickness may be calculated.

While the weighing and stripping methods give fairly accurate average coating weights of the zinc coating, these methods do not provide any information about how evenly the coating is distributed.

A variant of this is the Priece Test, which uses the chemical stripping method to test the thickness of galvanized coating on a chain link fence. You may see a chain link fence rated 10M, for example, which means that according to the test criteria, the coating could be submerged in the acid for 10 one-minute intervals before failure.

- Magnetic thickness test

The standard Type 1 and Type 2 magnetic thickness test instruments also may be used to determine spot thickness of the applied coating.

Adhesion

A hot-dip galvanized coating should have sufficient adhesion to satisfy the job specification.

The coating inspector should note that adhesion may be affected by the base metal. Hot-dip galvanized coatings applied to high-silicon steels may exhibit poor adhesion.

The coating inspector should understand the adhesion requirements and enforce the degree of adhesion required by the specification.

One recognized method for testing adhesion of galvanized coating is the:

- Paring test

This method is not a true measure of the metallurgical bonding of the galvanized coating to the base steel, but can serve as a quick field measure of adhesion.

The inspector uses a sharp knife and considerable pressure to attempt to remove a portion of the coating.

Depending on the job specification, adhesion is usually considered satisfactory when it is possible to remove only small particles of the coating.

It should not be possible to peel any portion of the coating in the form of a layer to expose the underlying iron or steel.

TABLE 28.3
Visual Inspection of Hot-Dip Galvanized Articles

Conditions	Causes	Grounds for Rejection
Bare spots	<ul style="list-style-type: none"> * Paint, grease, or oil residue on steel * Scale or rust residue * Weld slag * Rolling defects * Sand embedded in casting * Over drying * Excess aluminum * Articles in contact during galvanizing 	Yes, except where spots are small and suitable for patching
General roughness	<ul style="list-style-type: none"> * Composition or original surface condition of substrate * Over pickling * Uneven cold working * High galvanizing temperature and/or long immersion time 	No, except by prior agreement
Dross protrusion		* No, unless dross contamination is heavy
Blisters	<ul style="list-style-type: none"> * Surface defects in substrate * Absorbed hydrogen 	No, not if due to steel composition
Lumpiness and runs	<ul style="list-style-type: none"> * Withdrawal speed too high * Cold galvanizing bath 	No, except by prior agreement

	<ul style="list-style-type: none"> * Delayed run-off from seams, joints, etc. * Articles in contact during withdrawal 	
Flux inclusions	<ul style="list-style-type: none"> * Stale flux burned on during dipping * Surface residues on steel * Flux picked up from top of bath 	Yes Yes Yes, unless removed
Ash inclusions	<ul style="list-style-type: none"> * Ash burned on during dipping * Ash picked up from top of bath 	Yes, if in gross lumps
Dull gray or mottled appearance	<ul style="list-style-type: none"> * Composition of substrate (high silicon, phosphorus, or carbon) * Severe cold working * Slow cooling after galvanizing 	No, not if due to steel or severe composition or condition, or limited to occasional area
Rust stains	<ul style="list-style-type: none"> * Weeping of acid, etc., from seams and folds * Storage on or near rusty material 	No
Wet storage stain (white rust)	<ul style="list-style-type: none"> * Storage of close-packed articles under damp conditions * Packing of articles while damp 	No. Attack is generally superficial. May be prevented or delayed by chromate in treating after galvanizing

Appearance

The basic finish requirements of the galvanized coating are that it be relatively smooth, continuous, lustrous, and free from gross surface imperfections, such as cracking, peeling, bare spots, lumps, blisters, and inclusions of flux, ash, or dross.

Smoothness is a relative term, and the job specification must be the determining factor in setting tolerances for smoothness.

The galvanized coating should be continuous to provide optimum corrosion protection. Handling techniques for galvanizing may require the use of chain slings, wire, or other holding devices to immerse materials into the galvanizing kettle if the item has no suitable lifting fixtures.

Differences in the luster and color of galvanized coatings generally do not significantly affect corrosion resistance, and the presence or absence of spangle (zinc crystals) has no effect on coating performance. The well-known spangle effect found on galvanized products is simply a factor of primary crystallization. It chiefly depends upon such elements as the zinc bath chemistry, rate of cooling, method of pickling, steel chemistry, and thickness of the coating. In fact, dull-gray or patchy matte-gray galvanized coatings give service lives equal to bright or spangled coatings.

Illustrated here is a typical hot-dip galvanized surface. It is silver-gray and has spangles of different sizes.

Cooling rate has a direct effect on surface brightness and spangle size. Faster cooling usually results in a brighter coating with smaller spangles. Alloy composition of the base metal also may affect appearance.



Figure 28.11: Typical Galvanized Surface

Some conditions which may be noted in visual inspection of hot-dip galvanized articles include:

- Bare spots
- General roughness
- Dross protrusion
- Lumpiness and runs
- Flux inclusions
- Ash inclusions
- Dull-gray galvanized coating
- Mottled appearance
- Rust stains
- White rust

These conditions and causes are listed in Table 28.3.

These were mentioned in the overview slide show we saw earlier, but because of their importance, we are going to review them now.

- Bare Spots

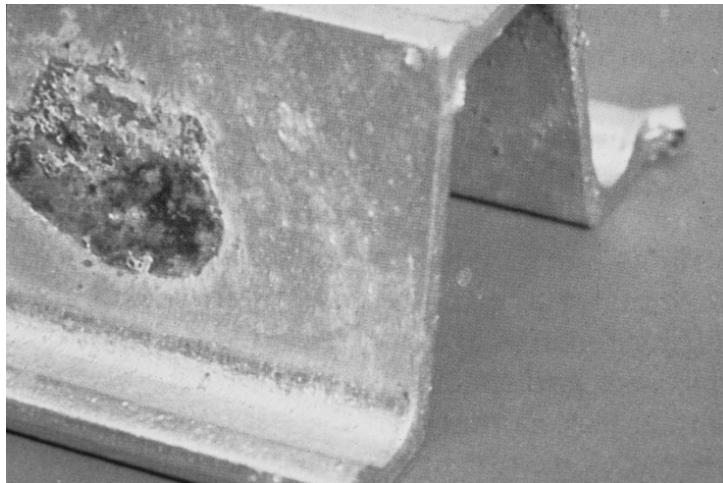


Figure 28.12: Bare Spots Caused by Oil, Grease, etc.

As seen in Table 28.3, bare spots can occur for a variety of reasons.

- Paint, grease, or oil residues on the steel, if not removed prior to hot-dip galvanizing, can cause localized black or ungalvanized areas in an otherwise normal galvanized coating. These areas can vary in color from gray to black to brown, but no galvanized coating is formed.
- Mill scale or rust scale on an iron or steel product generally is caused by the process used to form the item. A localized black or ungalvanized area in an otherwise normal coating can occur if scale has not been removed. These ungalvanized areas also may occur in a linear pattern on an angle, channel, or other rolled product.

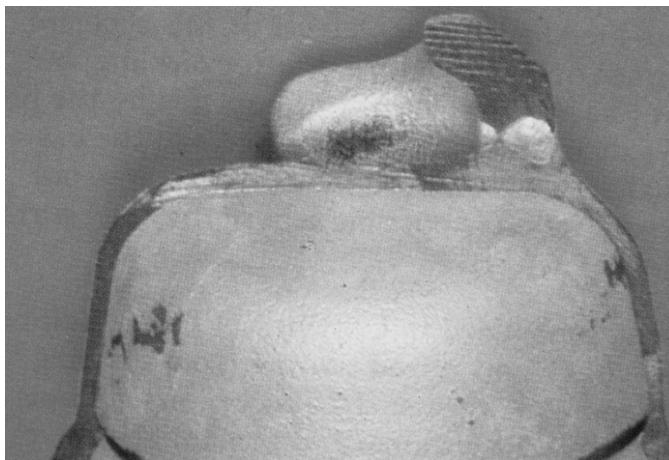


Figure 28.13: Ungalvanized Area Caused by Scale

- Residual welding slag also can cause a localized black or ungalvanized area.



Figure 28.14: Ungalvanized Weld Area

- Rolling defects in steel may be broadly classified as discontinuities in the steel which have been closed and elongated during rolling, but have not welded. Examples are laminations, laps and folds, and nonmetallic impurities rolled into the metal surfaces. Defects of this type sometimes are detected before or after pickling, but may not become apparent until opened by the heat of the galvanizing bath. Minor flaws in the basic material may be removed by local grinding, but little reclamation is possible where the steel surface is seriously defective.



Figure 28.15: Bare Spot Caused by Rolling Defect

- Other causes of bare spots include:
 - * Sand embedded in castings: This condition can prevent a galvanized coating from forming. Sand and other surface inclusions are not removed by conventional acid pickling, and abrasive cleaning of castings generally is required to attain a clean surface for galvanizing.
 - * Over drying: If the time between pre-fluxing and galvanizing is prolonged or the drying temperature is too high, the corrosion protection afforded the cleaned steel by a pre-flux may be lost. This is indicated by a rusty appearance on the galvanized article. The appearance of the galvanized coating is similar, in extreme cases, to that of under preparation.
 - * Excess aluminum: A condition sometimes referred to as *black spots* may occur if the aluminum content of a bath, on which a flux blanket is used, is too high. No trouble should be experienced if the aluminum content of the bath is maintained below approximately 0.01%, which is well above the range needed to brighten the coating.
 - * Articles in contact: The zinc in the galvanizing bath should have free access to all parts of the surface. Articles entering and passing through the galvanizing bath should not be in tight contact with each other.
 - * Improperly removed drips
- General roughness

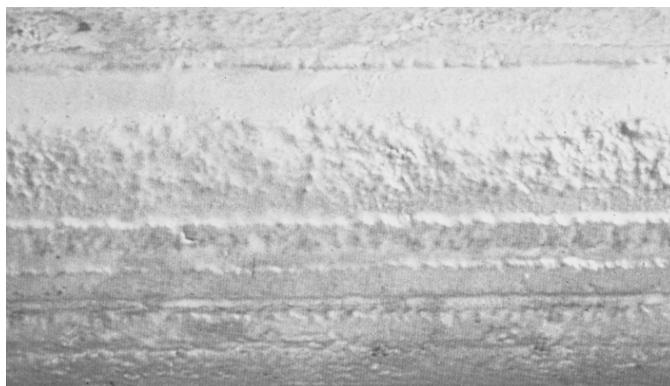


Figure 28.16: General Roughness

Rough, heavy coating refers to galvanized components with markedly rough surfaces. This can include coatings that have just a rough surface and, in some cases, can involve some groove-type surface configurations.

A rough coating usually is caused by excessive growth or unevenness of the alloy layer. This condition is attributable to the chemical composition of the steel or its original surface condition. The irregularity of the alloy layer tends to increase with its thickness; thus, heavy coatings are usually rougher than light ones. Where thick protection is applied, some degree of roughness may be unavoidable.

- Dross protrusion

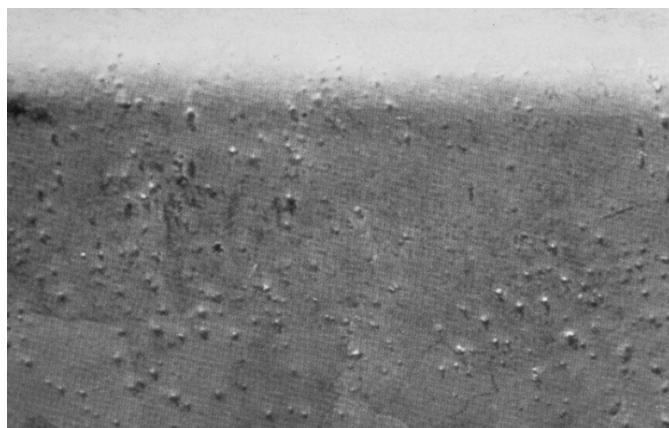


Figure 28.17: Dross Protrusions

Dross protrusions, stipple, appear as small, hard lumps on an otherwise normal galvanized surface. The protrusions result from agitation of the dross layer at the bottom of the bath or from dragging material through the dross layer. A clean kettle is less likely to produce this defect. The dross incorporated in the coating prevents drainage of the bath zinc in the immediate area and a buildup occurs. Some think that because the dross consists of the same iron-zinc alloy as the coating, it may provide the same corrosion protection as a normal galvanized coating, however, this may not be the case.

You may be interested to know that this dross is removed from the kettle and may be either:

- Reclaimed and resold to galvanizer or other zinc users, or
- Processed into zinc dust for zinc-rich coatings
- Lumpiness and runs

A lumpy and uneven coating results when the speed of withdrawal is too fast or the bath temperature is too low to allow surplus zinc to run back into the bath. Runs also may be caused by delayed drainage from bolt holes, folds, seams, and other pockets where zinc collects, and are a direct consequence of the product design.

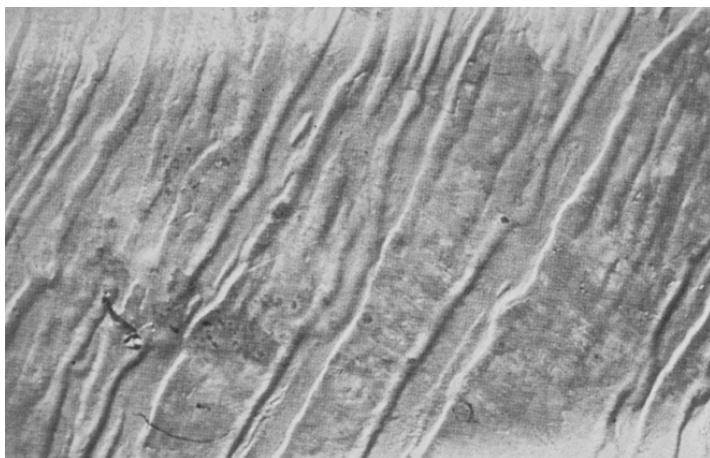


Figure 28.18: Uneven Drainage

Drips can be removed by filing or other means, if required. The inspector should look for voids where drips have been carelessly removed or knocked off.

- Flux inclusions



Figure 28.19: Flux Inclusions

Flux inclusions may originate in several ways. Stale or spent kettle flux, for example, tends to adhere to the steel instead of separating cleanly from the surface as the work is dipped. This may occur even with active flux if residual grease, scale, or other surface contaminants resist the cleansing action of the flux blanket.

In both instances, the inclusions are associated with bare spots in the coating. Black spots formed by the included flux particles are distinguishable from dirt smuts, splash marks, and other less harmful types of contamination by their tendency to pick up moisture.

- Ash inclusions



Figure 28.20: Ash Inclusions

Ash inclusions are zinc ash, the oxide film that sometimes develops on the surface of the galvanizing bath. As with flux, ash may be burned on the steel during dipping, or picked up from the top of the bath during withdrawal. Ash inclusions can occur on work pieces that are cumbersome and require slow withdrawal from the bath.

- Dull-gray galvanized coating

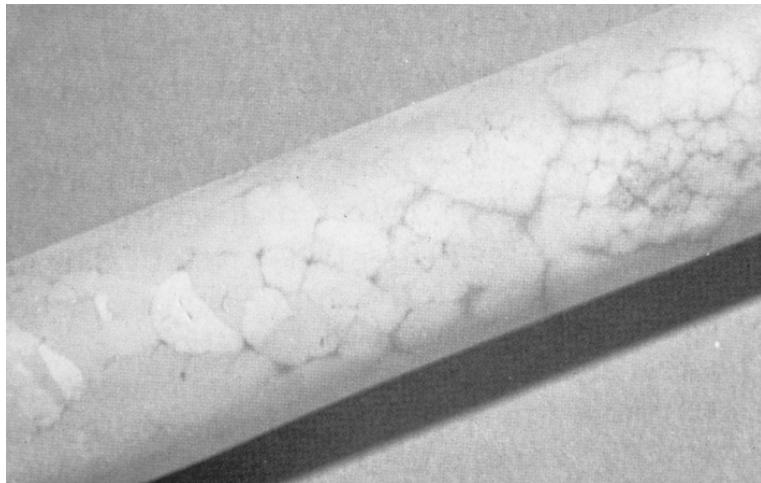


Figure 28.21: Dull-Gray Galvanized Coating

A gray or mottled appearance develops during cooling and is caused by diffusion of the zinc-iron alloy phase to the surface of the coating. It usually appears as a localized dull patch on an otherwise normal surface, although, in extreme cases, it may extend over the entire surface of the steel.

Dull coatings, usually more brittle, may occur on steels with:

- Silicon
- Phosphorus
- High carbon

A gray coating is most frequently found on heavy sections that cool slowly, and with certain types of steel, such as those with relatively high silicon or phosphorus content, or severely cold-worked steel, all of which may exhibit abnormally rapid alloy growth.

- Rust stains



Figure 28.22: Dull-Gray Galvanized Coating

Rust stains may be caused by seepage from joints and seams after galvanizing, as shown in the slide, or by material being stored under or in contact with rusty steel.

With certain high-silicon content steels, a slight rusty appearance on the surface may form after some period of exposure. This is not a failure of the galvanizing, but a phenomenon with this type of steel.

- White rust (wet storage stains)

Wet storage stain is the name given to the porous, bulky deposit which may form on the surface of closely stacked, freshly galvanized articles that become damp (from exposure to the weather or from condensation) in poorly ventilated conditions during storage or transit.



Figure 28.23: Wet Storage Stains (White Rust)

If wet storage stain is noticed, the coating inspector should closely examine the articles to ensure that the hot-dip galvanized coating is still intact and meets specified thickness requirements.

Whether or not any of these conditions are grounds for rejection depends on the job specification. Some of these conditions do not always impair the corrosion resistance of the coating, and it is important that the buyer, fabricator, and inspector have a mutual understanding of what constitutes unacceptable work.

A copy of *Users Guide to Hot-Dip Galvanizing for Corrosion Protection in Atmospheric Service*, TPC-9, is provided to you for future reference.

Other Methods of Metallizing

Sherardizing

Sherardizing is a metallizing alternative for fastener coatings. The fasteners are rotated in a drum for long periods at moderate heat with zinc dust. The dust tends to diffuse into the surface of the steel fasteners.

Sherardizing improves corrosion resistance, but it is not as long lasting as hot-dip galvanizing.

Aluminizing

Hot-dip aluminizing is now being done. The bath metal is an aluminum-zinc alloy. The compositions vary among manufacturers and much of the work is proprietary.



Level 2

Chapter 29

Spray Metallizing

Spray Metallizing

Coating steel by spraying molten metal, *metallizing*, is one technique used for corrosion protection.

Metallizing was developed in Europe in the early part of the 20th century as a means to repair or conserve metals used in machinery. Today, a wide range of metals is used in many industries to build worn or deteriorated parts. Stainless steel, zinc, aluminum, tungsten carbide, and a variety of ceramic materials can be applied by a spray technique, which may use gas flame, electric arc, or gas plasma to spray materials in wire or powder form.

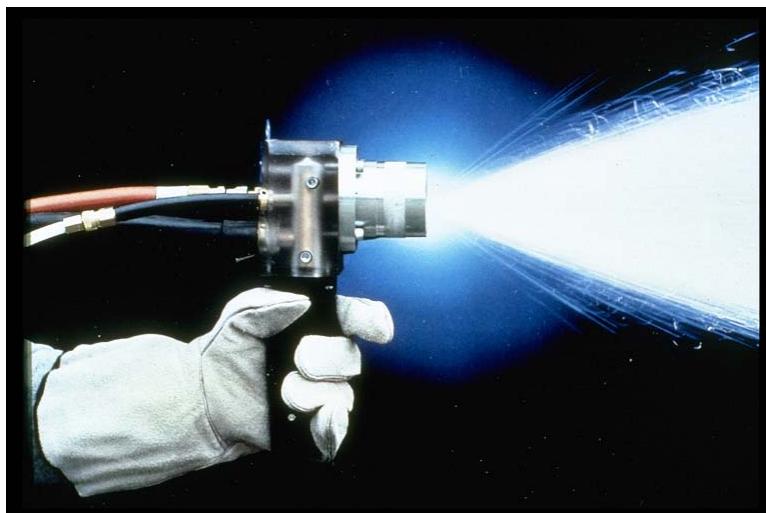


Figure 29.1: Thermal Spray Hand Gun

For large components, and particularly for field work, flame spray or arc spray generally are chosen. Both of these application methods use metals in a wire form. Heavy, unwieldy hand spray guns and the need to move the associated equipment have, in the past, led to operator fatigue and reduced the effectiveness of thermal-spray application techniques, particularly for field application. Recent advances in equipment design have brought more portable arc-spray units which are as easy to transport, set up, and use as regular paint application spray units.

Spray metallizing equipment sprays many metals in wire form, including:

- Aluminum
- Zinc



Figure 29.2: Thermal Spray on Bridge

The principal metals used in corrosion protection are zinc and aluminum, although sometimes lead is applied by spray metallizing to the interior of vessels that will contain strong chemicals.

Composite metals have been developed more recently for corrosion protection, including:

- 85% zinc-15% aluminum

This mixture of zinc and aluminum provides a dense film suitable for application to steel or concrete and acts as an anode for impressed current cathodic protection systems.

Historically, thermal-sprayed aluminum (TSA) has been the coating of choice for corrosion protection in immersion, and either TSA or thermal-sprayed zinc (TSZ) for the same purpose in atmospheric service. The fact that TSZ is a little cheaper probably influences its selection by some owners. TSZ also looks good when put in service, while TSA often shows rust stains if not

sealed. Eventually the rust stains go away (if the TSA film thickness is adequate), but the effect does not look as good as TSZ, another reason for preferring the TSZ in some cases.



Figure 29.3: Thermal Spraying Pipe



Figure 29.4: Thermal Spraying Metal Parts

A wide variety of coatings can be applied by metallizing. Tungsten carbide alloy coatings can be applied by metallizing to improve abrasion resistance and reduce wear; the United States Navy has used tungsten carbide on rudder rams. Such exotic metals as titanium have been

applied to fight corrosion in critical exposures; the United States Navy has used titanium on seawater piping flanges to mitigate crevice corrosion.

Spray metallized coatings find application in a wide range of settings, including:

- Fresh-water tanks (AWWA Standard D102)
- Industrial atmospheres
- Bridges
- Salt environments
- Ship hulls
- Tanker interiors
- Hot surfaces (to which aluminum is applied by spray metallizing to stacks, mufflers, steam, and process piping, etc.)

The process of applying metallized coating systems for corrosion protection of iron and steel includes:

- Surface preparation—generally considered to be critical, and a minimum standard of blast cleaning to near-white metal is required. Blasting to white metal is standard practice for coatings in immersion service, or to achieve the best long-term performance.
- Application of the metallized coating— influences the success of the finished coating film. The most critical factors in the process are:
 - The spray angle, which should be as near perpendicular to the surface as possible.
 - Quality of the applied film. Most metallized films are porous to some extent. The porosity is influenced by the type of application equipment, how well it is adjusted, and by the application technique. The spray operator must maintain a consistent distance from the surface, and

preferably, a consistent speed of gun movement across the surface.

- Consistency of application. The operator must use a reliable spray method to ensure even coverage, and measure DFT frequently to ensure that he has applied the correct amount. Most metals are difficult to see against the background of blast cleaned steel, particularly through a welding mask or goggles, and frequent checking is essential.
- Surface pre-heating—can improve adhesion. Testing has demonstrated that adhesion improved significantly with pre-heating, presumed to be due to improved coating integrity. Common pre-heat temperatures range from 35 to 65°C (95 to 150°F). A side benefit of pre-heating is it ensures the surface is dry (significantly above the dew point), provided the pre-heat temperature is higher than the ambient condition, and higher than the steel temperature might become when exposed to the elements. In many locations, this would suggest pre-heat temperature should be higher by a reasonable margin than 40°C (96°F). As always, the specification should state the acceptable temperature range, allowing a margin for operator error.

Pre-heating is probably more significant to coating quality when using the flame-spray technique, and is often achieved by rapidly passing the flame of the gun over the surface in a series of passes. Propane torches also can be used. Pre-heating usually is not done when arc-spray application is specified.

- Seal coat—In service, corrosion products of zinc or aluminum develop as the porous coating begins to corrode. In time, the porosity essentially is sealed by its own corrosion products. However, the application of a sealer film immediately after application of the metallizing significantly extends the life of the coating. Successful sealers include thin coats of vinyl, PVBA etch primer (generally followed by at least one more coat), and aluminum-pigmented silicone sealers for coatings in

high-heat service. Penetrating epoxy sealers also have been used successfully.

- Inspection at appropriate intervals—surface preparation for metallizing requires the same steps as surface preparation for other coatings we have discussed, and hence, similar inspection techniques can be used, including:
 - Pre-cleaning to remove residues of oil, grease, dirt, chemical salts, etc. Inspection steps include visual confirmation that contaminants have been removed, use of a black light to check for oil, and chemical testing for salts.
 - Abrasive blasting. Inspection includes appraisal of the surface for cleanliness and anchor pattern.

Any of the methods of abrasive blast cleaning discussed in this course may be called in by the job specification. As the coating inspector, you are responsible for reading and understanding the specification, and ensuring that it is enforced. The abrasive blast step is critical. Best performance of the metallized coating can be gained by cleaning to white metal (NACE No. 1/SSPC-SP 5—*White Metal Blast Cleaning*) (ISO Sa 3). Generally, the thicker the coating, the more anchor pattern is required, ranging from a minimum requirement of 50 µm (2 mils) to a maximum of 150 µm (6 mils) or more. There is probably no commercial advantage in achieving a higher anchor profile than 125 µm (5 mils), though it is technically acceptable.

- Pre-heat—surface temperature should be monitored during pre-heat, using either a contact thermometer or an infrared (non-contact) thermometer.



Thermal-Sprayed Coatings

Some of the characteristics of thermal-sprayed coatings include:

- Long performance life

One of the first signs of widespread acceptance of the thermal-spray method in the United States was the research work by the American Welding Society (AWS) that resulted in publication of a well-known 19-year study. Other reports have shown that protection to steel may be provided for as long as 50 years.

- Rapid turnaround

Shipping thermal-spray coated parts

Application of thermal-sprayed coatings offers considerable time savings compared to conventional coatings. Multiple-coat systems require dry times between each coat and final cure time before parts can be handled without damage. Thermal-sprayed coatings can be sealed immediately after coating and, if a topcoat is desired, it can be applied within four hours.

When not sealed, thermal-spray coated parts can be shipped immediately after the coating is applied without risk of damage to the coatings. When topcoated, the parts can be shipped within eight hours.

- Resistance to mechanical damage during transport (or installation)

Thermal-sprayed coatings have excellent resistance to mechanical damage, showing relatively little delamination in even the worst handling situations. Damaged areas (which usually are small) can be repaired with thermal-sprayed coatings or with conventional coatings, if more convenient.

Localized repair to any damaged topcoat can restore the integrity of the system since topcoats are cosmetic only.



- Suitable for immersion service

Thermal-sprayed aluminum coatings are suitable for immersion service, providing barrier protection and cathodic protection (acting as a sacrificial anode). Once again, the ability of thermal-sprayed coatings to resist mechanical damage is important. Conoco calculated that an area coated with TSA could protect when up to 4% of the area was bare steel, and still give a life of 30 years in salt-water immersion. Describing experience with the Hutton tension-leg platform risers and tendons, Conoco reported that TSA-coated surfaces provide long-term protection. The same report stated that the TSA coatings had “not been scraped off during handling and service; thus, there are few holidays after 10 years in service.”

- Low VOC emissions

Thermal-sprayed coatings have zero VOC emissions

Volatile organic compounds (VOC) emissions are increasingly at issue in the coatings world. Thermal-sprayed coatings emit zero VOCs, with the possible exception of the sealer coating, when applied. Small quantities of sealer are used, because the objective is not to provide film build, but to fill the small amount of porosity of the metallized film. Sealer coats require at least 50% thinning to ensure penetration of the zinc or aluminum porosity, but application is easily controlled, because the sealers can be brushed or sprayed. Some water-based sealers currently are being tested.

The coating applicator's problems with collection, storage, and disposal of hazardous waste are significantly reduced.

- Safe Working Environment

The application of thermal-spray coatings requires either ignition to light the gas flame or electrical contact of two arc wires. The metal wire is used only when the operator is ready. With arc-spray equipment, release of the trigger turns off the electric arc and ends consumption of wire.

With flame-spray equipment, the air motor driving the wire and the gas flame must be turned off separately.

The use of regular coatings requires that equipment be cleaned after use, which uses more solvent and creates additional VOCs and hazardous waste.

Spray areas are easier to keep clean. Thermal-spray coatings' overspray tends to be in the form of dust, which can be contained and collected. This contrasts with conventional coatings, which stick to surfaces where they land. Damage from overspray is unlikely, and work areas stay relatively clean.

Like all dust, there is a possibility that explosions could occur with heavy dust concentration. Aluminum dust, in particular, can burn with an aggressive flame. Aluminum fires are most likely to happen when sparks are transported into dust collection housings.

Both aluminum and zinc are used in a form that is more than 99% pure metal, and health hazards are not associated with metallizing. Breathing the dust and fumes should be avoided as much as possible, and respirators should be worn.

A temporary illness known as *zinc flu*, similar in symptoms to a heavy cold, affects operators who breathe large amounts of zinc dust or fumes. Normal health is restored usually with 24 hours of rest, with no long-term adverse effects. Some metallizing companies provide milk to the operators to drink to reduce the effects of exposure to the fumes.

- Applicator Expertise

Operator accuracy is key to a high-quality coating with few errors.

Operators can apply 50 or 75 μm (2 or 3 mils) per pass of the gun, and must make at least four passes with consistent speed. Spray passes must overlap, but the operator must recognize where the passes have been made to achieve a specified film thickness.

Operator training is required, together with a high standard of quality control. An operator's work often is scrutinized by testing the articles the operator metallized. The coated articles are checked for quality by bend testing, which can be performed daily, and by adhesion testing. Bend tests are discussed later.

Operator skills are tested most often in accordance with the guidelines of MIL Standard DOD-STD-2138A (SH). Each operator must adequately perform the tests described in the standard in order to become "certified." Anyone who does not spray for a period of six months must recertify. Separate certification is required for flame spray and arc spray.

- Quality Control

Quality control (QC) is important in the metallizing process. Specifiers often require regular production tests, such as adhesion tests, either on the actual parts or on production coupons, intended to minimize damage or hold-up to the parts. Bend testing also may be performed on production coupons.

Some significant QC issues include:

- Anchor Profile—At least 50 μm (2 mils), and preferably 75 μm (3 mils), should be specified for anchor profile, and up to 150 μm (6 mils) can be tolerated without problems and perhaps beneficially. Anchor profiles of more than 112 μm (4.5 mils) cannot always be measured by the most common replica tape, though the manufacturer now has replica tape available for deeper profiles.
- Surface Finish—Research shows that the surface finish (roughness) can be improved by controlling such parameters as spray distance, air pressure, and arc-spray voltage. Other factors, such as porosity, are considered to be more important, and good control of these tends to minimize surface roughness.

Surface roughness from 30 to 100 μm (1.2 to 4 mils) is expected with arc-spray techniques. There probably is



no value in trying to control this parameter by specification unless roughness is important for a specific reason. Inspection criteria are difficult to define.

The application of a sealer coating helps smooth the surface and resists dirt and other contamination, but the user will not achieve the same surface finish that can be achieved with regular paint coatings.

- Dry-Film Thickness—DFT of thermal-sprayed coatings on steel can be measured using normal paint DFT gauges. Achievement of accurate DFT by the applicator can be tricky, so careful and frequent measurement is required.

Given that accurate control of thickness is difficult to achieve and depends on applicator technique, DFT should be carefully specified, stating both minimum and maximum DFT.

- Adhesion—This factor is considered a significant indicator of long-term performance. The adhesion of thermal-sprayed coatings to a substrate is, to some extent, dependent on the method of application. With TSA coatings, 14 to 21 plus MPa (2,000 to 3,000 plus psi) adhesion strength (bond strength) can be expected. Rather than test to destruction, it is normal to specify a lower minimum value (7 to 10 MPa [1,000 to 1,500 psi]), and suspend the test once the minimum test value is reached. Test dollies can then be removed by heating the adhesive without damage to the surface.

Adhesion strength is usually greater with arc-spray application than with flame spray.

It can be useful to test actual adhesion to determine whether adhesion is truly as good as the system designer requires. These tests can be performed on representative samples prepared alongside the work piece. If these resultant adhesion values are to be included in specification requirements, they should be at least double the minimum value referred to above. Sample coupons may be retained for reference purposes. To be truly representative, the sample

coupon should be treated in exactly the same manner (degreasing, steam cleaning, pre-heating, etc.) as the main work piece.

The adhesion strength measured is dependent on the equipment used to make the measurement. Adhesion of TSA coatings measured using an Elcometer® model 106 showed 7 to 9 MPa (1,000 to 1,300 psi); using a “HATE” gauge showed 8 to 14 MPa (1,200 to 2,100 psi); and using the ASTM Method D 633 showed up to 17 MPa (2,500 psi). When using adhesion as a quality-control factor, the user should be careful to specify the test method in addition to the adhesion values required.

- Bend Tests—A relatively simple adhesion test is produced by applying the thermal-sprayed coating to a sample coupon, which can then be bent around a narrow radius.

Small sample coupons, generally 5 x 10 x 0.5 cm (2 x 4 x 0.19 in.) are blast cleaned and coated, then bent over a 1.25-cm (0.5-in.) -diameter mandrel. Minor cracking is considered acceptable, but major cracking or delamination indicates problems with the application process, and is considered to be a failure.

The coupon should have a similar metallurgy as that of the substrate being coated, but should be thin enough to bend. Surface preparation and coating application should be identical to that used for the main job.

Porosity—is critical to a finished coating’s protective capability. The splatter technique of application ensures that the applied film is not homogeneous. The porosity of applied thermal-sprayed coating films has been estimated to be between 3 and 18%, depending on the application technique (arc spray produces films with greater density than flame-spray techniques).

One application factor that significantly affects porosity is the distance of the spray head from the substrate. It has been reported that an arc spray distance greater than 150 mm (6 in.) made a substantial difference in the nature of the coating, increasing porosity from 2 to 3% (distance



below 150 mm [6 in.]) to around 14% (distance above 150 mm [6 in.]).

Porosity is difficult to measure. Traditionally, a random sample of cross sections of the coating is physically measured by comparison with a grid. When seen under a microscope, the proportion of the cross section that shows voids represents the porosity.

The specification can refer to an acceptable porosity in percentage terms, for example:

Porosity shall be less than 12% of the sample area when viewed in cross section.

This technique is useful when laboratory facilities are available and representative samples can be prepared for testing purposes. For site testing, it has the disadvantage of results that are not immediate, sometimes taking several days before results are available.

NACE No. 12/AWS C2.23M/SSPC-CS 23.00, *Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel*, covers the requirements for thermal-sprayed metallic coatings, with and without sealers and topcoats. Observing these requirements are the means of preventing the corrosion of steel surfaces. A copy of this standard is included with your student manual.

MIL Standard DOD-STD-2138A (SH), *Metal Sprayed Coatings for Corrosion Protection Aboard Naval Ships*, is used frequently to guide the preparation of specifications.



Item No. 21100

Joint Standard

NACE No. 12/AWS C2.23M/SSPC-CS 23.00 Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel

This NACE International (NACE)/American Welding Society (AWS)/SSPC: The Society for Protective Coatings standard represents a consensus of those individual members who have reviewed this document, its scope, and provisions. It is intended to aid the manufacturer, the consumer, and the general public. Its acceptance does not in any respect preclude anyone, whether he has adopted the standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not addressed in this standard. Nothing contained in this NACE/AWS/SSPC standard is to be construed as granting any right, by implication or otherwise, to manufacture, sell, or use in connection with any method, apparatus, or product covered by Letters Patent, or as indemnifying or protecting anyone against liability for infringement of Letters Patent. This standard represents current technology and should in no way be interpreted as a restriction on the use of better procedures or materials. Neither is this standard intended to apply in all cases relating to the subject. Unpredictable circumstances may negate the usefulness of this standard in specific instances. NACE, AWS, and SSPC assume no responsibility for the interpretation or use of this standard by other parties and accept responsibility for only those official interpretations issued by NACE, AWS, or SSPC in accordance with their governing procedures and policies which preclude the issuance of interpretations by individual volunteers.

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Foreword

This "Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, Their Alloys, and Composites for the Corrosion Protection of Steel" is issued to meet a critical industry and government need.

Thermal spray coatings (TSCs) are used extensively for the corrosion protection of steel and iron in a wide range of environments. The corrosion tests carried out by the American Welding Society⁽¹⁾ and the marine-atmosphere performance reports of ASTM⁽²⁾ and the LaQue Center for Corrosion Technology⁽³⁾ confirm the effectiveness of flame-sprayed aluminum and zinc coatings over long periods of time in a wide range of hostile environments. The British Standards Institution "Code of Practice for the Corrosion Protection of Steel"⁽⁴⁾ specifies that only TSCs give protection for more than 20 years to first maintenance for the 19 industrial and marine environments considered and that only sealed, sprayed aluminum or zinc gives such protection in seawater immersion or splash zones.

This standard may be used by owners, and design, fabrication, and maintenance engineers to detail and contract for the application of TSCs for the preservation and maintenance of steel structures. This standard may also be used by TSC inspectors and TSC applicators to develop and maintain application procedures, equipment inventory, and an operator-training program.

This standard presents the basic need-to-know information for the application of quality TSCs. Appendixes present amplifying information. The Table of Contents gives an overview of this standard and may be used to find specific information.

This standard was prepared by the AWS C2B Subcommittee on Thermal Spray Coatings for Corrosion Protection, SSPC C.1.2.B Committee on Thermal Spraying, and NACE Task Group (TG) 146 on Thermal Spray Coatings. TG 146 is administered by Specific Technology Group (STG) 02 on Protective Coatings and Linings—Atmospheric, and is sponsored by STG 39 on Process Industry—Materials Applications.

⁽¹⁾ AWS C2.14-74, "Corrosion Tests of Flame-Sprayed Coated Steel, 19-Year Report" (Miami, FL: AWS). AWS standards can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5776, Telephone (800)-854-7179, Fax (303) 307-2740, Internet www.global.ihc.com

⁽²⁾ R.M. Kain, E.A. Baker, "Marine Atmospheric Corrosion Museum Report on the Performance of Thermal Spray Coatings on Steel," ASTM STP 947 (West Conshohocken, PA: ASTM, 1987). Available from ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

⁽³⁾ S.J. Pikul, "Appearance of Thermal Sprayed Coatings After 44 Years Marine Atmospheric Exposure at Kure Beach, North Carolina," LaQue Center for Corrosion Technology, Inc, February 1996. Available from the LaQue Center for Corrosion Technology, Inc., 702 Causeway Drive, Wrightsville Beach, NC 28480.

⁽⁴⁾ BS 5493, "Code of Practice for Protective Coatings of Iron and Steel Structures Against Corrosion" (London, UK: British Standards Institution). Available from the American National Standards Institute (ANSI), 11 West 42nd Street, New York, NY 10036-8002, USA; and the British Standards Institution (BSI), British Standards House, 389 Chiswick High Rd., London W4 4AL, UK.

Joint Standard

NACE No. 12/AWS C2.23M/SSPC-CS 23.00

Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel

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Section 1: General

1.1 General

This standard is a procedure for the application of metallic thermal spray coating (TSC) of aluminum, zinc, and their alloys and composites for the corrosion protection of steel. Required equipment, application procedures, and in-pro-

cess quality control (QC) checkpoints are specified. This standard may be used as a procurement document. Appendix A presents a fill-in-the-blanks model procurement specification. The flow diagram in Figure 1 provides an overview of the thermal spray coating process presented in this standard.

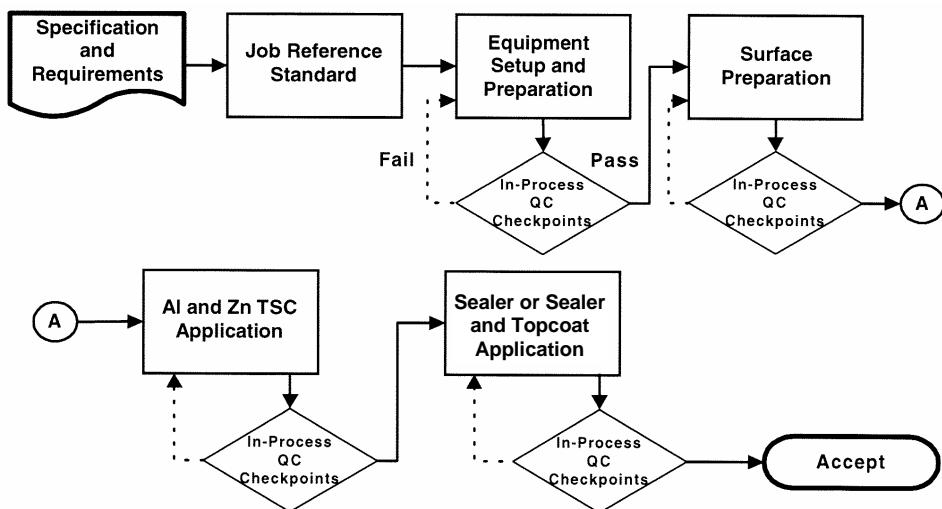


Figure 1: Thermal Spray Coating Process

Not included in this standard are requirements for design and fabrication, thermal spray equipment qualification, coating selection, and operator and inspector certification. For successful thermal spray application, the steel structure and components should be designed and fabricated according to NACE Standard RP0178.⁽⁵⁾ Additional consideration should be given to weldments whose oxyfuel cut edges may affect hardness which may preclude adequate profile depth.

1.2 Safety

The basic precautions for thermal spraying are essentially the same as for welding and cutting. Information on safety can be found in the Safety Chapter in AWS *Thermal Spraying: Practice, Theory, and Application*; ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*; and NFPA 58,⁽⁶⁾ *Standard for the Storage and Handling of Liquefied Petroleum Gases*. Safety precautions can also be found in the manufacturer's equipment technical instructions and manuals and the feedstock Material Safety Data Sheet. This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

Potential thermal spraying hazards include exposure to vapors, dust, fumes, gases, noise (from the spray gun), and arc ultraviolet (UV) radiation. Additionally, improperly used thermal spray equipment can create potential fire and explosion hazards from the fuel and carrier gases and a potential electrical shock hazard from the electrical and electronic equipment and charged wire spools. To minimize hazards, proper safety precautions shall be followed. Operators shall comply with the procedures in the safety references, the manufacturer's technical manuals, and the material safety data sheets.

Thermal spraying can be a completely safe process when performed by an operator who follows the recommended precautionary measures, has a proper understanding of thermal spraying practices, and has knowledge, skill, and exercises care in using thermal spray equipment.

1.3 Units of Measure

This specification makes use of both the International System (SI) and U.S. Customary units. The measurements are not exact equivalents; therefore each system must be used independently of the other without combining in any way.

⁽⁵⁾ NACE standards can be obtained from NACE International, 1440 South Creek Drive, Houston, TX 77084-4906.

⁽⁶⁾ Available from the National Fire Protection Association (NFPA), 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

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The specification ANSI/AWS C2.23M/NACE No. 12/SSPC-CS 23.00 uses SI units. U.S. Customary units are shown in appropriate columns in tables or within parentheses when

used in the text. Suitable conversions encompassing standard sizes of both can be made, however, if appropriate tolerances are applied in each case.

Section 2: Referenced Documents

The following standards contain provisions which, through reference in this text, constitute provisions of this AWS/NACE/SSPC standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this AWS/NACE/SSPC standard are encouraged to investigate the possibility of applying the most recent editions of the documents shown below. For undated references, the latest edition of the standard referred to applies

ASTM B 833, *Standard Specification for Zinc and Zinc Alloy Wire for Thermal Spraying (Metallizing)*⁽⁷⁾

ASTM C 633, *Standard Test Method for Adhesion or Cohesive Strength of Flame-Sprayed Coatings*

ASTM D 4285, *Method for Indicating Oil or Water in Compressed Air*

ASTM D 4417, *Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel*

ASTM D 4541, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*

ASTM D 4940, *Standard Test Method for Conductimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives.*

ASTM E 3, *Standard Practice for Preparation of Metallographic Examination*

ANSI/AWS C2.18, *Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites*

ANSI/AWS C2.25/C2.25M, *Specification for Solid and Composite Wires, and Ceramic Rods for Thermal Spraying*

ISO 8502-3, *Preparation of steel substrates before application of paints and related products—Tests for the assessment of surface cleanliness—Part 3: Assessment of dust on steel surfaces prepared for painting (pressure-sensitive tape method)*⁽⁸⁾

NACE No. 1/SSPC-SP 5, *White Metal Blast Cleaning*

NACE No. 2/SSPC-SP 10, *Near-White Metal Blast Cleaning*

NACE Standard RP0178, *Fabrication Details, Surface Finish Requirements, and Proper Design Considerations for Tanks and Vessels to Be Lined for Immersion Service*

NACE Standard RP0287, *Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape*

SSPC-AB 1, *Mineral and Slag Abrasive*⁽⁹⁾

SSPC-AB 2, *Specification for Cleanliness of Recycled Ferrous Metallic Abrasives*

SSPC-AB 3, *Newly Manufactured or Remanufactured Steel Abrasives*

SSPC-PA 1, *Shop, Field, and Maintenance Painting of Steel*

SSPC-PA 2, *Measurement of Dry Coating Thickness with Magnetic Gages*

SSPC-SP 1, *Solvent Cleaning*

SSPC-VIS 1, *Guide and Visual Reference Photographs for Steel Surfaces prepared by Dry Abrasive Blast Cleaning*

Section 3: Definitions

3.1 Aluminum MMC TSC: Aluminum metal matrix composite (MMC) TSC is a coating that contains a composite material in an aluminum matrix. It is produced by flame or arc spraying a solid or cored wire that contains the composite material.

3.2 Bend Test: The bend test (180° bend on a mandrel diameter based on the TSC thickness) is a qualitative test of the ductility and tensile bond of the TSC. The bend test is a macro-system test of surface preparation, equipment setup, spray parameters, and application procedures.

⁽⁷⁾ ASTM standards can be obtained from ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

⁽⁸⁾ ISO standards can be obtained from American National Standards Institute (ANSI), 11 W. 42nd Street, New York, NY 10036-9002.

⁽⁹⁾ SSPC standards can be obtained from SSPC: The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, PA 15222-4656.

3.3 Bond Test: A test to determine the tensile strength of a thermal spray coating.

3.4 Companion Coupon: A small rectangular metal sample surface prepared and coated concurrently with the work-piece, used for inspection.

3.5 Contract Pre-Award Validation: The purchaser's contract pre-award evaluation of the thermal spray coating applicator includes (a) written procedures for and (b) demonstration of surface-preparation and thermal spray materials, equipment capabilities, and application process proposed for the contract work.

3.6 Cut Test: The TSC cut test shall consist of a single cut 40 mm (1.5 in.) long through the TSC to the substrate without severely cutting into the substrate. All cuts shall be made with sharp-edge tools. The chisel cut shall be made at a shallow angle. The cutting tool shall be specified in the contract.

3.7 Holding Period: Holding period is the time between the completion of the final anchor-tooth blasting, or final brush blasting, and the completion of the thermal spraying. The holding period, by definition, ends with the onset of rust bloom.

3.8 Job Control Record (JCR): The JCR is a record form that enumerates the essential job information and the in-process QC checkpoints required by this standard. The JCR includes information on safety precautions, and the equipment, parameters, and procedures for surface preparation, thermal spraying, and sealing or sealing and top-coating. Appendix B is a model JCR.

3.9 Job Reference Standard (JRS): The JRS is a job site pass/fail reference standard representative of the whole job or major sections of the job. See Paragraph 13.2 and Figure 2.

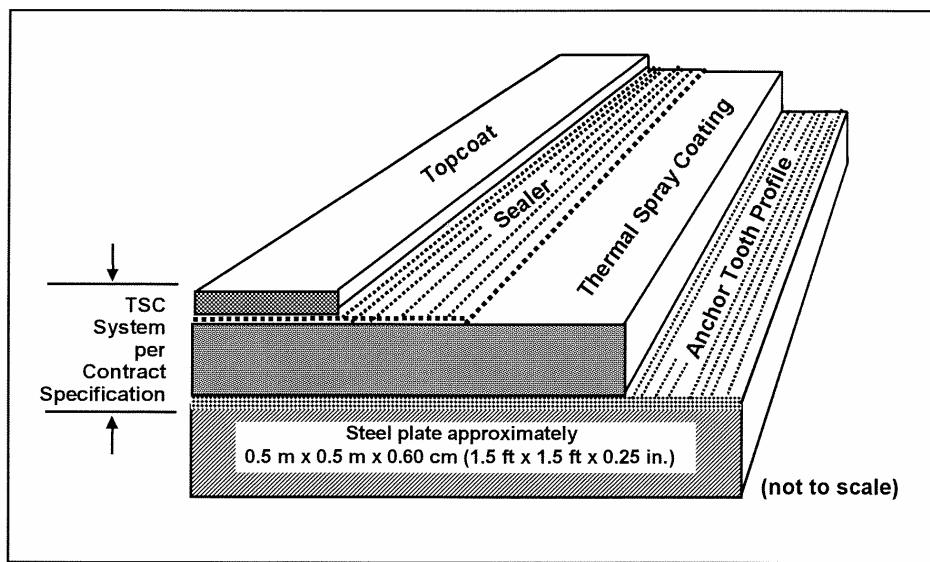


Figure 2: Job Reference Standard Illustration

3.10 Overspray: The portion of the thermal spray deposit that is not deposited on the desired area of the workpiece.

3.11 Rust Bloom: Discoloration indicating the beginning of rusting. For the purpose of this standard, rust bloom is rusting that occurs after specified surface preparation.

3.12 Sealer: The sealer is a thin paint coat about 38 μm (1.5 mils) thick that is absorbed into the pores of the TSC. Aluminum and zinc TSCs have porosities ranging up to 15%. Interconnected porosities may extend from the surface to the substrate. Sealing extends the service life. Sealing is accomplished (a) naturally by the oxidation of the sprayed aluminum or zinc filling the pores with a tightly ad-

herent oxide layer or (b) by applying thin paint sealer coatings that penetrate and are absorbed into the pores of the TSC.

3.13 Soluble-Salt Contaminants: These water-soluble salts are inorganic compounds (such as chlorides and sulfates) that contaminate a product. If soluble salts are present on a prepared steel surface, they may cause rust bloom and premature coating failure.

3.14 Topcoat: The topcoat is a paint coat over the seal coat. Note: Paint topcoats should never be applied over an unsealed TSC.

Section 4: Summary of Practice

4.1 The procedure for application of TSCs for the corrosion protection of steel includes (a) proper surface preparation of the substrate steel, (b) proper application of the TSC, and (c) proper application of the sealer or sealer and topcoat. The procedure includes the use of suitable abrasive blasting, thermal spraying, sealing/topcoating equipment, and in-

process QC checkpoints. Table 1 summarizes the TSC system requirements and the inspection and acceptance tests for shop and field applications. The TSC system material, thickness, adhesion strength, and sealer or sealer and topcoat should be related to the required service.

Section 5: Surface Finish Requirements

5.1 Surface Finish

5.1.1 The steel substrate shall be prepared to:

- (1) White metal finish, NACE No. 1/SSPC-SP 5, for marine and immersion service, or
- (2) The minimum of near-white metal finish, NACE No. 2/SSPC-SP 10, for other service applications.

(3) The level of soluble-salt contamination on the surface shall conform to the contract specifications.

5.1.2 Surface finish and cleanliness shall be confirmed according to SSPC-VIS 1.

5.2 Angular Profile Depth

5.2.1 The steel substrate shall have, at a minimum, an angular profile depth $\geq 65 \mu\text{m}$ (2.5 mils) with a sharp angular shape.

5.3 Angular Profile Depth Measurement Schedule

5.3.1 The profile depth shall be measured according to NACE Standard RP0287 or ASTM D 4417, Method C

(replica tape, x-coarse, 38 to 113 μm [1.5 to 4.5 mils]), or Method B (profile depth gauge), or both.

(1) Manual Blasting. At a minimum, take one profile depth measurement every 1 to 2 m^2 (10 to 20 ft^2) of blasted surface.

(2) Automated Blasting. At a minimum, take one profile depth measurement every 100 to 200 m^2 (1,000 to 2,000 ft^2) of blasted surface.

(3) Angular Blast Media. Use clean dry angular blasting media. Mineral and slag abrasives shall be selected and evaluated per SSPC-AB 1, recycled ferrous metallic abrasives per SSPC-AB 2, and steel grit per SSPC-AB 3. The absence of oil contamination shall be confirmed using the test for oil in the appropriate abrasive specification (no oil film or slick). The soluble salt contamination shall be measured by ASTM D 4940. The suitability of the angular blast media, blasting equipment, and blasting procedures shall be validated according to Section 14, Contract Pre-Award Evaluation, Demonstration, and Validation. Table 2 indicates blasting media and mesh size found suitable for TSCs on steel substrates.

Section 6: TSC Requirements

6.1 Feedstock and TSC Thickness

6.1.1 The TSC feedstock material and thickness should be selected according to intended service environment and service life. (See ANSI/AWS C2.18)

6.1.2 The TSC feedstock material shall be specified according to ANSI/AWS C2.25/C2.25M or ASTM B 833.

6.1.3 The minimum and maximum TSC thickness shall be measured with an SSPC-PA 2, Type 2 fixed probe gauge or equivalent. The thickness scheduled is specified in Paragraph 6.3.

Table 1: TSC System Requirements and Acceptance Tests

Surface Preparation	TSC System Requirements		Acceptance Tests
	TSC	Sealer or Sealer and Topcoat	
NACE No. 2/SSPC-SP 10 minimum ^(A)	Smooth and uniform. No blisters, cracks, loose particles, or exposed steel.	Smooth and uniform. No runs, sags, lifting, pinholes, or overspray.	Per the contract surface preparation standard.
Angular-profile depth $\geq 65 \mu\text{m}$ (2.5 mils)	---	---	Profile tape according to NACE Standard RP0287 or micrometer depth gauge according to ASTM D 4417
Specify blasting media	Specify feedstock	Specify paint(s)	Manufacturer's certificate ^(B) and MSDS
---	Coating Thickness ^(C) Minimum: <u> </u> μm (<u> </u> mils) Maximum: <u> </u> μm (<u> </u> mils)	Coating thickness Minimum: <u> </u> μm (<u> </u> mils) Maximum: <u> </u> μm (<u> </u> mils)	SSPC-PA 2 Type 2 Fixed Probe Gauge
---	Portable tensile bond (\geq Table 3 values) Minimum: <u> </u> MPa (<u> </u> psi)	---	ASTM D 4541 ^(D)
Companion coupon bend/tensile-bond test ^(E) :		---	Bend/tensile-bond test
Condition of substrate surface preparation and TSC interface and morphology (structure) ^(F)		---	Metallographic examination of companion coupon
---	No peeling or delimitation	---	TSC Cut Test ^(G)
	Other as specified by the Contract		Other as specified by the Contract

^(A) For critical surfaces and marine and underwater service, clean to a white metal finish (NACE No. 1/SSPC-SP 5) with $\geq 65 \mu\text{m}$ (2.5 mils) angular profile. The owner should specify the minimum required blast quality and its validation according to Section 5, Job Reference Standard. The angularity of the blast profile can be determined by a metallographic analysis of a companion coupon according to ASTM E 3 using a specimen cut from a successful bend coupon prepared and thermal sprayed per the contract specifications and tested according to Paragraph 6.5.

^(B) Verification that the manufacturers or suppliers provide a certificate or affidavit that (1) the blasting media conforms to SSPC-AB 1 for mineral and slag abrasive, SSPC-AB 2 for recycled ferrous metallic abrasives, or SSPC-AB 3 for newly manufactured or remanufactured steel abrasive; (2) the TSC-feedstock chemical composition, obtained from a representative sample of each heat during the pouring or subsequent processing, conforms to ANSI/AWS C2.25; and (3) the sealer and topcoat paints are formulated for the contract-specified thermal spray coating. The Material Safety Data Sheets (MSDS) provide supporting physical and chemical information.

^(C) Measure the TSC thickness according to SSPC-PA 2. Calibrate the instrument using a calibration wedge near the contract-specified thickness placed over a representative sample of the contract-specified abrasive blasted steel, a prepared bend coupon, or both.

^(D) Specify the ASTM D 4541 self-adjusting portable tensile instrument to be used and its minimum acceptable value for the Job Reference Standard and the job work surfaces.

^(E) As an alternative to the portable tensile-bond test, which may be considered potentially destructive on a finished part, a companion coupon may be bend tested, or a companion tensile test specimen may be tested in accordance with ASTM C 633 to validate the coating adhesion strength. The bend test is a macro system test for proper surface preparation, equipment set-up, and spraying parameters.

^(F) Metallographic analysis of a companion coupon may be specified to establish the suitability of the surface preparation, TSC application, and/or porosity of the TSC.

^(G) TSC cut test should be made by a tool cutting through the TSC to the steel surface. The TSC is defective if any part of the coating lifts off the surface.

Table 2: Blasting Media and Mesh Size Found Suitable for TSCs on Steel Substrates

Thermal Spray Material	Process	Blasting Media	Size ^(A)
Al, Zn, 85/15 Zn/Al, 90/10 Al- Al ₂ O ₃ MMC	Flame wire and arc wire	Aluminum oxide	10-30 mesh
		Angular steel grit	G-16 to G-40
		Copper and nickel slag	G-16 to G-24
		Almandite garnet	G-16 to 30/40
		Chilled iron grit	G-16 to G-40
Al, Zn	Flame powder	Aluminum oxide	10-30 mesh
		Angular steel grit	G-16 to G-40
		Chilled iron grit	G-16 to G-40

^(A) Mesh size shall be selected as appropriate to the anchor-tooth depth requirement and the blasting equipment used.

6.2 TSC Thickness

6.2.1 Thickness Less Than Contract Specification

6.2.1.1 If upon later inspection, and prior to sealer application, the TSC thickness is less than the contract requirement, the applicator shall apply additional TSC to meet the thickness requirement.

6.2.2 Thickness Greater Than Contract Specification

6.2.2.1 If the TSC thickness is greater than the contract specification, information shall be recorded in the JCR and the inspector shall be notified immediately. The inspector should then notify the purchaser for resolution of this discrepancy. The TSC applicator and the purchaser should record all areas in excess of 150% of the acceptable coating thickness. If these areas are damaged during shipping, loading/unloading, or erection, they should be repaired in accordance with maintenance repair procedures as outlined in ANSI/AWS C2.18.

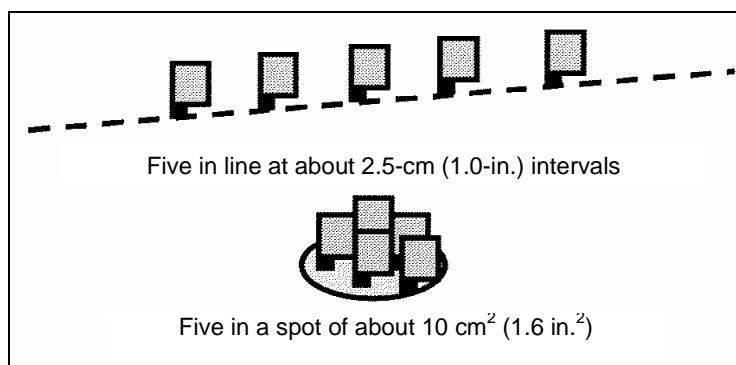
6.3 TSC Thickness Measurement Schedule

6.3.1 For flat surfaces a measurement line shall be used. The average value of five readings taken in line at 2.5-cm (1.0-in.) intervals shall be determined. The line measurement measures the peaks and valleys of the TSC.

6.3.2 For complex geometries and geometry transitions a measurement spot shall be used. The measurement spot should have an area of approximately 10 cm² (1.6 in.²). The spot measurement may not measure the peaks and valleys of the TSC.

6.3.3 Figure 3 illustrates the line and spot measurements.

6.3.4 Measurement Schedule: One line or spot measurement shall be taken every 10 to 20 m² (100 to 200 ft²) of applied TSC.

**Figure 3: Line and Spot Measurements**

6.4 TSC Tensile Bond and Measurement Schedule

6.4.1 The TSC tensile bond shall be measured according to ASTM D 4541 using a self-aligning adhesion tester or approved equivalent.

**Table 3: Minimum Tensile Bond Requirements
(According to ASTM D 4541 using self-aligning adhesion tester)**

Feedstock	MPa (psi)
Zn	3.45 (500)
Al	6.89 (1,000)
85/15 Zn/Al	4.83 (700)
90/10 Al ₂ O ₃ MMC	6.89 (1,000)

6.4.1.2 One portable tensile-bond measurement shall be made every 50 m² (500 ft²). If the tensile bond is less than the contract specification, the degraded TSC shall be removed and reapplied.

6.4.1.3 For nondestructive measurement: Tensile force shall be measured to the *contract-specified tensile*. The tensile force shall then be reduced and the tensile fixture removed without damaging the TSC.

6.4.2 Note: The tensile-bond measurement of the portable test instrument may be calibrated according to the ASTM C 633 test method as described in Appendix C.

6.5 Bend Test

6.5.1 The bend test (180° bend on a mandrel) is used as a qualitative test for proper surface preparation, equipment setup, and spray parameters. The bend test puts the TSC in tension. The mandrel diameter for the threshold of cracking depends on substrate thickness and coating thickness.

6.5.2 Table 4 summarizes a very limited bend-test cracking threshold for arc-sprayed zinc TSC thickness on steel coupons 1.3 mm (0.05 in.) thick versus mandrel diameter.

**Table 4: Bend-Test Cracking Threshold: Mandrel Diameter vs. TSC Thickness
For steel coupons 1.3 mm (0.05 in.) thick**

TSC Thickness, μm (mils)	≥ 250 (10)	≥ 380 (15)	≥ 640 (25)
Mandrel Diameter, mm (in.)	13 (0.50)	16 (0.63)	<25 (1.0) ^(A)

^(A) Confirm diameter with JRS.

6.5.3 Bend-Test Procedure for TSC Thickness Range 175 to 300 μm (7 to 12 mils)

- (1) Five corrosion-control bend coupons shall be sprayed and shall pass the following bend test:
 - (a) Carbon steel coupons of approximate dimensions 50 x 100 to 200 x 1.3 mm (2 x 4 to 8 x 0.050 in.) shall be used.
 - (b) Surface shall be prepared according to contract specification.
 - (c) The TSC shall be sprayed 175 to 300 μm (7 to 12 mils) thick. The TSC should be sprayed in crossing passes laying down approximately 75 to 100 μm (3 to 4 mils) in each pass.

(d) Coupons shall be bent 180° around a 13-mm (0.50-in.) diameter mandrel.

- (2) *Bend test passes* if, on the bend radius (see Figure 4), there is
 - (a) no cracking or spalling, or
 - (b) only minor cracking that cannot be lifted from the substrate with a knife blade.
- (3) *Bend test fails* if the coating cracks with lifting from the substrate.

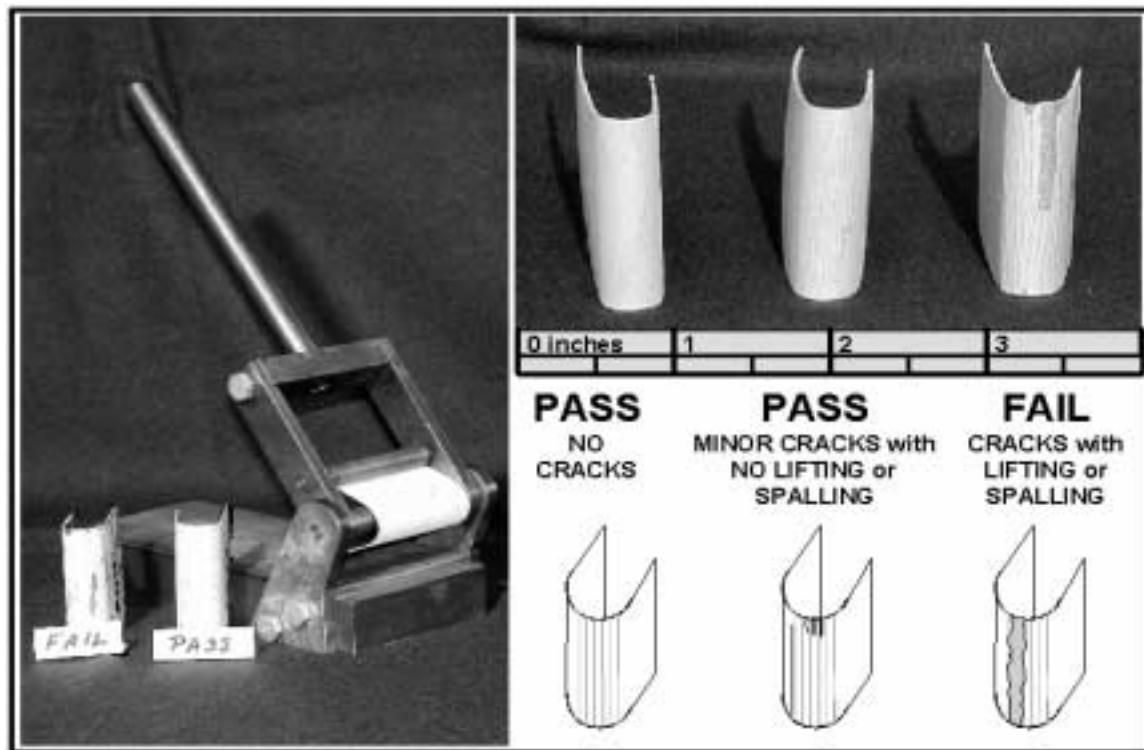


Figure 4: TSC Bend Test: Pass and Fail Samples

6.6 TSC Finish

6.6.1 The deposited TSC shall be uniform without blisters, cracks, loose particles, or exposed steel as examined with 10x magnification.

6.7 TSC Porosity

6.8.1 If required by the purchaser, the maximum allowable porosity and the metallographic measurement method to be used for the evaluation shall be specified. Note: Porosity measurements are not used for in-pro-

cess quality control in metallizing for corrosion protection of steel. However, porosity measurements may be used to qualify thermal spray application processes and spray parameters.

6.8 TSC QC Measurement Procedures and Instruments

6.8.1 The suitability of the TSC thickness, portable tensile bond, bend test, and cut-test measurement procedures and instruments shall be validated during the Contract Pre-Award Validation according to Section 14.

Section 7: TSC Application Procedure

7.1 General

7.1.1 Appendix D details the key production and quality control checkpoints for applying TSCs.

7.2 Thermal Spray Equipment Setup

7.2.1 Thermal spray equipment shall be set up, calibrated, and operated (1) according to the manufacturer's instructions and technical manuals or the TSC applicator's refinement thereto, and (2) as validated by the JRS (See Paragraph 13.2).

7.2.2 Spray parameters and thickness of each crossing pass shall be set for spraying the specified thermal spray material and, at a minimum, be validated with the bend test.

7.2.3 The thermal spray equipment spray-parameter set-up shall be validated with a bend test at the beginning of each shift or crew change.

7.2.4 A copy of the spray parameters used shall be attached to the JCR.

7.3 Post-Blasting Substrate Condition and Thermal Spraying Period

7.3.1 Steel Surface Temperature

7.3.1.1 The steel surface temperature shall be at least 3°C (5°F) above the dewpoint of the ambient air temperature.

7.3.2 Holding Period

7.3.2.1 Time between the completion of the final anchor-tooth blasting (or final brush blasting) and the completion of the thermal spraying should be no greater than six hours for steel substrates with the following exceptions:

(1) In high-humidity and damp environments, shorter holding periods shall be used. If rust bloom or a degraded coating appears at any time while spraying, spraying shall be stopped. (See Paragraph 8.2.4.)

(2) In low-humidity environments or in controlled environments with enclosed structures using industrial dehumidification equipment, it may be possible to retard the oxidation of the steel and hold the surface finish for more than six hours. The TSC applicator, with the concurrence of the purchaser, can establish a holding period greater than six hours by determining the acceptable temperature-humidity envelope for the work enclosure by spraying and analyzing bend coupons, tensile-bond specimens, or both. The following method shall be used for bend-test coupons: (a) establish, measure, and record the low-humidity environment; (b) prepare four bend-test coupons according to contract specifications; (c) place bend-test coupons in the low-humidity environment; (d) after target holding period duration, apply the contract-specified thermal spray coating; (e) perform the bend test according to Paragraph 6.5; (f) the low-humidity environment and holding period are satisfactory if the four bend coupons meet the requirement of Paragraph 6.6.3 (2). Alternately, tensile-bond specimens can be similarly tested.

(3) For small and movable parts, if more than 15 minutes is expected to elapse between the completion of surface preparation and the start of thermal spraying, or if the part is moved to another location, the prepared surface should be protected from moisture, contamination, and finger/hand marks. Wrapping with clean ink-free paper is normally adequate.

7.4 TSC Flash Coat

7.4.1 Application Time

7.4.1.1 A 25- to 50- μm (1- to 2-mil) flash coat of the TSC may be applied within six hours of completing surface preparation to extend the holding period for up to four more hours beyond the complete application of the flash coat. The final TSC thickness, however, shall be applied within four hours of the completion of the application of the flash coat provided the TSC can be maintained free of contamination.

7.4.2 Validation Procedure

7.4.2.1 The use of a flash TSC to extend the holding period shall be validated with a tensile-bond measurement, bend test, or both. The use of a flash TSC shall be validated by:

(1) Cleaning and abrasive blasting a representative job area for a portable tensile-bond measurement, a bend-test coupon, or both.

(2) Applying a flash TSC.

(3) Waiting the delay period and applying the final TSC thickness.

(4) Measuring the tensile bond, performing the bend test, or both.

7.4.2.2 The flash TSC and holding period are acceptable if the tensile bond, bend tests, or both, are satisfactory.

Section 8: TSC Application

8.1 Preheat

8.1.1 Preheating the starting area has been common practice for flame spraying and should be continued until proven not to be a benefit or inconsequential. The initial 0.1- to 0.2- m^2 (1- to 2- ft^2) starting-spray area shall be preheated to prevent water in the flame from condensing on the substrate.

8.1.1.1 For flame spraying, the initial starting area shall be preheated to approximately 120°C (250°F).

8.1.1.2 Preheating requirements shall be validated with the JRS and the bend test, tensile test, or both.

8.2 Thermal Spraying

8.2.1 Crossing Passes

8.2.1.1 The specified coating thickness shall be applied in several crossing passes. The coating tensile-bond strength is greater if the spray passes are kept thin. Laying down an excessively thick spray pass increases the internal stresses in the TSC and decreases the ultimate tensile-bond strength of the total TSC. The suitability of the crossing-pass thickness shall be confirmed with a bend test, tensile-bond measurement, or both.

8.2.2 Manual Spraying

8.2.2.1 For manual spraying, right-angle crossing passes shall be used to minimize the thin areas in the coating.

8.2.3 Mechanized Spraying

8.2.3.1 For mechanized spraying (mechanized movement of the gun, workpiece, or both), overlapping and crossing passes shall be programmed to eliminate thin spots and stay within the coating thickness specification.

8.2.4 Rust Bloom

8.2.4.1 If rust bloom, blistering, or a degraded coating appears at any time during the application of the TSC or flash TSC, the following procedure applies:

(1) Stop spraying.

(2) Mark off the acceptable sprayed area.

(3) Re-prepare the unsatisfactory areas to the required degree of surface cleanliness and surface profile, including any areas where the TSC was applied to unsatisfactory surfaces.

(a) Blast the edges of the TSC to provide for a 5.0- to 7.5-cm (2.0- to 3.0-in.) feathered-area overlap of the new work into the existing TSC.

(b) Apply TSC to the newly prepared surfaces, and overlap the existing TSC to the extent of the feathered edge so that the overlap is a consistent thickness.

8.2.5 TSC Thickness

8.2.5.1 The TSC thickness shall be that specified in Table 1 and Paragraph 6.1.3.

8.2.6 Low-Temperature Spraying

8.2.6.1 Thermal spraying in low-temperature environments (below freezing) must:

(1) Meet the substrate surface temperature and holding period specified in Paragraphs 7.3.1 and 7.3.2. No moisture condensation on the surface is permissible during thermal spraying.

(2) Be qualified with a bend test, portable tensile-bond test, or both.

Note: TSCs are mechanically bonded to the substrate. Preheating may be required to improve the TSC tensile bond to the substrate and reduce internal stresses.

Section 9: Application of Sealers and Topcoats

9.1 General

9.1.1 Thermal sprayed steel should be sealed and/or topcoated under any of the following conditions:

(1) The environment is very acidic or very alkaline (normal pH range for pure zinc is 6 to 12 and for pure aluminum, 4 to 11).

(2) The metallic coating is subject to direct attack by specific chemicals.

(3) A particular decorative finish is required.

(4) Additional abrasion resistance is required.

(5) Frequent saltwater spray, splash, or immersion service.

(6) Frequent freshwater spray, splash, or immersion service, excluding potable water.

9.1.2 Sealers and topcoats shall meet the local restrictions on volatile organic compound (VOC) content. Sealer and topcoats shall be applied according to the paint manufacturer's instructions for use with a TSC, or as specified by the purchaser.

9.2 Sealer

9.2.1 The seal coat, if applied, shall be thin enough to penetrate into the body of the TSC and seal the interconnected surface porosity. Typically the seal coat is applied at a spreading rate resulting in a theoretical 38- μm (1.5-mil) dry-film thickness (DFT).

9.2.2 For shop and field work, sealers should be applied as soon as possible after thermal spraying and preferably within eight hours.

9.2.3 If a sealer cannot be applied within eight hours, it shall be verified that the TSC (a) has not been contaminated by visual inspection, and (b) is dust-free using the clear cellophane tape test per ISO 8502-3 before applying the sealer.

9.3 Topcoat

9.3.1 A topcoat is essentially a full coat of paint. Topcoats shall be chemically compatible with the sealer and shall be applied according to the paint manufac-

turer's instructions for a topcoat on a sealed TSC, or as specified by the purchaser. Full topcoats greatly reduce or entirely diminish the cathodic protection effects of the TSC in immersion or underground service.

9.3.2 A paint topcoat shall only be applied to an unsealed TSC if the compatibility of this (sealer-topcoat) painting system has been demonstrated.

9.4 Applying Paints

9.4.1 All paint coatings shall be applied according to SSPC-PA 1 and the paint manufacturer's recommendations for use of the product with a TSC system.

Section 10: Records

10.1 The TSC applicator shall use a JCR to record the production and QC information and other information required by the purchasing contract. Additionally, the TSC applicator shall have its own Quality Assurance Program. The TSC applicator shall keep records for a time period consistent

with the TSC applicator's quality assurance and records program and as required for regulatory compliance and the purchasing contract. Records should be kept a minimum of one year.

Section 11: Debris Containment and Control

11.1 The TSC applicator and the purchaser shall coordinate the specific requirements, responsibilities, and actions

for the containment, collection, and removal of the debris produced by the TSC applicator and its subcontractors.

Section 12: Work Procedures and Safety

12.1 The purchaser shall provide its standard operating and safety procedures and compliance requirements to the TSC applicator. The TSC applicator shall follow all appro-

priate procedures and meet all appropriate regulatory requirements.

Section 13: Documentation

13.1 TSC Applicator's Application Procedure

13.1.1 The TSC applicator shall submit its application procedure proposed for the contract work. The application process shall include information on the equipment capabilities, materials, and process or application procedures, and in-process quality control checkpoints for (a) surface preparation, (b) thermal spraying, and (c) paint work (sealer or sealer and topcoat).

13.2 Job Reference Standard (JRS)

13.2.1 A job site pass/fail JRS representative of the whole job or major sections of the job shall be prepared by the TSC applicator. The JRS shall be used as a

"comparator" to evaluate the suitability of the application process.

(1) The JRS shall be made on a steel plate approximately 46 x 46 x 0.60 cm (18 x 18 x 0.25 in.) (see Figure 2). *For structural steel, the reference standard does not need to be more than 0.60 cm (0.25 in.) thick because steel does not thermally distort when TSC is applied.* If the actual work is less than 0.60 cm (0.25 in.) thick, the JRS should be made from material of a representative thickness.

(2) The JRS shall be made with the actual field equipment and the process parameters and procedures (surface preparation, thermal spraying, sealing or sealing

and topcoating in-process QC checkpoints) that shall be used for the contracted work.

(3) The JRS shall be made in representative environmental conditions spraying with or without enclosure as appropriate.

(4) Thickness and tensile-bond measurements shall be made according to Figure 5.

- (a) Four “five in-line” thickness measurements.
- (b) Four portable tensile-bond measurements according to Paragraph 6.4.
- (c) The JRS is unsatisfactory if any measurements are less than the contract-specified value.

(5) The JRS is used as a pass/fail reference for the applicator's in-process QC and the purchaser's inspector.

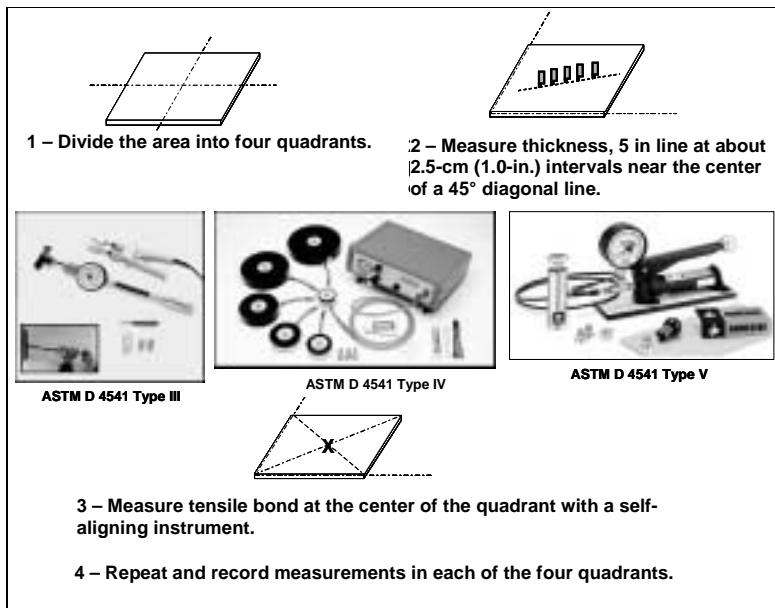


Figure 5: Thickness and Tensile-Bond Measurements for JRS Qualifications

Section 14: Contract Pre-Award Evaluation, Demonstration, and Validation

14.1 The purchaser shall evaluate the suitability of the TSC applicator's application process submitted according to Paragraph 13.1.

14.2 The purchaser, as an option for physically validating the TSC applicator's application process, may schedule, witness, and evaluate a contract pre-award demonstration

of the TSC applicator's application process for the surface preparation, thermal spraying, sealing, and topcoating, using the equipment, materials, and process procedures proposed for the contract work. The JRS should be made during this demonstration and witnessed by the purchaser or his designated representative.

Section 15: TSC Applicator Warranty

15.1 TSC Applicator Warranty

15.1.1 The TSC applicator shall warrant the quality of its workmanship as mutually agreed to by the purchaser and the TSC applicator.

15.2 Materials Used

15.2.1 The TSC applicator shall provide the purchaser with a Certificate of Materials Used to include:

(1) For angular blasting media: Media type, grit size range, chemical composition, and MSDS.

(2) For TSC spray feedstock: Alloy type/designation, lot number, wire diameter, chemical composition of the wire lot, and MSDS.

(3) Sealer and topcoat: Manufacturer's product and application data sheets for application on the TSC system and MSDS.

Further Reading

- ANSI Z49.1. "Safety in Welding, Cutting, and Allied Processes." Washington, DC: ANSI.⁽¹⁰⁾
- AWS C2.14. "Corrosion Tests of Flame-Sprayed Coated Steel, 19-Year Report." 1974.⁽¹¹⁾
- BS 5493. "Code of Practice for Protective Coatings of Iron and Steel Structures Against Corrosion." London, UK: BSI.⁽¹²⁾
- Kain, R.M., and E.A. Baker. "Marine Atmospheric Corrosion Museum Report on the Performance of Thermal Spray Coatings on Steel." ASTM STP 947. 1987.
- NFPA 58. "Standard for the Storage and Handling of Liquefied Petroleum Gases." Quincy, MA: NFPA.⁽¹³⁾
- Pikul, S.J. "Appearance of Thermal Sprayed Coatings after 44 Years Marine Atmospheric Exposure at Kure Beach, North Carolina." LaQue Center for Corrosion Technology Report.⁽¹⁴⁾
- SSPC Publication. *Inspection of Coatings and Linings: A Handbook of Basic Practice for Inspectors, Owners, and Specifiers*. B.R. Appleman, R. Drisko, J. Neugebauer, eds.
- SSPC-TU 4. "Field Methods for Retrieval and Analysis of Soluble Salts on Substrates." Pittsburgh, PA: SSPC.
- Thermal Spraying: Practice, Theory, and Application*. Miami, FL: AWS, 1985.⁽¹⁵⁾

⁽¹⁰⁾ Available from the American National Standards Institute, 1819 L Street NW, 6th floor, Washington, DC 20036.

⁽¹¹⁾ AWS publications can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5776, Telephone (800)-854-7179, Fax (303) 307-2740, Internet www.global.ihs.com.

⁽¹²⁾ BSI standards can be obtained from the British Standards Institution (BSI), British Standards House, 389 Chiswick High Rd., London W4 4AL, UK.

⁽¹³⁾ Available from the National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

⁽¹⁴⁾ Available from the LaQue Center for Corrosion Technology, Inc., 702 Causeway Drive, Wrightsville Beach, NC 28480.

⁽¹⁵⁾ AWS publications can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5776, Telephone (800)-854-7179, Fax (303) 307-2740, Internet www.global.ihs.com

Appendix A: Model Procurement Specification

This Appendix is not a part of NACE No. 12/AWS C2.23M/SSPC-CS 23.00, but is included for informational purposes only.

Appendix A is included to illustrate how this standard may be used to specify a thermal spray job.

The Model Specification <i>(Bolded text is the model specification. Scripted text is optional and if used, should match the format and style used in the final specification.)</i>	Instructions/Rationale
<p>1. Scope of Work</p> <p>1.1 Application Procedure</p> <p>The TSC system (surface preparation, thermal spraying, and sealing or sealing and topcoating) shall be applied in accordance with Sections 4, 5, and 6 of this specification.</p> <p>1.2 Items/Areas to Be Thermal Sprayed.</p> <p>Apply TSC systems to:</p> <hr/> <hr/> <hr/>	<p>The major production and quality control (QC) steps for applying a TSC coating system are summarized in Appendix D. Appendix D should be appended to the procurement specification to inform the TSC applicator of the application requirements.</p> <p>Specify the item(s) and surface(s) to be (and not to be) thermal sprayed. Reference and append engineering drawings or other technical documents that quantitatively describe the job.</p>
<p>2. Codes and Standards</p> <p>This specification takes precedence in event of conflict with cited Codes and Standards.</p> <p>The following codes and standards (latest issue) apply:</p> <p>ASTM B 833, Standard Specification for Zinc Wire for Thermal Spraying (Metallizing).</p> <p>ASTM C 633, Test Method for Adhesive/Cohesive Strength of Flame Sprayed Coatings.</p> <p>ASTM D 4285, Method for Indicating Oil or Water in Compressed Air.</p> <p>ASTM D 4417, Test Method for Field Measurement of Surface Profile of Blasted Steel.</p> <p>NACE Standard RP0287, Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape.</p> <p>ASTM D 4541, Test Method for Pull-Off Strength of Coating Using Portable Adhesion Testers.</p> <p>ANSI/AWS C2.18, Guide for the Protection of Steel with Thermal Spray Coatings of Aluminum, Zinc, and Their Alloys and Composites.</p> <p>NACE No. 12/AWS C2.23M/SSPC-CS 23.00, Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel.</p> <p>SSPC Publication, The Inspection of Coatings and Linings: A Handbook of Basic Practice for Inspectors, Owners, and Specifiers.</p> <p>SSPC-AB 1, Mineral and Slag Abrasives.</p> <p>SSPC-AB 3, Ferrous Metallic Abrasives.</p> <p>SSPC-PA 1, Shop, Field, and Maintenance Painting of Steel.</p> <p>SSPC-PA 2, Measurement of Dry Coating Thickness with Magnetic Gages.</p> <p>NACE No. 1/SSPC-SP 5, White Metal Blast Cleaning.</p> <p>NACE No. 2/SSPC-SP 10, Near-White Metal Blast Cleaning.</p> <p>SSPC-VIS 1, Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning.</p>	<p>List the Codes and Standards cited in this procurement specification. Add other standards as required.</p>

The Model Specification <i>(Bolded text is the model specification. Scripted text is optional and if used, should match the format and style used in the final specification.)</i>	Instructions/Rationale
3. TSC System Requirements	
3.1 Surface Preparation Requirement.	
3.1.1 Surface Finish. Degrease according to SSPC-SP 1 if oil/grease contaminated. The steel substrate shall be abrasive blasted to <u>(a)</u> . Using SSPC VIS 1, confirm that the blast cleaned finish meets NACE No. 1/SSPC-SP 5 or NACE No. 2/SSPC-SP 10.	(a) Specify either white metal finish, NACE No. 1/SSPC-SP 5, for marine and immersion service; or near-white metal finish, NACE No. 2/SSPC-SP 10, for other service applications.
3.1.2 Blasting Media Requirement. Use <u>(a)</u> angular blasting media to produce the angular profile depth specified by Paragraph 3.1.3. Mineral and slag abrasives shall be selected and evaluated per SSPC-AB 1; recycled ferrous metallic abrasives per SSPC-AB 2; and steel grit per SSPC-AB 3.	(a) Specify abrasive blasting media type and size. See Table 2 of this NACE No. 12/AWS C2.23M/SSPC-CS 23.00 standard.
3.1.3 Blast Angular Profile Depth. The steel substrate shall have an angular profile depth $\geq 65 \mu\text{m}$ (2.5 mils) with a sharp angular shape per NACE Standard RP0287 or ASTM D 4417, Method B or C.	
3.1.4 Blast Profile Measurement Schedule. Measure the angular profile depth in a measurement spot approximately every <u>(a)</u> blasted surface. Take three measurements for each spot in an area approximately 10 cm^2 (1.5 in. ²). Average the measurements and record in the JCR.	(a) Specify the minimum area, e.g., 10 to 20 m^2 (100 to 200 ft ²)
3.2 TSC Requirement.	
3.2.1 Thermal Spray Feedstock Requirement.	
Use <u>(a)</u> thermal spray wire.	(a) Specify wire according to ANSI/AWS C2.25 or ASTM B 833.
3.2.2 TSC Thickness Requirement and Measurement Schedule	
(a) Thickness (1) The minimum TSC thickness shall be <u>(a)</u> . (2) The maximum TSC thickness shall be <u>(b)</u> . (3) Measure TSC thickness using a SSPC-PA 2 Type 2 fixed probe gauge or equivalent.	(a) Specify the minimum thickness. (b) Specify the maximum thickness.
(b) Measurement Schedule One portable tensile-bond measurement shall be made every 50 m^2 (500 ft ²). If the tensile bond is less than the contract specification, the degraded TSC shall be removed and reapplied.	
3.2.3 TSC Tensile-Bond Requirement.	
(a) The TSC shall have a minimum tensile bond of <u>(a)</u> MPa (<u>(b)</u> psi) according to ASTM D 4541 using the Type <u>(b)</u> self-aligning portable test instrument for coating thickness specified in Paragraph 3.2.2.	(a) Specify the minimum tensile bond. (b) Specify either the Type III or IV portable self-aligning test instruments.
(b) Use adhesive recommended by the instrument manufacturer, or equivalent. Attach adhesive manufacturer's instructions to the JCR.	

The Model Specification (Bolded text is the model specification. Scripted text is optional and if used, should match the format and style used in the final specification.)	Instructions/Rationale
<p>3.2.4 Bend Test.</p> <p>Conduct a bend test at the beginning of each work shift or crew change:</p> <p>(1) Use carbon steel coupons of approximate dimensions 50 x 100 to 200 x 1.3 mm (2 x 4 to 8 x 0.050 in.).</p> <p>(2) Surface preparation according to contract specification.</p> <p>(3) Spray 200- to 250-μm (8- to 10-mil) thick TSC in crossing passes laying down approximately 75 to 100 μm (3 to 4 mils) for each pass.</p> <p>(4) Bend coupons 180° around a 13-mm (0.5-in.) diameter mandrel.</p> <p>(a) Bend test passes if there is no cracking or only minor cracks with no spalling or lifting (by a knife blade) from the substrate.</p> <p>(b) Bend test fails if the coating cracks with lifting (by a knife blade) from the substrate.</p>	<p>The bend test (180° bend on a mandrel) is used as a qualitative test for proper surface preparation, equipment setup, and spray parameters. The mandrel diameter for the threshold of cracking depends on substrate thickness, coating thickness, and mandrel diameter.</p>
<p>3.2.5 TSC Porosity Requirement.</p> <p>The TSC shall have a porosity \leq <u>(a)</u> % for each metallographic analysis of a bend coupon made during the Contract Pre-Award Evaluation, Demonstration, and Validation.</p>	<p>Flame and arc spraying aluminum and zinc for the corrosion protection of steel generally have porosity \leq 15%. The TSC thickness should be selected so there is no interconnected porosity to the substrate. A lower-porosity TSC requires less thickness. Porosity measurements are not used for in-process quality control in metallizing for corrosion protection of steel. However, a metallographic sample must be used to evaluate TSC porosity and confirm the TSC nonporous thickness for the contract-specified thickness. If required, the porosity metallographic sample should be taken from the bend coupon made during the purchaser's witnessing of the preparation of the JRS.</p>
<p>3.3 Sealers and Topcoats</p> <p>All paint coatings shall be applied according to SSPC-PA 1 and the paint manufacturer's instructions for use of the product with a thermal sprayed coating system.</p> <p>Use a heat-resistant silicone alkyd aluminum paint or equivalent sealer on components whose operating temperatures are greater than 80°C (175°F).</p>	<p>Specify use of sealer if (a) the service environment precludes effectiveness of the natural oxidation to "fill and seal" the pores or (b) a paint topcoat (cosmetic and/or functional purpose) is specified. Long delay times will preclude adequate penetration of the sealer into the pores of the TSC. The sealer must be chemically compatible with the TSC material and the topcoat.</p>

The Model Specification (Bolded text is the model specification. Scripted text is optional and if used, should match the format and style used in the final specification.)	Instructions/Rationale
<p>3.3.1 Sealer</p> <p>(1) Use the sealer _____ (a) _____ manufactured by _____ (b) _____.</p> <p>(2) Follow paint manufacturer's application instructions for applying the sealer on TSCs. The seal coat shall be thin enough to penetrate into the body of the TSC and seal the porosity. Typically the seal coat is applied at a spreading rate resulting in a theoretical 38-μm (1.5-mil) DFT.</p> <p>(3) Sealer Application</p> <p>For shop work, apply the sealer immediately after thermal spraying.</p> <p>For field work, apply the sealer as soon after thermal spraying as possible but preferably within eight hours.</p> <p>If sealer cannot be applied within eight hours, verify that the TSC (a) has not been contaminated by visual (10x) inspection and (b) is dust-free using the clear cellophane tape test (ISO 8502-3).</p>	<p>(a) Specify formula or other unique identification.</p> <p>(b) Specify manufacturer.</p>
<p>3.3.2 Topcoat</p> <p>(1) Use the topcoat _____ (a) _____ manufactured by _____ (b) _____.</p> <p>(2) Apply the topcoat to a dry-film thickness (DFT) of _____ (c) _____ according to manufacturer's instructions.</p> <p>(3) Measure DFT using an SSPC-PA 2 Type 2 fixed probe gauge.</p>	<p>(a) Specify formula or other unique identification.</p> <p>(b) Specify manufacturer.</p> <p>(c) Specify thickness from similar successful applications or manufacturer's recommendations for topcoating sealers on TSCs.</p>
<p>4. Surface Preparation.</p> <p>Use blasting equipment, materials, and procedures that will produce the Paragraph 3.1 metal finish and an angular profile \geq65 μm (2.5 mils).</p> <p>The suitability of the blasting, media, procedures, and equipment shall be validated in the contract pre-award evaluation, demonstration, and validation.</p>	<p>Blasting media is specified in Paragraph 3.1.2.</p>
<p>5. TSC Application.</p> <p>5.1 Thermal Spray Equipment Setup.</p> <p>5.1.1 Thermal spray equipment shall be set up, calibrated, and operated according to the manufacturer's instructions and technical manuals or the TSC applicator's refinement thereto and as validated by the JRS.</p> <p>5.1.2 Spray parameters shall be set for spraying the specified thermal spray material and, at a minimum, be validated with the bend test. A bend test shall be satisfactorily performed at the beginning of crew and shift change.</p> <p>5.1.3 A copy of the spray parameters used shall be attached to the JCR.</p>	

The Model Specification (Bolded text is the model specification. Scripted text is optional and if used, should match the format and style used in the final specification.)	Instructions/Rationale
5.2 Post-Blasting Substrate Condition and Thermal Spraying Period	
5.2.1 Steel Surface Temperature. (1) the steel surface temperature shall be at least 3°C (5°F) above the dew-point.	
5.2.2 Holding Period. (1) Time between the completion of the final anchor-tooth blasting (or final brush blasting) and the completion of the thermal spraying should be no greater than six hours for steel substrates. In high-humidity and damp environments, shorter holding periods shall be used. If rust bloom or a degraded coating appears at any time within the six-hour window, Paragraph 5.5.4 of this model specification applies. (2) In low-humidity environments or in enclosed spaces using industrial dehumidification equipment, it will be possible to retard the oxidation of the steel and hold the surface finish for more than six hours. The TSC applicator, with the concurrence of the purchaser, can validate a holding period greater than six hours by determining the acceptable temperature-humidity envelope for the work enclosure by spraying and analyzing bend coupons, tensile-bond coupons, or both. (3) For small and movable parts, if more than 15 minutes is expected to elapse between completion of surface preparation and the start of thermal spraying, or if the part is moved to another location, the prepared surface should be protected from moisture, contamination, and finger/hand marks. Wrapping with clean print-free paper is normally adequate.	
5.3 TSC Flash Coat 5.3.1 A 25- to 50- μm (1- to 2-mil) flash coat of the TSC may be applied within six hours of completing surface preparation to extend the holding period for up to four further hours beyond the complete application of the flash coat. The final TSC thickness, however, shall be applied within four hours of the completion of the application of the flash coat provided the TSC can be maintained free of contamination. 5.3.2 Validate the use of the flash TSC holding period with a _____ (a). Clean and abrasive blast a representative job area and three bend-test coupons. Apply a flash TSC to the representative job area and the three bend coupons. Wait the delay period in representative environmental conditions and apply the final TSC thickness. Flash TSC and holding period are acceptable if the tensile bond specified in Paragraph 3.2.3, or bend test, or both, are satisfactory.	<p>Specify the use of a flash TSC if there is a requirement to extend the time-based holding period beyond that specified in Paragraph 5.2.2.</p> <p>(a) Specify validation method, i.e., with a tensile-bond measurement, bend test, or both.</p>

The Model Specification (Bolded text is the model specification. Scripted text is optional and if used, should match the format and style used in the final specification.)	Instructions/Rationale
<p>5.4 Preheating</p> <p>For flame spraying, preheat the initial starting area to approximately 50°C (120°F) to prevent condensation of moisture in the flame onto the substrate. Validate preheating and non-preheating requirements with a _____ (a) _____.</p>	<p>Specify the preheating requirement for flame spraying. Preheating is not normally required for arc spraying.</p> <p>(a) Specify validation method, i.e., with a tensile-bond measurement, bend test, or both.</p>
<p>5.5 Thermal Spraying</p> <p>5.5.1 Apply the specified coating thickness (Paragraph 3.2.2) in overlapping passes. The coating tensile-bond strength is greater when the spray passes are kept thin. Laying down an excessively thick spray pass increases the internal stresses in the TSC and decreases the ultimate tensile-bond strength of the total TSC. Confirm the suitability of the crossing-pass thickness with _____ (a) _____ measurement.</p>	<p>(a) Specify validation method, i.e., with a tensile bond measurement, bend test, or both.</p>
<p>5.5.2 For manual spraying:</p> <p>On non-fixed components, spray perpendicular crossing passes to minimize thin (below contract-specified thickness) areas.</p> <p>On fixtured rotating components, spray perpendicular overlapping passes to obtain the contract-specified thickness as the spray gun is advanced over the rotating component.</p> <p>5.5.3 For mechanized spraying, program overlapping or crossing passes, or both, to eliminate thin spots and stay within the coating thickness specification.</p> <p>5.5.4 If rust bloom, blistering, or a degraded coating appears at any time during the application of the TSC, the following procedure applies:</p> <ol style="list-style-type: none"> (1) Stop spraying. (2) Mark off the satisfactorily sprayed area. (3) Repair the unsatisfactory TSC (i.e., remove degraded TSC and reestablish the minimum near-white metal finish and anchor-tooth profile depth). (4) In the JCR, record the actions taken to resume the job. (5) Call the TSC inspector to observe and report the remedial action to the purchaser. 	
<p>5.6 Thermal spraying in low-temperature environments (below freezing). No moisture or condensation is permissible on the surface during surface preparation and thermal spraying.</p> <p>Qualify TSC period with a _____ (a) _____.</p> <p>Meet the tensile bond and metallographic requirements of the purchasing contract.</p>	<p>Include Paragraph 5.6 for thermal spraying in low-temperature environments (below freezing).</p> <p>(a) Specify validation method, i.e., with a tensile-bond measurement, bend test, or both.</p>

The Model Specification (Bolded text is the model specification. Scripted text is optional and if used, should match the format and style used in the final specification.)	Instructions/Rationale
<p>5.7 TSC Measurement Schedule.</p> <p>(1) The TSC dry film thickness (DFT) shall be measured using a SSPC-PA 2 Type 2 fixed probe gauge.</p> <p>(2) Use a measurement line for flat surfaces. Take the average value of five readings taken in line at 2.5-cm (1.0-in.) intervals. The line measurement measures the peaks and valleys of the TSC.</p> <p>(3) Use a measurement spot approximately 10 cm² (1.5 in.²) for complex geometries and geometry transitions. Do not measure the peaks and valleys of the TSC.</p> <p>(4) Record in the JCR.</p>	
<p>6. Sealer or Sealer and Topcoat.</p> <p><i>The sealer and topcoat shall be applied according to SSPC-PA 1 and the paint manufacturer's recommendations for use of the product with a TSC system.</i></p> <p>6.1 Apply sealer as specified in Paragraph 3.3.1.</p> <p>6.2 Apply topcoats as specified in Paragraph 3.3.2.</p>	<p><i>Include this section if a sealer is specified.</i></p> <p><i>Include this section if a sealer is specified.</i></p> <p><i>Include this section if a topcoat is specified.</i></p>
<p>7. TSC Applicator's Detailed Procedure.</p> <p>The TSC applicator shall submit the detailed procedures conforming to Section 5 (Surface Preparation), Section 7 (TSC Application), and Section 9 (Sealer or Sealer and Topcoat) of the specification. The procedures shall detail the equipment, application process, in-process quality control, and JCR to be used for the contract work. The information shall include:</p> <p>(1) Detailed procedures for surface preparation, thermal spraying, sealing or sealing and topcoating, and the in-process quality control checkpoints.</p> <p>(2) Equipment (surface preparation, thermal spraying, sealing or sealing and topcoating, and the in-process quality control) to be used and for which the detailed procedures apply.</p> <p>(3) Blasting media, thermal spray feedstock, and sealing or sealing and topcoating materials.</p> <p>(4) JRS.</p> <p>(5) JCR. See Appendix B.</p> <p>(6) Repair defective TSCs per ANSI/AWS C2.18.</p>	<p>Specify the requirements for the following information as required: safety, thermal spray operator qualification, TSC applicator work performance history, and customer contact references for validation.</p>
<p>8. Contract Pre-Award Evaluation, Demonstration, and Validation.</p> <p>8.1 Data Requirements.</p> <p>The TSC applicator shall submit the detailed information cited in Section 7. This information shall be submitted prior to contract approval and at least _____ (a) _____ days prior to Contract Pre-Award Evaluation Demonstration and Validation.</p>	<p>(a) Specify lead time.</p>

The Model Specification (Bolded text is the model specification. Scripted text is optional and if used, should match the format and style used in the final specification.)	Instructions/Rationale
8.2 Equipment and Process Demonstration and Validation. The actual equipment and processes to be used for the contract work shall be demonstrated and validated to produce the specified TSC. This demonstration and validation shall be scheduled <u>(a)</u> days after delivery of the data requirements. See Paragraph 8.1.	(a) Specify lead time.

Appendix B: Model Job Control Method

This Appendix is not a part of NACE No. 12/AWS C2.23M/SSPC-CS 23.00, but is included for informational purposes only.

Model Job Control Record (JCR) (Add steps specified in the contract if not specified in the model JCR. Delete steps not specified in the contract.)							
TSC Applicator:	JCR#:	Date:					
TSC Applicator Point of Contact:	Tel:						
Customer/Contract #							
Customer POC:	Tel:						
Spray Equipment Data: Spray machine mfg.: _____ Model: _____ Feedstock: _____ TSC minimum/maximum thickness, μm (mils): _____ min./ _____ max. Thickness/pass: _____ μm (mils) Standoff Distance: _____ mm (in.) Other: _____							
DAILY PRODUCTION RECORD		DATE: _____					
Work Item/Area <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th colspan="2" style="text-align: center;">Environmental Requirements</th> <th rowspan="2" style="text-align: center; vertical-align: middle;">Initials for Check-Off</th> </tr> </thead> <tbody> <tr> <td colspan="2">1—The steel surface temperature shall be at least 3°C (5°F) above the dewpoint.</td> </tr> </tbody> </table>			Environmental Requirements		Initials for Check-Off	1—The steel surface temperature shall be at least 3°C (5°F) above the dewpoint.	
Environmental Requirements		Initials for Check-Off					
1—The steel surface temperature shall be at least 3°C (5°F) above the dewpoint.							
Step	Production Process						
	Requirement	In-Process QC Checkpoint					
	Surface Preparation—NACE No. 2/SSPC-SP 10 with $\geq 65\text{-}\mu\text{m}$ (2.5-mil) angular profile. (NACE No. 1/SSPC-SP 5 finish required for marine, immersion, and other critical service.)						
1	Degrease to remove oil, salts, and other contamination.	1.1—Dust/dirt: Clear tape pull-off and visual/10x magnification 1.2—Oil/grease: solvent evaporation test. 1.3—Na and S salts: Potassium ferrocyanide filter paper test.					
2	Validate clean blasting air and media.	2.1—Clean blasting media using the test oil in the appropriate abrasive specification (No oil film or slick. No fines.). 2.2—Clean blasting air according to ASTM D 4285 (air discharge on absorbent or nonabsorbent collector).					
3	Blast to specified finish with $>64\text{-}\mu\text{m}$ (2.5-mil) angular profile.	3.1—Angular profile depth: Profile tape according to NACE Standard RP0287 or depth-gauge measurement according to ASTM D 4417 and contract sampling schedule.					
4	Clean and dust-free surface.	4.1—Clean and dust-free surface according to visual/10x magnification and the clear-tape pull-off test.					

Step	Requirement	Thermal Spraying	Initials for Check-Off
5	Holding period between completion of surface preparation and completion of thermal spraying.	5.1—Holding periods shall be no more than six hours for steel substrates if there is no flash rusting prior to completion of thermal spraying. See Paragraph 8.2.4.	
		5.2—In low-humidity environments or in enclosed spaces using industrial dehumidification equipment, a holding period > six hours shall be validated using bend coupons, a portable tensile-bond test, or both according to Paragraph 7.3.2.1 (2).	
		5.3—Small and movable parts shall be protected if more than 15 minutes is expected to elapse between surface preparation and the start of thermal spraying or if the part is moved to another location.	
6	TSC Flash Coat	6.1—A 25- to 50- μm (1.0- to 2.0-mil) flash coat of the TSC may be applied within six hours of completing surface preparation to extend the holding period for up to a further four hours beyond the complete application of the flash rust coat.	
		6.2—The final TSC thickness shall be applied within four hours of the completion of the application of the flash coat provided the TSC can be maintained free of contamination.	
7	Preheating	7.1—For flame spraying, the initial starting area shall be preheated to approximately 120°C (250°F) to prevent water in the flame from condensing on the substrate. Preheating and non-preheating equipment shall be validated using a bend test, tensile-bond measurement, or both.	
8	Thermal Spraying	8.1—The specified coating thickness, _____ (insert value from the specification) in overlapping passes. Confirm the suitability of the inter-pass thickness with a bend test, tensile-bond measurement, or both.	
		8.2—If rust bloom, blistering, or a degraded coating appears at any time during the application of the TSC, the following process shall be followed: (a) Stop spraying. (b) Mark off the acceptable sprayed area. (c) Call the TSC inspector to observe and evaluate the error, report the deficiency to the purchaser for remedial action, and record the deficiency and actions taken to resume the job.	
9	TSC Measurement Schedule	Measurements shall be taken according to the contract and recorded in the JCR.	
		9.1—The TSC shall be measured in accordance with a SSPC-PA 2 Type 2 gauge.	
		9.2—The average value of five readings for each measurement line or spot shall be determined.	
		9.3—A measurement line shall be used for flat surfaces. The average value of five readings taken in line at 2.5-cm (1.0-in.) intervals shall be determined. The line measurement measures the peaks and valleys of the TSC.	
		9.4—A measurement spot shall be used for complex geometries and geometry transitions. The measurement spot should be approximately 10 cm^2 (1.6 in. ²). The spot measurement may not measure the peaks and valleys of the TSC.	

Step	Requirement	Sealing or Sealing and Topcoating	Initials for Check-Off
10	If sealer is specified:	10.1—The seal coats shall be applied as soon as possible after the TSC has been applied and before visible (10x magnification) oxidation of the TSC occurs: < 8 hours for zinc and zinc-alloy TSCs and < 24 hours for aluminum and aluminum alloys.	
		10.2—The seal coat shall be applied according to manufacturer's instructions or the purchasing contract and only to clean dry TSC surfaces.	
11	If topcoat is specified:	11.1—The topcoats shall be applied according to manufacturer's instructions or the purchasing contract.	
Remarks:			
Thermal Sprayer (or QC Inspector) print name: _____ Signature: _____ Date: _____			

Appendix C: Procedure for Calibration of Portable Test Instruments to the ASTM C 633 Test Method

This Appendix is not a part of NACE No. 12/AWS C2.23M/SSPC-CS 23.00, but is included for informational purposes only.

General. ASTM C 633 is the standard laboratory method for the measurement of the adhesion of TSCs to the substrate and forms the basis of the "literature." ASTM D 4541 is a method for portable tensile measurements and when compared to the C 633 method, gives a means of "calibrating" the portable to the laboratory measurements.

This proposed procedure is based on spraying a steel plate that has holes drilled to accept the ASTM C 633 tensile-bond test specimens, inserting the C 633 tensile specimen 0.65 cm (0.25 in.) above the calibration fixture, preparing the surface, and thermal spraying according to the application standard or contract specifications. Note: This procedure has not been validated experimentally or adopted by any standards-writing organization. It is, however, presented as a logical and simple method to relate D 4541 tensile bonds to the C 633 tensile bonds.

Procedure. Using the calibration fixture similar to Figure C1:

(1) Degrease calibration fixture and the ASTM C 633 and the ASTM D 4541 portable tester tensile-bond test specimens.

(2) Mount the ASTM C 633 tensile specimens about 0.65 cm (0.25 in.) above one face of the holding plate to prevent the thermal spray coating from bridging the holding plate. Use a release agent on the cylindrical surface of the tensile specimen to ease removal after thermal spraying. Use brackets or masking tape to firmly hold the tensile-test specimen in place during the blasting and spraying.

(3) Prepare the surface (angular grit blast) and apply TSC according to contract specifications. Prepare at the same time the JRS is being prepared. Use the same personnel, equipment, materials, and procedures to be used during the production work.

(4) Remove C 633 specimens and measure according to ASTM C 633 method. Designate the average value as C_c .

(5) Use ASTM D 4541 portable tensile-testing instrument and measure the tensile bond on the three locations on the steel plate. Designate the average value as D_c .

(6) The calibration ratio (p) of the portable tensile-instrument measurement to the laboratory tensile measurement is C_c/D_c .

(7) The portable ASTM C 633 equivalent tensile measurement, P_{C633} , is estimated by Equation (C1):

$$P_{C633} = pD_{4541\text{ avg}} \quad (C1)$$

Where

P_{C633} is the D 4541 tensile bond equivalent to the C 633 tensile bond

p is the calibration ratio of the portable-tensile measurement instrument to the laboratory C 633 measurement

$D_{4541\text{ avg}}$ is the average of a set of measurements on a specimen using the ASTM D 4541 tensile testing instrument.

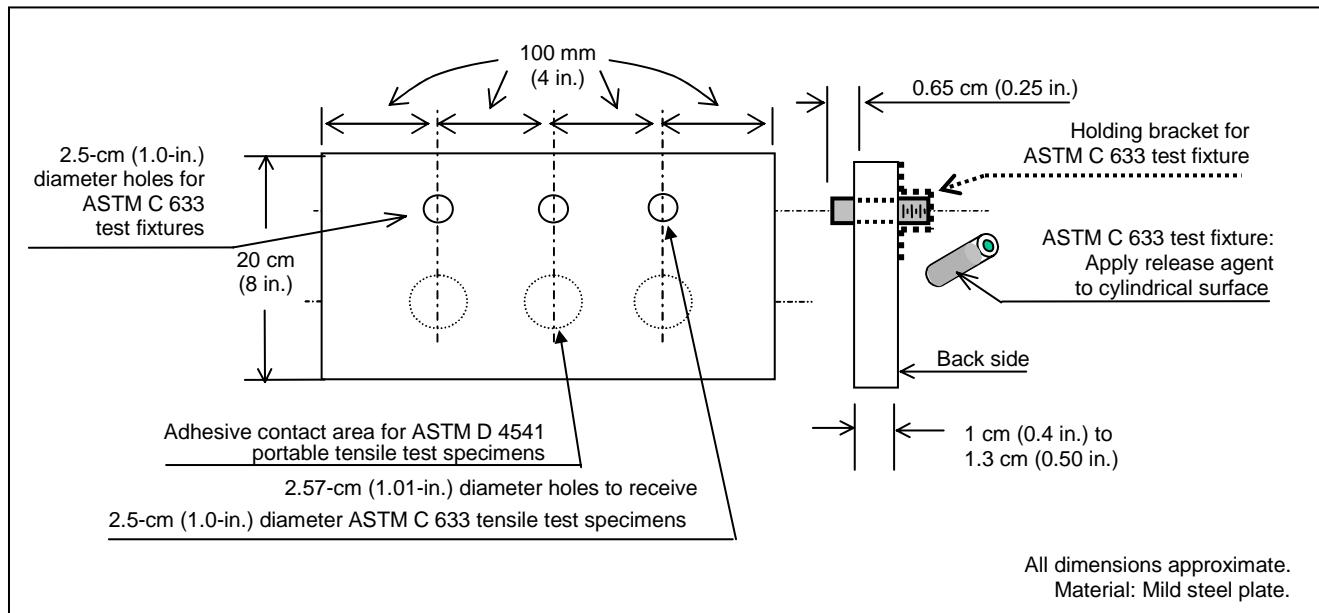


Figure C1: Calibration Fixture

Appendix D: Application Process Method

This Appendix is a part of NACE No. 12/AWS C2.23M/SSPC-CS 23.00, and includes mandatory requirements for use with this standard.

The major production and QC activities are shown in Figure D1. The applicable Section and Quality Control Checkpoint (QCCP) numbers are noted in the lower right-hand corner of each process action.

Section D1: Surface Preparation

Proper surface preparation is a critical and necessary step for successful thermal spray applications.

D1.1 Criteria

The steel substrate shall be prepared to at least a near-white metal finish according to NACE No. 2/SSPC-SP 10. Marine service requires white metal finish according to NACE No. 1/SSPC-SP 5.

Abrasive or centrifugal blast with a sharp angular abrasive to a $\geq 65\text{-}\mu\text{m}$ (2.5-mil) angular profile so as to mechanically anchor the TSC.

D1.2 Procedure

Surface preparation should be accomplished in one abrasive blast cleaning operation whenever possible. Steel substrates require approximately 0.6 to 0.7 MPa (87 to 100 psi) air-blasting pressure at the nozzle. Air pressures and media size should be reduced and adjusted to preclude

damage/distortion to thin-gauge materials. The blasting time on the workpiece should be adjusted to only clean the surface and cut the required anchor-tooth with minimum loss of metal. Blast angle should be as close to perpendicular as possible but in no case greater than $\pm 30^\circ$ from the perpendicular to the work surface. Do not overblast; this forces the peaks back into the valleys. Only angular and clean blasting media of suitable mesh size should be used to cut the $\geq 65\text{-}\mu\text{m}$ (2.5-mil) anchor-tooth profile. The blasting media must be free of debris, excessive fines, hazardous materials, and contamination such as sodium chloride and sulfur salts.

Section D2: New Steel Substrate

D2.1 Degreasing

The substrate shall be degreased according to SSPC-SP 1. Use QCCP #1 to validate absence of oil and grease contamination.

D2.2 Masking

The following shall be masked for protection:

- (a) All fit-and-function surfaces.
- (b) Overspray-control areas.
- (c) Areas not to be thermal sprayed.

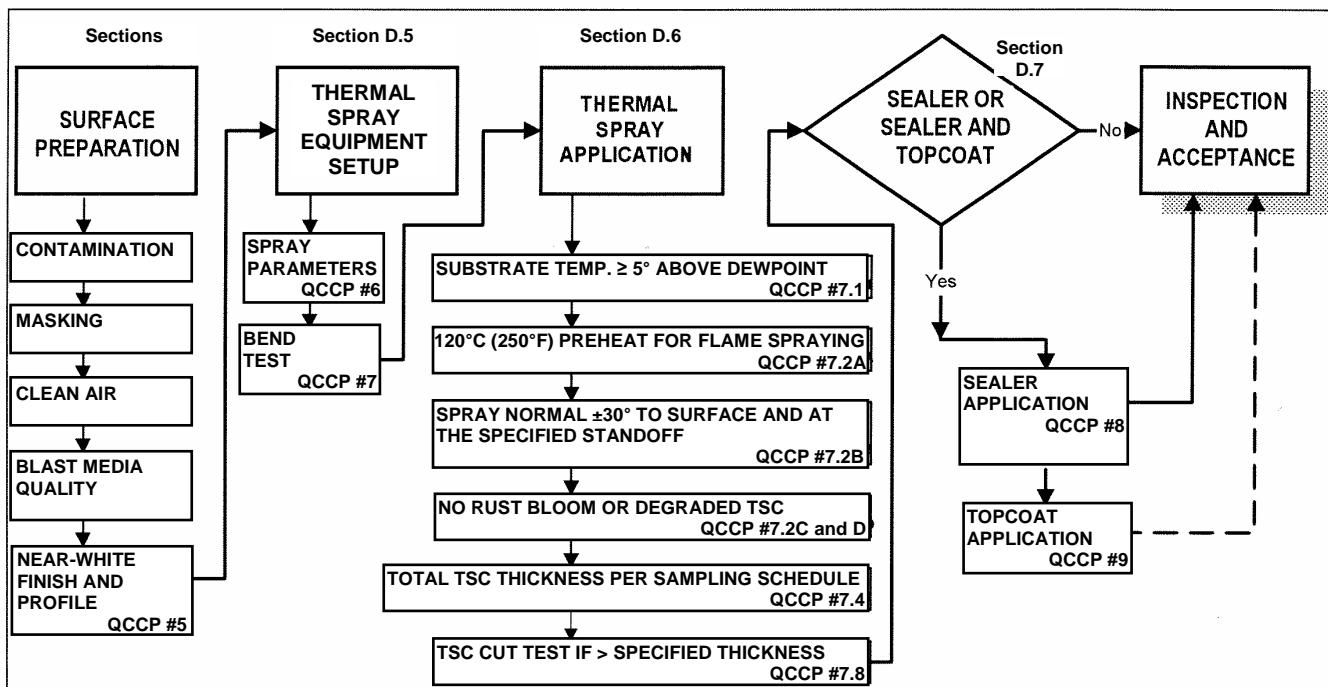


Figure D1: Key Production and Quality Control Checkpoints (QCCPs) for Applying Thermal Spray Coatings

QCCP #1: Oil and Grease	
Inspect for the absence of oil and grease contamination by the following:	
1.1	Visual inspection during removal of oil/grease contamination. Continue degreasing until all visible signs of contamination are removed.
1.2	Conduct the UV-light test, the qualitative-solvent evaporation test, or the heat test. <ul style="list-style-type: none"> (a) Use a UV lamp to confirm the absence of oil or grease contamination. (b) Conduct a solvent evaporation test by applying several drops or a small splash of a residue-free solvent such as trichloromethane on the areas suspected of oil and grease retention (e.g., pitting and crevice-corrosion areas, depressed areas, especially those collecting contamination, etc.). An evaporation ring forms if oil or grease contamination is present. (c) Conduct a heat test by using a torch to heat the degreased metal to about 110°C (225°F). Residual oil/grease contamination is drawn to the metal surface and is visually apparent.
1.3	Continue inspection and degreasing until the test is passed.

The fit-and-function areas must be protected from the blast cleaning, thermal spraying, and sealing or sealing and top-coating operations.

Overspray-control areas have complex geometry where overspray cannot be eliminated. Use QCCP #2 to validate masking suitability.

QCCP #2: Masking	
2.1	All fit-and-function surfaces and those other surfaces and areas specified by the purchaser not to be abrasive blasted or to be thermal sprayed shall be visually inspected.
2.2	Covers and masking shall be inspected to ensure they are attached securely to survive the blasting and thermal spraying operations.
2.3	Complex geometries (e.g., pipe flanges, intersections of structural beams, and valve manifolds) shall be masked to eliminate or minimize overspray. <i>Overspray is that TSC applied outside the authorized parameters, primarily the gun-to-substrate standoff distance and spray angle (perpendicular ±30°).</i>
2.4	Potential overspray surfaces should be protected with clean, metal masks or clean, removable masking materials to prevent overspray from depositing on surfaces not already sprayed to the specified parameters.

D2.3 Blast Equipment

The TSC applicator shall use mechanical (centrifugal wheel) and/or pressure-pot blast-cleaning equipment and procedures. Suction-blasting equipment shall not be used. QCCP #3 shall be used to validate clean and dry air.

QCCP #3: Clean and Dry Air

When pressure-pot blast cleaning is used, the air used for final anchor-tooth blasting and brush blasting or blow-down prior to thermal spraying shall be clean and dry and without moisture and oil. The compressed air shall be checked for oil and water contamination per ASTM D 4285:

3.1 Slightly open a valve downstream from the filter or dryer. Allow the air to vent with a slightly audible flow into an open, dry container for one minute. Any wetting or staining indicates contamination.

3.2 If moisture or contamination is detected, correct any deficiency before going further.

3.3 Repeat step 3.1 above, but place a clean, white cloth over the valve outlet. Any wetting or staining indicates contamination.

D2.4 Surface Finish and Profile

The surface shall be blast cleaned to NACE No. 1/SSPC-SP 5 for marine and immersion service or to at least NACE No. 2/SSPC-SP 10 for other service both with a $\geq 65\text{-}\mu\text{m}$ (2.5-mil) sharp angular profile. The substrate should be thick enough to preclude damage to the workpiece or deformation from the abrasive blasting. QCCP #4 shall be used to validate clean-blasting media. QCCP #5 shall be used to validate metal finish and profile depth.

Section D3: Contaminated Steel Substrate

Steel contaminated with deicing salts, oil, grease, bird droppings, etc., and corroded and pitted steel requires more intensive surface preparation than new steel. To produce the minimum required near-white metal finish with a $\geq 65\text{-}\mu\text{m}$ (2.5-mil) profile, the surface preparation schedule should be tailored for the specific steel surfaces to be cleaned. High-pressure water cleaning, heat cleaning, chemical washing (followed by water flushing), steam cleaning, and abrasive-blast cleaning, singly and in combination, may be required to clean contaminated steel.

D3.1 Degreasing

The surface shall be degreased as required according to contract specifications (e.g., hydroblast, steam clean, solvent wash, or detergent wash).

QCCP #4: Clean Blasting Media

Prior to the use of the abrasive-blasting media for final anchor-tooth blasting or brush blasting:

4.1 The blasting media shall be visually inspected for the absence of contamination and debris using 10x magnification.

4.2 Inspection for the absence of oil contamination shall be conducted using the test for oil in the appropriate abrasive specification (no oil film or slick) and/or the following procedure:

(1) Fill a small, clean 100- to 200-mL (4- to 6-oz) bottle half-full of abrasive particles.

(2) Fill the remainder of the bottle with potable water.

(3) Cap and shake the bottle.

(4) Inspect water for oil film/slick. If any oil film/slick is observed, do not use the blasting media.

(5) Clean blasting equipment, especially the pot and hoses, then replace blasting media and retest.

QCCP #5: Near-White Finish and Anchor-Tooth Profile

5.1 Using SSPC-VIS 1, the surface shall be visually inspected for conformance with NACE No. 2/SSPC-SP 10 or NACE No. 1/SSPC-SP 5 if specified in the contract. The clear-cellophane-tape test shall be used to confirm absence of dust as required. The frequency of use of the cellophane tape test shall be determined by the specifier.

5.2 The anchor-tooth profile shall be measured with profile tape (NACE Standard RP0287) or a depth-gauge micrometer. At least one measurement shall be taken every 10 to 20 m^2 (100 to 200 ft^2) or as otherwise specified by the purchaser.

5.3 If the profile is $< 65\text{ }\mu\text{m}$ (2.5 mils) blasting shall continue until a $\geq 65\text{-}\mu\text{m}$ (2.5-mil) profile is obtained.

5.4 Information shall be recorded on sketches or drawings or as required by the purchasing contract.

D3.2 Thermal Cleaning

SAFETY AND PROCEDURE PRECAUTION: This procedure shall be used only if there is no danger of an explosion or fire and no degradation of the metal temper. Temperatures shall not exceed 300°C (570°F) on steel alloys.

(1) The contamination shall be baked out or burned off (the dark brown or black surface areas) in an oven or with a rosebud torch. The substrate temperature shall be kept between 250 and 300°C (480 and 570°F) for the time necessary to bake out or burn off the oil and grease contamination.

(2) The substrate area to be thermal sprayed within the next six hours or longer according to Paragraph D4.2 shall be blasted to a minimum near-white metal finish with $>65 \mu\text{m}$ (2.5 mils) anchor-tooth.

(3) Repeat steps (1) and (2) above as required until the thermal spray job is completed.

D3.3 Removal of Soluble Salts:

If required by owner specifications, the surface should be tested for the presence of soluble salts. Methods for testing are described in SSPC-TU 4. The acceptable levels and methods of removal of soluble salts shall be determined by the specifier.

D3.4 Rust Bloom

The thermal spray coating shall be applied within six hours after blast cleaning. If rust bloom (i.e., the visual appearance of rust on the blast-cleaned surface) appears on the blasted surface before thermal spraying, the rust bloom shall be removed and the TSC applicator shall wait 24 hours to observe for any recurrence before spraying. Under very dry conditions, a longer waiting period may be necessary.

D3.4.1 Light Rust Bloom

If there is light rust bloom (light in color and greater than 10% of the surface area), the substrate area that will be thermal sprayed within the next six hours shall be reblasted to achieve the specified level of cleanliness.

D3.4.2 Heavy Rust Bloom

If there is heavy rust bloom (dark brown or black color), other cleaning methods shall be continued (e.g., wet-abrasive, high- and ultra high-pressure water, or thermal cleaning singly or in combination) to remove the contamination.

Section D4: Post-Blasting Substrate Condition and Thermal Spraying Period

D4.1 Steel Surface Temperature and Cleanliness

The steel surface temperature shall be at least 3°C (5°F) above the dewpoint. The surface shall be cleaned to NACE No. 2/SSPC-SP 10 finish as a minimum.

D4.2 Holding Period

(1) The TSC shall always be applied to white metal NACE No. 1/SSPC-SP 5 or near-white metal finish (NACE No. 2/SSPC-SP 10), free of visible and invisible contaminants. It is common practice in field work to apply the TSC during the same work shift as the final blast cleaning is performed. The logical end point of the holding period is when the sur-

face cleanliness degrades or a change in performance (bend or tensile test) occurs.

(2) As a general guide, however, the time between the completion of the final anchor-tooth blasting (or final brush blasting) and the completion of the thermal spraying shall be no greater than about six hours for steel substrates. In high-humidity and damp environments, shorter holding periods shall be used. If rust bloom or a degraded coating appears at any time while spraying, Paragraph D4.2 (6), shall be strictly observed.

(3) In low-humidity environments or in controlled environments with enclosed structures using industrial dehumidification equipment, it may be possible to retard the oxidation of the steel and hold the near-white metal finish for more than six hours. The TSC applicator, with the concurrence of the purchaser, can validate a holding period greater than six hours by determining the acceptable temperature-humidity envelope for the work enclosure by spraying and analyzing bend coupons, tensile-bond coupons, or both.

(4) If specified by the purchasing contract, a flash coat of TSC equal to or greater than $25 \mu\text{m}$ (1.0 mil) may be applied within six hours of completing the surface preparation to extend the holding period for up to four hours beyond the complete application of the flash coat. The final TSC thickness, however, shall be applied within four hours of the completion of the application of the flash coat. This procedure shall be validated with a tensile-bond measurement, bend test, or both, by spraying a flash coat and waiting the delay period before applying the final coating thickness.

(5) For small and movable parts, if more than 15 minutes is expected to elapse between the surface preparation and the start of thermal spraying, or if the part is moved to another location, the prepared surface should be protected from moisture, contamination, and finger/hand marks. Wrapping with clean print-free paper is normally adequate.

(6) If rust bloom, blistering, or degraded coating appears at any time during the application of the TSC, the following procedure applies:

- (a) Stop spraying.
- (b) Mark off the satisfactorily sprayed area.
- (c) Repair the unsatisfactory TSC (i.e., remove degraded TSC and re-establish the minimum near-white metal finish and anchor-tooth profile depth).
- (d) Record the actions taken to resume the job in the JCR.
- (e) Call the TSC inspector to observe and report the remedial action to the purchaser.

Section D5: Thermal Equipment Set-Up and Spraying Sequence

D5.1 Thermal Spray Equipment Set-Up

(1) Thermal spray equipment shall be set up, calibrated, and operated according to the manufacturer's instructions

and technical manuals, or the TSC applicator's refinement thereto, and as validated by the JRS.

(2) Spray parameters shall be set for spraying the specified thermal spray material and, at a minimum, be validated with the bend test of QCCP #6.

(3) A copy of the spray parameters shall be attached to the JCR.

QCCP #6: Macro-System Bend Test (Required at beginning of each work shift or crew change)	
6.1	The equipment parameter settings shall be in accordance with those used for the validated JRS.
6.2	The successful surface preparation shall be observed, spraying the specified TSC thickness in crossing passes, and performing a bend test of at least one bend coupon at the beginning of each work shift. This is a macro- or overall-systems check.
6.3	If the bend test fails, problems shall be identified and fixed before continuing.
6.4	Results shall be recorded, identification noted, and the bend-test coupons retained in the JCR.

D5.2 Plan the Thermal Spraying Sequence

Thermal spraying should be started as soon as possible after the final anchor-tooth or brush blasting and completed within six hours for steel substrates subject to the temperature to dewpoint and holding-period variations in Section D4.

(1) The surface geometry of the item or area to be sprayed should be inspected. The spraying pass or sequence should be planned according to the following:

(a) Maintain the gun as close to perpendicular as possible and within $\pm 30^\circ$ from the perpendicular to the substrate.

(b) Use the manufacturer's recommended standoff distance for the air cap installed or the TSC applicator's refinement thereto. See Table D1 for nominal standoff and spray-pass width values.

(2) For complex geometries where overspray cannot be eliminated, an overspray-control area should be established. Clean, metal masks or clean, removable masking materials should be used to prevent overspray from depositing on surfaces not already sprayed to the specified thickness.

Table D1: Flame- and Arc-Spray Standoff Distances and Spray Widths, Nominal

Thermal Spray Method	Perpendicular Standoff, mm (in.)	Spray-Pass Width, mm (in.)	
		Regular	Fan
Flame wire	130 to 180 (5 to 7)	20 (0.75)	Not Available
Flame powder	200 to 250 (8 to 10)	50 (2)	75 to 100 (3 to 4)
Arc wire	150 to 200 (6 to 8)	40 (1.5)	75 to 150 (3 to 6)

Section D6: TSC Application

D6.1 Preheating

Preheating the starting area has been common practice in the past and should be continued until proven inconsequential. Preheating the initial 0.1- to 0.2-m² (1- to 2-ft²) starting-spray area prevents water in the flame from condensing on the substrate.

(1) For flame spraying, the initial starting area shall be pre-heated to approximately 120°C (250°F).

(2) Preheating requirements shall be validated with the JRS and the bend test, tensile test, or both.

D6.2 Startup and Adjustment

Start-up and adjustment of the spray gun shall be made from the workpiece (or surface to be thermal sprayed). In

an enclosed space, the spray shall be applied to a scrap-metal sheet. Spray coating shall not be sprayed until it is validated.

D6.3 Specification Thickness

The specified coating thickness shall be applied in several perpendicular overlapping passes. The coating tensile-bond strength is greater when the spray passes are kept thin. Laying down an excessively thick spray pass increases the internal stresses in the TSC and decreases the ultimate tensile-bond strength of the TSC.

(1) For manual spraying, crossing passes shall be used to minimize thin spots in the coating.

(2) For mechanized spraying, overlapping and crossing passes shall be programmed to eliminate thin spots and stay within the coating thickness specification. The auto-

mated spraying parameters and spraying program shall be validated with tensile-bond, metallographic analysis, or both.

(3) Use spray-gun extensions to reach into recessed spaces and areas.

D6.4 Rust Bloom

If rust bloom, blistering, or a degraded coating appears at any time during the application of the TSC, the following procedure applies:

(1) Stop spraying.

(2) Mark off the satisfactorily sprayed area.

(3) Repair the unsatisfactory TSC (i.e., remove degraded TSC and reestablish the minimum near-white metal finish and anchor-tooth profile depth).

(4) In the JCR, record the actions taken to resume the job.

(5) Call the TSC inspector to observe and report the remedial action to the purchaser.

D6.5 TSC Requirement

The TSC shall meet the system requirements and acceptance tests cited in Section 6, main body of this standard.

The QCCP #7 shall be used to validate proper TSC application process.

Section D7: Low-Temperature Spraying

Thermal spraying in low-temperature environments, less than 5°C (40°F) must:

(1) Meet the substrate surface temperature and holding period of Section D 4.1 and D 4.2. Moisture condensation on the surface is not permissible during thermal spraying.

(2) Be qualified with a bend test, portable tensile-bond test, or both.

TSCs are mechanically bonded to the substrate. Substrate preheating may be required to improve the TSC tensile bond to the substrate and reduce internal stresses. The preheating requirement, or non-requirement, shall be validated during the preparation of the JCR (see Paragraph D6.1).

Section D8: Sealer or Sealer and Topcoat

D8.1 General

The sealer or sealer and topcoat shall meet the requirements of this standard. Sealers or sealers and topcoats for TSCs shall be applied in accordance with SSPC-PA 1, the paint manufacturer's instructions for sealing or sealing and

topcoating the contract-specified TSC, and/or the purchasing contract.

If moisture is present or suspected in the TSC pores, the steel may be heated to 50°C (120°F) to remove the moisture prior to the seal coat application. If possible, the steel from the reverse side of the TSC shall be heated to minimize oxidation and contamination of the TSC prior to sealing.

D8.2 Sealer Application

If applied, the seal coat shall be thin enough to penetrate into the body of the TSC and seal the porosity. Typically, the seal coat is applied at a spreading rate resulting in a theoretical 38-µm (1.5-mil) dry-film thickness.

For shop and field work, sealers should be applied as soon as possible after thermal spraying and preferably within eight hours.

If sealer cannot be applied within eight hours, it shall be verified that the TSC (a) has not been contaminated, using visual inspection and (b) is dust-free using the clear cellophane tape test (ISO 8502-3), before applying the sealer.

QCCP # 8 shall be used to validate proper application.

QCCP #7: TSC Application	
7.1	Substrate surface temperature shall be measured/confirmed with a contact pyrometer to be $\geq 3^{\circ}\text{C}$ (5°F) above the dewpoint:
(a)	Air temperature $\text{_____}^{\circ}\text{C}$ ($\text{_____}^{\circ}\text{F}$).
(b)	Relative Humidity (RH) $\text{_____}\%$.
(c)	Dewpoint $\text{_____}^{\circ}\text{C}$ ($\text{_____}^{\circ}\text{F}$).
(d)	Substrate surface temperature $\text{_____}^{\circ}\text{C}$ ($\text{_____}^{\circ}\text{F}$).
(e)	Surface temperature (d) $\geq 3^{\circ}\text{C}$ (5°F) above the dewpoint (c): (Yes/No) _____
(f)	If Yes \rightarrow Continue.
(g)	If No \rightarrow STOP. Wait for proper conditions and/or adjust the work-area space temperature and humidity conditions so that the steel temperature is $\geq 3^{\circ}\text{C}$ (5°F) above the dewpoint.
7.2	The spraying process shall be observed as specified in Section D6:
(a)	Preheat to 120°C (250°F) when flame spraying.
(b)	Proper spray-gun adjustment and spraying process ($\pm 30^{\circ}$ from the perpendicular, thickness/pass, and crossing passes). (See Figure D2.)
(c)	No rust bloom on prepared steel during spraying.
(d)	No degraded TSC.
7.3	Specified TSC thickness. Proper coating thickness in the contour-transition areas (see Step 7.5) shall be ensured.
7.4	The total TSC thickness shall be measured according to Figure D3 using a SSPC-PA Type 2 gauge:

QCCP #7: TSC Application

- (a) One measurement line or spot every 10 to 20 m^2 (100 to 200 ft^2) of applied TSC.
- (b) Take the average value of five readings for each measurement line or spot.
- (c) Use a measurement line for flat surfaces. Take the average value of five readings taken in line at 2.5-cm (1.0-in.) intervals. The line measurement will measure the peaks and valleys of the TSC.
- (d) Use a measurement spot for complex geometries and geometry transitions. The measurement spot should be approximately 10 cm^2 (1.6 in. 2). The spot measurement does not measure the peaks and valleys of the TSC.

7.5 The TSC thickness in surface plane changes and attachments (brackets, angles, plates, studs, etc.) welded or permanently attached to the substrate shall be measured.

7.6 If the TSC is too thin, spraying shall continue until the specified thickness range is achieved.

7.7 If the TSC is within the contract specified thickness range, the applicator shall proceed to Step 7.9.

7.8 If the TSC is too thick:

- (a) Record the areas that are over 150% of the maximum contract-specified thickness in the JCR.
- (b) Notify the purchaser. If these areas are damaged during shipping, loading/unloading, or erection, they should be repaired in accordance with maintenance repair procedures as outlined in ANSI/AWS C2.18.

7.9 The locations and values of the TSC-thickness measurements shall be recorded in the JCR.

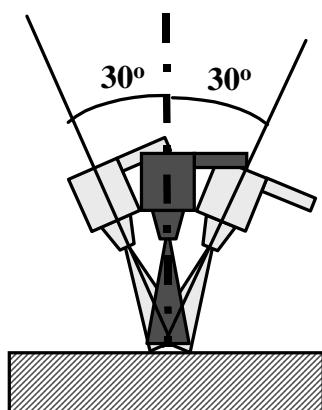


Figure D2: Proper Spray Gun Adjustment

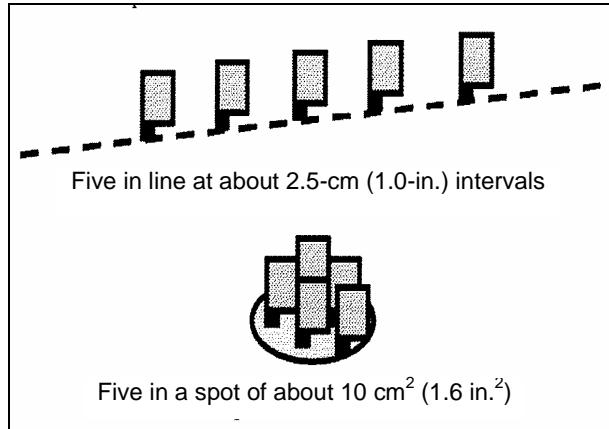


Figure D3: Line and Spot Measurements

QCCP #8: Sealer Application

- 8.1 During application of the seal coat, complete coverage shall be visually validated. If applied, the seal coat shall be thin enough to penetrate into the body of the TSC and seal the porosity.

D8.3 Topcoat Application

Topcoats shall be applied according to manufacturer's instructions or as specified in the purchasing contract. A paint coating shall not be applied over an unsealed TSC.

Use QCCP #9 to validate proper application.

QCCP #9: Topcoat Application and Thickness

- 9.1 During application of the topcoat, complete coverage shall be visually validated.
- 9.2 If required by the contract, the thickness of the topcoat shall be measured according to SSPC-PA 2 using a Type 2 fixed-probe gauge. The measurement may be made on (a) the companion coupon or (b) the sealed TSC if the TSC thickness has been previously measured.



Level 2

Chapter 30

Self-Study Questions

Chapter 24—Pipeline Coatings

1. A _____ coating is defined as the total coating on the body of the pipe, less any _____ coating.
2. Fiberglass reinforced pipe is usually joined together with _____ using special resins or by bolted flanges.
3. Ductile iron pipe is joined together by flanges or by _____ couplings.
4. Ductile iron is often encased in _____ sleeves in corrosive soils.
5. The top interior (vapor space) of large-diameter concrete pipe in sewer service is often coated with _____.
6. Polyethylene pipe used for natural gas service is often joined together by _____.
7. The criteria for the protection of pipelines is as follows: “Pipeline protection shall consist of:
 - a. Adequate _____ and
 - b. Supplementary _____ protection”.
8. Coatings may be used on the interior of pipelines to improve the _____ and for corrosion control.
9. Most cathodic disbondment tests (in the USA) are performed in accordance with ASTM Standards _____ or _____.
10. Extruded polyethylene is applied only in a _____.
11. _____ can be plant or field applied.
12. _____ is often reinforced with a glass wrap.
13. If coal tar enamel is overheated, it becomes _____, brittle, and unsuitable for use as a protective coating.
14. The _____ process may be used to apply polyethylene to valves, bends, couplings, etc.
15. Frequently, pipelines laid offshore are given a _____ to provide them with negative buoyancy.

16. Pipelines laid offshore are often fitted with bracelet anodes to provide _____ cathodic protection.

Chapter 25—Fusion-Bonded Epoxy Pipeline Coatings

1. When first preparing pipe for FBE application, the inspector may be required to:
 - a. Check quality and _____ of the water _____
 - b. Monitor force _____ operations
 - c. Monitor open _____ cleaning
 - d. Look for defects such as _____, _____
2. At the pre-blast station, the inspector may be required to _____ and mark defects exposed by blasting.
3. Before blast cleaning, pipe is hooked together with _____ couplings.
4. Many specifications call for NACE No. 1/SSPC-SP 5 with a surface profile of _____ to _____ mils.
5. The pipe is heated to about _____ to _____ F for powder application.
6. If the pipe temperature rises above 290°C, _____ may occur.
8. In some FBE powder systems, there may be a post-heating stage called _____ heating.
9. FBE powder applied to pipe passes through four distinct stages:
 - a. _____
 - b. _____
 - c. _____
 - d. _____
10. Holidays may be repaired using a hot _____ or a two-pack _____.

11. In the field, the inspector may:
- Look for _____ damage to the coating
 - Observe application of _____ coatings
 - Monitor holiday _____
 - Observe pipe _____.

Chapter 26—Inspection and Reporting Procedures

- Almost every user of _____ coating inspection has his own concept of what the _____ of the inspector should be.
- Some clients regard the inspector as a _____.
- Some clients may instruct the inspector to avoid any _____ with the contractor and workers.
- For the purpose of CIP, NACE has defined the inspector's role as that of a _____.
- An ideal _____ would contain a _____ for the inspector to follow in performing inspection duties.
- In regard to thinning of the materials the inspector should:
 - Observe the _____ and _____ of solvent, if any.
 - Record the _____ and _____ of _____ added.
 - Ensure that the quantity and type of solvent meets the _____ of the _____.
- In regards to dry-film thickness measurements, the inspector should ensure that his/her DFT gauge is _____.
- In regards to safety, the inspector has a _____ to himself, primarily, but to other _____ on the job site and to the _____, as well.

Chapter 28—Hot-Dip Galvanizing

1. Materials to be galvanized should be free from _____, mill scale, _____, varnishes, oil, and grease.
2. Plain _____, alloy steels, iron and _____ can be galvanized.
3. Hot-dipped zinc coatings are sometimes _____.
4. Post treatment to improve properties or appearance of zinc may be done by chromating, _____, light rolling, and roller leveling.
5. _____ surfaces should not be hot-dip galvanized.
6. Zinc deposited by galvanizing is usually measured in _____ per square _____ (grams/sq. meter).
7. Thickness of the zinc can be determined by the use of _____ or _____ gauges.
8. Dross protrusion results from agitation of the _____ layer at the bottom of the kettle or from _____ the workpiece through the dross layer.
9. Dross protrusion may be a cause for _____ if it is _____.
10. Blisters may be caused by _____ or _____ hydrogen.
11. Flux inclusions may be due to stale _____ burnt on during dipping.
12. Rust stains may be caused by: weeping of _____, etc. from seams or folds, or by material being stored under, on, or near rusting steel.
13. _____ stains (white rust) is a bulky deposit that forms on the surface of freshly galvanized articles that become damp when exposed to weather or condensation under _____ areas during storage or transit.
14. In the _____ process, fasteners such as bolts and nuts are rotated in a barrel containing zinc dust at _____.

Chapter 29—Spray Metallizing

1. Stainless steel, zinc, aluminum, tungsten carbide, and a variety of ceramic materials can be applied by spray technique, which may use a _____, _____, or _____ to apply materials in wire or powder form.
2. Spray metallizing equipment can be used to spray metals such as _____ or _____ in wire form.
3. _____ may be applied by spray metallizing to the interior of vessels used to contain certain strong chemicals.
4. TSA (thermal sprayed aluminum) is the coating of choice for corrosion protection in _____ service. TSZ (thermal sprayed _____) is the coating of choice for corrosion protection in _____ service.
5. A critical factor in the application process is the spray angle, which should be as near _____ to the surface as possible.
6. Preheating the surface can improve _____.
7. Thermal spray coatings can be _____ immediately after application.
8. _____ produces films with greater density than _____.
9. The specification can refer to an acceptable porosity of thermal sprayed coatings in _____.



Level 2

Chapter 31

Cathodic Protection

Coating Inspection and Cathodic Protection

Introduction

Cathodic protection is a very widely used form of corrosion control. NACE International offers three courses on the subject, which tells us there is a lot to be learned over and beyond what we will discuss today. We are going to present a very basic overview based on what a coating inspector may need to know in this area.

Recall from our earlier discussions about corrosion that four things must be present for corrosion to occur:

- Anode
- Cathode
- Metallic Pathway
- Electrolyte

Recall that electrons flow from the anode to the cathode via the metallic pathway, that ions flow from the anode to the cathode through the electrolyte, and that wastage of the metal, corrosion, occurs at the anode.

One amp for one year removes 10.6 kg (23.5 lbs) of iron.

Cathodic protection is used to protect structures which are buried, submerged in water, or used to contain liquids that are either primarily water-based (aqueous) or contain some water (like an oil storage tank that has some water at the bottom). We will call the environment from which the structure is being protected the electrolyte.

Cathodic protection makes use of a flow of electric current through whatever the structure is buried or submerged in or what the structure contains.

One reason for applying coatings to a structure, among the many other reasons we have discussed in this course, is to provide electrical insulation between the structure and the electrolyte.

The more effectively the coating insulates the structure, the less electric current is required to provide cathodic protection, thereby making the system more efficient, reducing both corrosion and the costs of installing and maintaining the system.

Since we have a very limited time to cover a very extensive field of corrosion-control work, we will cover the major points. If you wish to pursue additional study along these lines, you might consider attending the week-long courses NACE sponsors on this subject.

We will just explain briefly what cathodic protection is, how it works, and what it means to the coating inspector.

Cathodic Protection

Definition

Cathodic protection is the reduction or elimination of corrosion by making the structure to be protected a cathode by means of an impressed current or attachment to a galvanic anode (usually magnesium, aluminum, or zinc).

Recall that the cathode is the electrode where, for the purpose of our discussion, we will assume that no significant corrosion will occur. Prior to applying cathodic protection, corroding structures will have both cathodic areas and anodic areas (those areas where corrosion is occurring). It follows, then, that if all anodic areas can be converted to cathodic areas, the entire structure will become a cathode and corrosion of the structure will be satisfactorily controlled.

How Cathodic Protection Works

Application of direct current electricity to a corroding metal structure can cause the structure to become entirely cathodic.

Direct current electricity is associated with the corrosion process on a buried or submerged metallic structure. This is illustrated by Figure 31.1 which shows the flow of direct current between anodic and cathodic areas on a section of buried pipe.

As shown in this example of a buried structure, direct current is flowing from the anodic areas into the soil, through the soil and onto the cathodic areas, and back through the pipe itself to complete the circuit.

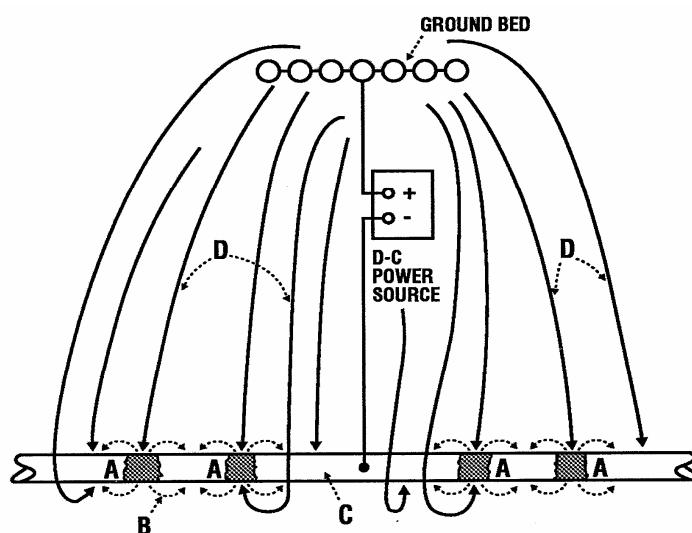


Figure 31.1: How Cathodic Protection Works

For a given driving voltage (the galvanic potential between anode and cathode), the amount of current is limited by such factors as the resistivity of the environment (expressed normally as ohm-centimeters) and the degree of polarization at anodic and cathodic areas.

Corrosion occurs where the current discharges from metal into the electrolyte (soil) at anodic areas. Where current flows from the environment onto the pipe (cathodic

areas), there is no corrosion. In applying cathodic protection to a structure, the objective is to force the entire surface exposed to the environment to be cathodic to the environment. When this condition has been attained, the structure's entire exposed surface becomes a cathode and corrosion of the structure is controlled.

The basic manner in which cathodic protection is accomplished is illustrated in this slide, which shows how the original corroding section of pipe illustrated in your notebook becomes a cathode with cancellation of current-discharging areas (anodes) on the pipe surface.

This slide shows that the cathodic protection current must flow into the environment from a special ground connection (usually called a *ground bed*) in buried-structure applications established for the purpose. By definition, the materials used in the ground beds are anodes, and material consumption (corrosion) must occur.

Original anodic areas discharging current and corroding

- Dotted lines represent lines of current flow which existed prior to applying protection
- Protected structure
- Current flowing from ground bed to surface of protected structure

Cathodic protection systems can be monitored by measuring the electrical potential (voltage) of the protected structure with a reference cell and a special voltmeter. Reference cells can be copper, copper sulfate, silver, silver chloride, mercury (calomel), or based upon a specially refined high-purity zinc.

Cathodic Protection Systems

We will discuss two types of cathodic protection systems:

- Galvanic
- Impressed current

Galvanic Systems

The term *galvanic* often refers to a dissimilar metal contact which results in electrolytic potential. An anode is the corroding member in a dissimilar metal combination. A galvanic (also called *sacrificial*) anode can be described as a metal that will have a voltage difference with respect to the corroding structure and will discharge current which will flow through the environment to the structure.

The galvanic anodes corrode preferentially to the protected structure, providing protection to the structure.

This slide diagrams the principle of galvanic cathodic protection systems.

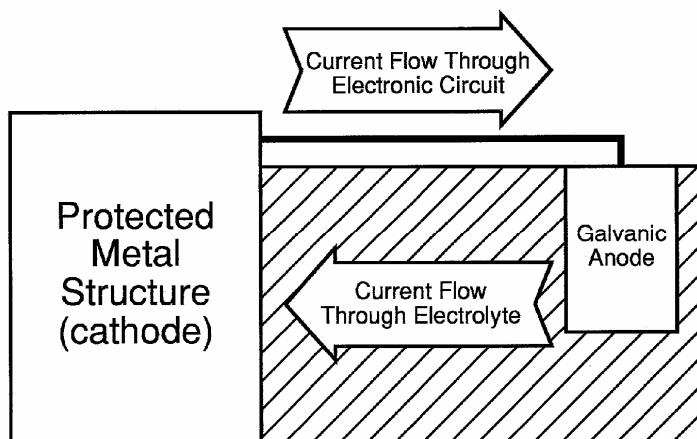


Figure 31.2: Galvanic Anode Cathodic Protection System

Materials suitable for use as galvanic anodes include aluminum, magnesium, and zinc.

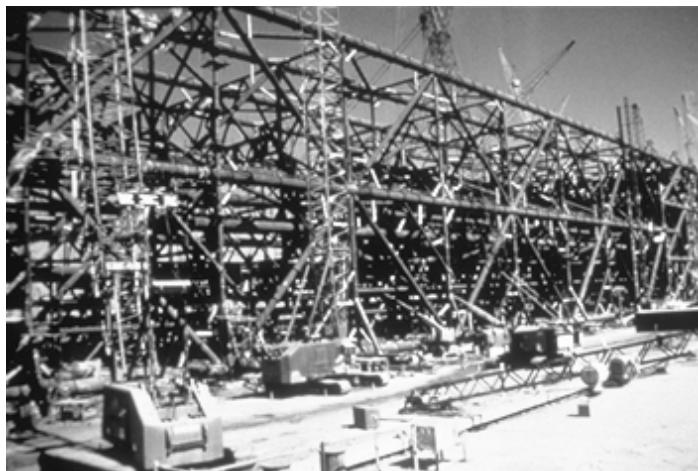


Figure 31.3: Aluminum Anodes

Anode materials are cast in numerous weights and shapes to meet cathodic protection design requirements. Data on available anodes can be obtained from suppliers of cathodic protection materials.

Impressed Current Systems

In an impressed current system, the ground bed anodes are not the source of electrical energy. Instead, an external source of direct current power is connected (or impressed) between the structure to be protected and the ground bed.

This slide is a diagram of the principle of impressed current cathodic protection systems.

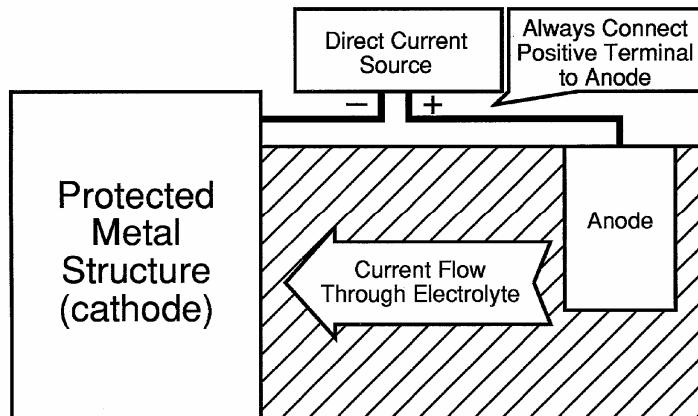


Figure 31.4: Impressed Current Cathodic Protection System

The positive terminal of the power source always must be connected to the ground bed, which is then forced to discharge as much cathodic protection current as is desirable. This is important. If a mistake is made and the positive terminal is connected to the structure to be protected, the structure will become an anode instead of a cathode and will corrode actively, which is the opposite of the desired results.

Impressed Current System Anodes

Ground bed anodes forced to discharge current will corrode. It is important to use anode materials that are consumed at relatively low rates and thus permit designing ground beds that discharge large amounts of current and still have long service lives.

Various materials are used for impressed current anodes:

- Scrap steel
- Graphite
- Iron oxide
- High-silicon chromium-bearing cast iron
- Platinized niobium and titanium

Impressed Current Power Sources

An impressed current system requires a current supply. Common current sources include:

- Rectified commercial power
- Solar cells
- Generators
- Fuel cells
- Wind-powered cells

- Thermoelectric cells

A rectifier is a device which uses power from electric utility lines to convert the alternating current to a lower voltage direct current by means of a step-down transformer.



Figure 31.5: Impressed Current Rectifier

Factors of Cathodic Protection Systems

Development of an effective cathodic protection system is a complex task requiring experience, knowledge, and judgment. In this course, we will only mention some of the factors that must be taken into consideration when designing a cathodic protection system:

- Regulatory requirements
- Economics
- Metal to be protected

- Service requirements
- Total current requirements
- Variation in environment
- Protective coatings
- Electrical shielding
- Maintenance
- Stray current effect
- Temperature
- Wire and cable
- Anode backfill

Problem areas are:

- Resistance/throw
- Cathodic disbondment
- Inspection criteria

Resistance and Throw

The potential of -0.85 V is a minimum requirement for protection. In order for the protected structure to be maintained at this potential (voltage), some areas of it will see an increased (more negative) potential. Due to the size, design, placement of the anodes, and the type and resistance of the electrolyte, this increased (more negative) potential can result in a phenomenon known as *cathodic disbondment*.

Cathodic Disbondment

Systems operating at a stable potential (voltage) of -0.85 V will usually have no detrimental effect upon the coating. However, as the potential is increased (made

more negative), reactions take place that can be detrimental to the coating. These reactions result in separation of the coating from the surface, that is, cathodic disbondment. As this potential is increased (made more negative) slightly, disbondment generally will occur through hydroxyl (OH^-) formation. As the potential is increased (made more negative), even more disbondment will occur through hydrogen formation.

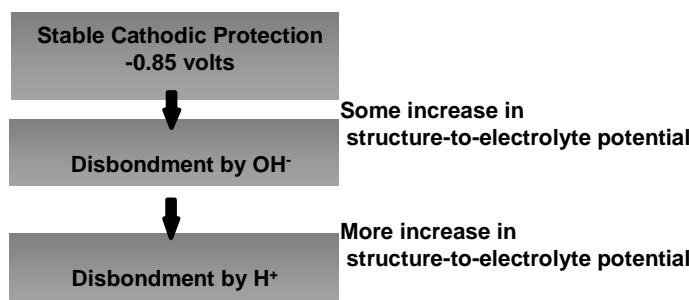


Figure 31.6: Cathodic Disbondment Sequence

Other Resources for Information

A copy of NACE Standard SP0169, *Control of External Corrosion on Underground or Submerged Metallic piping Systems*, is provided at the end of the chapter as supplemental information on cathodic protection.

For anyone further interested in cathodic protection training, NACE has a four-level cathodic protection training and certification program available.



**NACE SP0169-2007
(formerly RP0169-2002)
Item No. 21001**

Standard Practice

Control of External Corrosion on Underground or Submerged Metallic Piping Systems

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Foreword

This standard practice presents procedures and practices for achieving effective control of external corrosion on buried or submerged metallic piping systems. These recommendations are also applicable to many other buried or submerged metallic structures. It is intended for use by corrosion control personnel concerned with the corrosion of buried or submerged piping systems, including oil, gas, water, and similar structures. This standard describes the use of electrically insulating coatings, electrical isolation, and cathodic protection (CP) as external corrosion control methods. It contains specific provisions for the application of CP to existing bare, existing coated, and new piping systems. Also included are procedures for control of interference currents on pipelines.

This standard should be used in conjunction with the practices described in the following NACE standards and publications, when appropriate (use latest revisions):

SP0572¹ RP0177² RP0285³ SP0186⁴ SP0286⁵ SP0387⁶ SP0188⁷
TPC 11⁸ TM0497⁹

For accurate and correct application of this standard, the standard must be used in its entirety. Using or citing only specific paragraphs or sections can lead to misinterpretation and misapplication of the recommendations and practices contained in this standard.

This standard does not designate practices for every specific situation because of the complexity of conditions to which buried or submerged piping systems are exposed.

This standard was originally published in 1969, and was revised by NACE Task Group (TG) T-10-1 in 1972, 1976, 1983, and 1992. It was reaffirmed in 1996 by NACE Unit Committee T-10A on Cathodic Protection, and in 2002 and 2007 by Specific Technology Group (STG) 35 on Pipelines, Tanks, and Well Casings. This standard is issued by NACE International under the auspices of STG 35, which is composed of corrosion control personnel from oil and gas transmission companies, gas distribution companies, power companies, corrosion consultants, and others concerned with external corrosion control of buried or submerged metallic piping systems.

In NACE standards, the terms *shall*, *must*, *should*, and *may* are used in accordance with the definitions of these terms in the NACE Publications Style Manual, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. The term *should* is used to state something considered good and is recommended but is not mandatory. The term *may* is used to state something considered optional.

NACE International Standard Practice

Control of External Corrosion on Underground or Submerged Metallic Piping Systems

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Section 1: General

1.1 This standard presents acknowledged practices for the control of external corrosion on buried or submerged steel, cast iron, ductile iron, copper, and aluminum piping systems.

1.2 This standard is intended to serve as a guide for establishing minimum requirements for control of external corrosion on the following systems:

1.2.1 New piping systems: Corrosion control by a coating supplemented with CP, or by some other proven method, should be provided in the initial design and maintained during the service life of the piping system, unless investigations indicate that corrosion control is not required. Consideration should be given to the construction of pipelines in a manner that facilitates the use of in-line inspection tools.

1.2.2 Existing coated piping systems: CP should be provided and maintained, unless investigations indicate that CP is not required.

1.2.3 Existing bare piping systems: Studies should be made to determine the extent and rate of corrosion on existing bare piping systems. When these studies indicate that corrosion will affect the safe or economic operation of the system, adequate corrosion control measures shall be taken.

1.3 The provisions of this standard should be applied under the direction of competent persons who, by reason of knowledge of the physical sciences and the principles of engineering and mathematics, acquired by education and related practical experience, are qualified to engage in the practice of corrosion control on buried or submerged metallic piping systems. Such persons may be registered professional engineers or persons recognized as corrosion specialists or CP specialists by NACE if their professional activities include suitable experience in external corrosion control of buried or submerged metallic piping systems.

1.4 Special conditions in which CP is ineffective or only partially effective sometimes exist. Such conditions may include elevated temperatures, disbonded coatings, thermal insulating coatings, shielding, bacterial attack, and unusual contaminants in the electrolyte. Deviation from this standard may be warranted in specific situations provided that corrosion control personnel in responsible charge are able to demonstrate that the objectives expressed in this standard have been achieved.

1.5 This standard does not include corrosion control methods based on chemical control of the environment, on the use of electrically conductive coatings, or on control of internal corrosion.

Section 2: Definitions ⁽¹⁾

Amphoteric Metal: A metal that is susceptible to corrosion in both acid and alkaline environments.

Anode: The electrode of an electrochemical cell at which oxidation occurs. Electrons flow away from the anode in the external circuit. Corrosion usually occurs and metal ions enter solution at the anode.

Anodic Polarization: The change of the electrode potential in the noble (positive) direction caused by current across the electrode/electrolyte interface. (See *Polarization*.)

Backfill: Material placed in a hole to fill the space around the anodes, vent pipe, and buried components of a cathodic protection system.

Beta Curve: A plot of dynamic (fluctuating) interference current or related proportional voltage (ordinate) versus the corresponding structure-to-electrolyte potentials at a selected location on the affected structure (abscissa) (see Appendix A [nonmandatory]).

Cable: One conductor or multiple conductors insulated from one another.

Cathode: The electrode of an electrochemical cell at which reduction is the principal reaction. Electrons flow toward the cathode in the external circuit.

Cathodic Disbondment: The destruction of adhesion between a coating and the coated surface caused by products of a cathodic reaction.

⁽¹⁾ Definitions in this section reflect common usage among practicing corrosion control personnel and apply specifically to how the terms are used in this standard. In many cases, in the interests of brevity and practical usefulness, the scientific definitions are abbreviated or paraphrased.

Cathodic Polarization: The change of electrode potential in the active (negative) direction caused by current across the electrode/electrolyte interface. See *Polarization*.

Cathodic Protection: A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Coating: A liquid, liquefiable, or mastic composition that, after application to a surface, is converted into a solid protective, decorative, or functional adherent film.

Coating Disbondment: The loss of adhesion between a coating and the pipe surface.

Conductor: A material suitable for carrying an electric current. It may be bare or insulated.

Continuity Bond: A connection, usually metallic, that provides electrical continuity between structures that can conduct electricity.

Corrosion: The deterioration of a material, usually a metal, that results from a reaction with its environment.

Corrosion Potential (E_{corr}): The potential of a corroding surface in an electrolyte relative to a reference electrode under open-circuit conditions (also known as *rest potential*, *open-circuit potential*, or *freely corroding potential*).

Corrosion Rate: The rate at which corrosion proceeds.

Criterion: Standard for assessment of the effectiveness of a cathodic protection system.

Current Density: The current to or from a unit area of an electrode surface.

Diode: A bipolar semiconducting device having a low resistance in one direction and a high resistance in the other.

Distributed-Anode Impressed Current System: An impressed current anode configuration in which the anodes are "distributed" along the structure at relatively close intervals such that the structure is within each anode's voltage gradient. This anode configuration causes the electrolyte around the structure to become positive with respect to remote earth.

Electrical Isolation: The condition of being electrically separated from other metallic structures or the environment.

Electrical Survey: Any technique that involves coordinated electrical measurements taken to provide a basis for deduction concerning a particular electrochemical condition relating to corrosion or corrosion control.

Electrode: A conductor used to establish contact with an electrolyte and through which current is transferred to or from an electrolyte.

Electroosmotic Effect: Passage of a charged particle through a membrane under the influence of a voltage. Soil or coatings may act as the membrane.

Electrolyte: A chemical substance containing ions that migrate in an electric field. For the purpose of this standard, electrolyte refers to the soil or liquid adjacent to and in contact with a buried or submerged metallic piping system, including the moisture and other chemicals contained therein.

Foreign Structure: Any metallic structure that is not intended as a part of a system under cathodic protection.

Galvanic Anode: A metal that provides sacrificial protection to another metal that is more noble when electrically coupled in an electrolyte. This type of anode is the electron source in one type of cathodic protection.

Galvanic Series: A list of metals and alloys arranged according to their corrosion potentials in a given environment.

Groundbed: One or more anodes installed below the earth's surface for the purpose of supplying cathodic protection.

Holiday: A discontinuity in a protective coating that exposes unprotected surface to the environment.

Impressed Current: An electric current supplied by a device employing a power source that is external to the electrode system. (An example is direct current for cathodic protection.)

In-Line Inspection: The inspection of a steel pipeline using an electronic instrument or tool that travels along the interior of the pipeline.

Insulating Coating System: All components of the protective coating, the sum of which provides effective electrical isolation of the coated structure.

Interference: Any electrical disturbance on a metallic structure as a result of stray current.

Interference Bond: An intentional metallic connection, between metallic systems in contact with a common electrolyte, designed to control electrical current interchange between the systems.

IR Drop: The voltage across a resistance in accordance with Ohm's Law.

Isolation: See *Electrical Isolation*.

Line Current: The direct current flowing on a pipeline.

Long-Line Current: Current through the earth between an anodic and a cathodic area that returns along an underground metallic structure.

Mixed Potential: A potential resulting from two or more electrochemical reactions occurring simultaneously on one metal surface.

Pipe-to-Electrolyte Potential: See *Structure-to-Electrolyte Potential*.

Polarization: The change from the open-circuit potential as a result of current across the electrode/electrolyte interface.

Polarized Potential: The potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization.

Reference Electrode: An electrode whose open-circuit potential is constant under similar conditions of measurement, which is used for measuring the relative potentials of other electrodes.

Reverse-Current Switch: A device that prevents the reversal of direct current through a metallic conductor.

Shielding: (1) Protecting; protective cover against mechanical damage. (2) Preventing or diverting the cathodic protection current from its intended path.

Shorted Pipeline Casing: A casing that is in direct metallic contact with the carrier pipe.

Sound Engineering Practices: Reasoning exhibited or based on thorough knowledge and experience, logically valid and having technically correct premises that demonstrate good judgment or sense in the application of science.

Stray Current: Current through paths other than the intended circuit.

Stray-Current Corrosion: Corrosion resulting from current through paths other than the intended circuit, e.g., by any extraneous current in the earth.

Structure-to-Electrolyte Potential: The potential difference between the surface of a buried or submerged metallic structure and electrolyte that is measured with reference to an electrode in contact with the electrolyte.

Telluric Current: Current in the earth as a result of geomagnetic fluctuations.

Voltage: An electromotive force or a difference in electrode potentials expressed in volts.

Wire: A slender rod or filament of drawn metal. In practice, the term is also used for smaller-gauge conductors (6 mm² [No. 10 AWG⁽²⁾] or smaller).

Section 3: Determination of Need for External Corrosion Control

3.1 Introduction

3.1.1 This section recommends practices for determining when an underground or submerged metallic piping system requires external corrosion control.

3.1.2 Metallic structures, buried or submerged, are subject to corrosion. Adequate corrosion control procedures should be adopted to ensure metal integrity for safe and economical operation.

3.2 The need for external corrosion control should be based on data obtained from one or more of the following: corrosion surveys, operating records, visual observations, test results from similar systems in similar environments, in-line inspections, engineering and design specifications, and

operating, safety, and economic requirements. The absence of leaks alone is insufficient evidence that corrosion control is not required.

3.2.1 Environmental and physical factors include the following:

3.2.1.1 Corrosion rate of the particular metallic piping system in a specific environment (see Appendix B [nonmandatory]);

3.2.1.2 Nature of the product being transported, the working temperature, temperature differentials within the pipeline causing thermal expansion and contraction, tendency of backfill to produce soil stress, and working pressure of the piping system as related to design specification;

⁽²⁾ American Wire Gauge.

- 3.2.1.3 Location of the piping system as related to population density and frequency of visits by personnel;
- 3.2.1.4 Location of the piping system as related to other facilities; and
- 3.2.1.5 Stray current sources foreign to the system.

- 3.2.2 Economic factors include the following:

- 3.2.2.1 Costs of maintaining the piping system in service for its expected life (see Appendix B [nonmandatory]);
- 3.2.2.2 Contingent costs of corrosion (see Appendix C [nonmandatory]); and
- 3.2.2.3 Costs of corrosion control (see Appendix D [nonmandatory]).

Section 4: Piping System Design

4.1 Introduction

4.1.1 This section provides accepted corrosion control practices in the design of an underground or submerged piping system. A person qualified to engage in the practice of corrosion control should be consulted during all phases of pipeline design and construction (see Paragraph 1.3). These recommendations should not be construed as taking precedence over recognized electrical safety practices.

4.2 External Corrosion Control

4.2.1 External corrosion control must be a primary consideration during the design of a piping system. Materials selection and coatings are the first line of defense against external corrosion. Because perfect coatings are not feasible, CP must be used in conjunction with coatings. For additional information, see Sections 5 and 6.

4.2.2 New piping systems should be externally coated unless thorough investigation indicates that coatings are not required (see Section 5).

4.2.3 Materials and construction practices that create electrical shielding should not be used on the pipeline. Pipelines should be installed at locations where proximity to other structures and subsurface formations do not cause shielding.

4.3 Electrical Isolation

4.3.1 Isolation devices such as flange assemblies, prefabricated joint unions, or couplings should be installed within piping systems in which electrical isolation of portions of the system is required to facilitate the application of external corrosion control. These devices should be properly selected for temperature, pressure, chemical resistance, dielectric resistance, and mechanical strength. Installation of isolation devices should be avoided or safeguarded in areas in which combustible atmospheres are likely to be present. Locations at which electrical isolating devices should be considered include, but are not limited to, the following:

4.3.1.1 Points at which facilities change ownership, such as meter stations and well heads;

4.3.1.2 Connections to mainline piping systems, such as gathering or distribution system laterals;

4.3.1.3 Inlet and outlet piping of in-line measuring and pressure regulating stations;

4.3.1.4 Compressor or pumping stations, either in the suction and discharge piping or in the main line immediately upstream and downstream from the station;

4.3.1.5 Stray current areas;

4.3.1.6 The junction of dissimilar metals;

4.3.1.7 The termination of service line connections and entrance piping;

4.3.1.8 The junction of a coated pipe and a bare pipe; and

4.3.1.9 Locations at which electrical grounding is used, such as motorized valves and instrumentation.

4.3.2 The need for lightning and fault current protection at isolating devices should be considered. Cable connections from isolating devices to arresters should be short, direct, and of a size suitable for short-term high-current loading.

4.3.3 When metallic casings are required as part of the underground piping system, the pipeline should be electrically isolated from such casings. Casing insulators must be properly sized and spaced and be tightened securely on the pipeline to withstand insertion stresses without sliding on the pipe. Inspection should be made to verify that the leading insulator has remained in position. Concrete coatings on the carrier pipe could preclude the use of casing insulators. Consideration should be given to the use of support under the pipeline at each end of the casing to minimize settlement. The type of support selected

should not cause damage to the pipe coating or act as a shield to CP current.

4.3.4 Casing seals should be installed to resist the entry of foreign matter into the casing.

4.3.5 When electrical contact would adversely affect CP, piping systems should be electrically isolated from supporting pipe stanchions, bridge structures, tunnel enclosures, pilings, offshore structures, or reinforcing steel in concrete. However, piping can be attached directly to a bridge without isolation if isolating devices are installed in the pipe system on each side of the bridge to isolate the bridge piping electrically from adjacent underground piping.

4.3.6 When an isolating joint is required, a device manufactured to perform this function should be used, or, if permissible, a section of nonconductive pipe, such as plastic pipe, may be installed. In either case, these should be properly rated and installed in accordance with the manufacturer's instructions.

4.3.7 River weights, pipeline anchors, and metallic reinforcement in weight coatings should be electrically isolated from the carrier pipe and designed and installed so that coating damage does not occur and the carrier pipe is not electrically shielded.

4.3.8 Metallic curb boxes and valve enclosures should be designed, fabricated, and installed in such a manner that electrical isolation from the piping system is maintained.

4.3.9 Insulating spacing materials should be used when it is intended to maintain electrical isolation between a metallic wall sleeve and the pipe.

4.3.10 Underground piping systems should be installed so that they are physically separated from all foreign underground metallic structures at crossings and parallel installations and in such a way that electrical isolation could be maintained if desired.

4.3.11 Based on voltage rating of alternating current (AC) transmission lines, adequate separation should be maintained between pipelines and electric transmission tower footings, ground cables, and counterpoise. Regardless of separation, consideration should always be given to lightning and fault current protection of pipeline(s) and personnel safety (see NACE Standard RP0177²).

4.4 Electrical Continuity

4.4.1 Nonwelded pipe joints may not be electrically continuous. Electrical continuity can be ensured by the use of fittings manufactured for this purpose or by bonding across and to the mechanical joints in an effective manner.

4.5 Corrosion Control Test Stations

4.5.1 Test stations for potential, current, or resistance measurements should be provided at sufficient locations to facilitate CP testing. Such locations may include, but are not limited to, the following:

- 4.5.1.1 Pipe casing installations,
- 4.5.1.2 Metallic structure crossings,
- 4.5.1.3 Isolating joints,
- 4.5.1.4 Waterway crossings,
- 4.5.1.5 Bridge crossings,
- 4.5.1.6 Valve stations,
- 4.5.1.7 Galvanic anode installations,
- 4.5.1.8 Road crossings,
- 4.5.1.9 Stray-current areas, and
- 4.5.1.10 Rectifier installations.

4.5.2 The span of pipe used for line current test stations should exclude:

- 4.5.2.1 Foreign metallic structure crossings;
- 4.5.2.2 Lateral connections;
- 4.5.2.3 Mechanical couplings or connections such as screwed joints, transition pieces, valves, flanges, anode or rectifier attachments, or metallic bonds; and
- 4.5.2.4 Changes in pipe wall thickness and diameter.

4.5.3 Attachment of Copper Test Lead Wires to Steel and Other Ferrous Pipes

4.5.3.1 Test lead wires may be used both for periodic testing and for current-carrying purposes. As such, the wire/pipe attachment should be mechanically strong and electrically conductive.

4.5.3.2 Methods of attaching wires to the pipe include (a) thermit welding process, (b) soldering, and (c) mechanical means.

4.5.3.3 Particular attention must be given to the attachment method to avoid (a) damaging or penetrating the pipe, (b) sensitizing or altering of pipe properties, (c) weakening the test lead wire, (d) damaging internal or external pipe coatings, and (e) creating hazardous conditions in explosive environments.

4.5.3.4 Attachment by mechanical means is the least desirable method. Such a connection may

loosen, become highly resistant, or lose electrical continuity.

4.5.3.5 The connection should be tested for mechanical strength and electrical continuity. All exposed portions of the connection should be thoroughly cleaned of all welding slag, dirt, oils, etc.; primed, if needed; and coated with materials compatible with the cable insulation, pipe coating, and environment.

4.5.4 Attachment of Aluminum Test Lead Wire to Aluminum Pipes

4.5.4.1 Aluminum test lead wire, or aluminum tabs attached to aluminum wire, may be welded to aluminum pipe using the tungsten inert-gas shielded arc (TIG) or metal inert-gas shielded arc (MIG) process. Welded attachments should be made to flanges or at butt weld joints. Attachment at other sites may adversely affect the mechanical properties of the pipe because of the heat of welding.

4.5.4.2 Test lead wire may be attached to aluminum pipe by soldering. If low-melting-point soft solders are used, a flux is required. Flux residues may cause corrosion unless removed.

NOTE: The use of copper test lead wire may cause preferential galvanic attack on the aluminum pipe. When copper wire or flux is used, care must be taken to seal the attachment areas against moisture. In the presence of moisture, the connection may disbond and be damaged by corrosion.

4.5.4.3 Aluminum tabs to which test lead wires have been TIG welded can be attached by an

explosive bonding technique called high-energy joining.

4.5.4.4 Mechanical connections that remain secure and electrically conductive may be used.

4.5.5 Attachment of Copper Test Lead Wire to Copper Pipe

4.5.5.1 Copper test lead wire, or copper tabs attached to copper wire, may be attached to copper pipe by one of the following methods. The relative thickness of the wire and the pipe wall dictates, in part, which of the methods can be used.

4.5.5.1.1 Arc welding (TIG, MIG, or shielded metal);

4.5.5.1.2 Electrical resistance (spot) welding;

4.5.5.1.3 Brazing;

4.5.5.1.4 Soldering; or

4.5.5.1.5 Mechanical connection.

4.5.5.2 Attention should be given to proper joining procedures to avoid possible embrittlement or loss of mechanical properties of the metals from the heat of welding or brazing.

4.5.5.3 A flux may be required, or self-produced, when brazing with some filler metals or soldering with some low-melting-point soft solders. Because flux residues may cause corrosion, they should be removed.

Section 5: External Coatings

5.1 Introduction

5.1.1 This section recommends practices for selecting, testing and evaluating, handling, storing, inspecting, and installing external coating systems for external corrosion control on piping systems.

The function of external coatings is to control corrosion by isolating the external surface of the underground or submerged piping from the environment, to reduce CP current requirements, and to improve current distribution.

5.1.2 External coatings must be properly selected and applied and the coated piping carefully handled and installed to fulfill these functions. Various types of external coatings can accomplish the desired functions.

5.1.2.1 Desirable characteristics of external coatings include the following:

5.1.2.1.1 Effective electrical insulator;

5.1.2.1.2 Effective moisture barrier;

5.1.2.1.3 Application to pipe by a method that does not adversely affect the properties of the pipe;

5.1.2.1.4 Application to pipe with a minimum of defects;

5.1.2.1.5 Good adhesion to pipe surface;

- 5.1.2.1.6 Ability to resist development of holidays with time;
 - 5.1.2.1.7 Ability to resist damage during handling, storage, and installation;
 - 5.1.2.1.8 Ability to maintain substantially constant electrical resistivity with time;
 - 5.1.2.1.9 Resistance to disbonding;
 - 5.1.2.1.10 Resistance to chemical degradation;
 - 5.1.2.1.11 Ease of repair;
 - 5.1.2.1.12 Retention of physical characteristics;
 - 5.1.2.1.13 Nontoxic to the environment; and
 - 5.1.2.1.14 Resistance to changes and deterioration during aboveground storage and long-distance transportation.
- 5.1.2.2 Typical factors to consider when selecting an external pipe coating include:
- 5.1.2.2.1 Type of environment;
 - 5.1.2.2.2 Accessibility of piping system;
 - 5.1.2.2.3 Operating temperature of piping system;
 - 5.1.2.2.4 Ambient temperatures during application, shipping, storage, construction, installation, and pressure testing;
 - 5.1.2.2.5 Geographical and physical location;
 - 5.1.2.2.6 Type of external coating on existing pipe in the system;
 - 5.1.2.2.7 Handling and storage;
 - 5.1.2.2.8 Pipeline installation methods;
 - 5.1.2.2.9 Costs; and

5.1.2.2.10 Pipe surface preparation requirements.

5.1.2.3 Pipeline external coating systems shall be properly selected and applied to ensure that adequate bonding is obtained. Unbonded coatings can create electrical shielding of the pipeline that could jeopardize the effectiveness of the CP system.

5.1.3 Information in this section is primarily by reference to other documents. It is important that the latest revision of the pertinent reference be used.

5.1.3.1 Table 1 is a listing of types of external coating systems, showing the appropriate references for material specifications and recommended practices for application.

5.1.3.2 Table 2 is a grouping of references for general use during installation and inspection, regardless of coating type.

5.1.3.3 Table 3 is a list of external coating system characteristics related to environmental conditions containing suggested laboratory test references for various properties.

5.1.3.4 Table 4 is a list of external coating system characteristics related to design and construction, with recommended laboratory tests for evaluating these properties.

5.1.3.5 Table 5 lists the references that are useful in field evaluation of external coating systems after the pipeline has been installed.

5.2 Storage, Handling, Inspection, and Installation

5.2.1 Storage and Handling

5.2.1.1 Coated pipe to be stored should be protected internally and externally from atmospheric corrosion and coating deterioration.

5.2.1.2 Damage to coating can be minimized by careful handling and by using proper pads and slings.

TABLE 1
Generic External Coating Systems with Material Requirements
and Recommended Practices for Application^(A)

Generic External Coating System	Reference
Coal Tar	ANSI ^(B) /AWWA ^(C) C 203 ¹⁰
Wax	NACE Standard RP0375 ¹¹
Prefabricated Films	ANSI/AWWA C 214 ¹² ANSI/AWWA C 209 ¹³
Fusion-Bonded Epoxy Coatings	<i>Peabody's Control of Pipeline Corrosion</i> ¹⁴ ANSI/AWWA C 213 ¹⁵ API ^(D) RP 5L7 ¹⁶ CSA ^(E) Z245.20M ¹⁷ NACE Standard RP0394 ¹⁸
Polyolefin Coatings	NACE Standard RP0185 ¹⁹ DIN ^(F) 30 670 ²⁰ ANSI/AWWA C 215 ²¹

^(A) NOTE: Many other references are available, and this table is not comprehensive. Listing does not constitute endorsement of any external coating system in preference to another. Omission of a system may be due to unavailability of reference standards or lack of data.

^(B) American National Standards Institute (ANSI), 1819 L St. NW, Washington, DC 20036.

^(C) American Water Works Association (AWWA), 6666 West Quincy Ave., Denver, CO 80235.

^(D) American Petroleum Institute (API), 1220 L St. NW, Washington, DC 20005-4070.

^(E) CSA International, 178 Rexdale Blvd., Toronto, Ontario, Canada M9W 1R3.

^(F) Deutsches Institut fur Normung (DIN), Burggrafenstrasse 6, D-10787 Berlin, Germany.

TABLE 2
References for General Use in the Installation and Inspection of External Coating Systems
for Underground Piping

Subject	Reference
Application of Organic Pipeline Coatings	ANSI/AWWA C 203 ¹⁰ NACE Standard RP0375 ¹¹ <i>Peabody's Control of Pipeline Corrosion</i> ¹⁴ ANSI/AWWA C 213 ¹⁵ API RP 5L7 ¹⁶ CSA Z245.20M ¹⁷
Film Thickness of Pipeline Coatings	ASTM ^(A) G 128 ²²
Inspection of Pipeline Coatings	NACE Standard RP0274 ²³

^(A) ASTM, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

TABLE 3
External Coating System Characteristics Relative to Environmental Conditions^(A)

Environmental Factor	Recommended Test Methods^(B)
General underground exposure with or without CP	<i>Peabody's Control of Pipeline Corrosion</i> ¹⁴ ANSI/AWWA C 213 ¹⁵ API RP 5L7 ¹⁶ CSA Z245.20M ¹⁷ ASTM G 8 ²⁴ ASTM G 19 ²⁵ ASTM G 42 ²⁶ ASTM G 95 ²⁷
Resistance to water penetration and its effect on choice of coating thickness	ASTM G 9 ²⁸
Resistance to penetration by stones in backfill	ASTM G 17 ²⁹ ASTM D 2240 ³⁰ ASTM G 13 ³¹ ASTM G 14 ³²
Soil stress	<i>Underground Corrosion</i> ³³ ASTM D 427 ³⁴
Resistance to specific liquid not normally encountered in virgin soil	ASTM D 543 ³⁵ Federal Test Standard ^(C) No. 406A, Method 7011 ³⁶ ASTM G 20 ³⁷
Resistance to thermal effects	ASTM D 2304 ³⁸ ASTM D 2454 ³⁹ ASTM D 2485 ⁴⁰
Suitability of supplementary materials for joint coating and field repairs	ASTM G 8 ²⁴ ASTM G 19 ²⁵ ASTM G 42 ²⁶ ASTM G 95 ²⁷ ASTM G 9 ²⁸ ASTM G 18 ⁴¹ ASTM G 55 ⁴²
Resistance to microorganisms	ASTM G 21 ⁴³ Federal Test Standard No. 406A, Method 6091 ⁴⁴

^(A) NOTE: Apply only those factors pertinent to the installation.

^(B) No specific criteria are available. Comparative tests are recommended for use and evaluation as supplementary information only.

^(C) Available from General Services Administration, Business Service Center, Washington, DC 20025.

TABLE 4
External Coating System Characteristics Related to Design and Construction

Design and Construction Factor	Recommended Test Methods^(A)
Yard Storage, Weathering	ASTM G 11 ⁴⁵
Yard Storage, Penetration Under Load	ASTM G 17 ²⁹ ASTM D 2240 ³⁰
Handling Resistance, Abrasion	ASTM G 6 ⁴⁶
Handling Resistance, Impact	ASTM G 13 ³¹ ASTM G 14 ³²
Field Bending Ability	ASTM G 10 ⁴⁷
Driving Ability (Resistance to Sliding Abrasion)	ASTM G 6 ⁴⁶ ASTM D 2197 ⁴⁸
Special Requirements for Mill-Applied Coating	ANSI/AWWA C 203 ¹⁰ NACE Standard RP0375 ¹¹ ANSI/AWWA C 214 ¹² ANSI/AWWA C 209 ¹³ <i>Peabody's Control of Pipeline Corrosion</i> ¹⁴ ANSI/AWWA C 213 ¹⁵ API RP 5L7 ¹⁶ CSA Z245.20M ¹⁷ NACE Standard RP0185 ¹⁹ DIN 30 670 ²⁰ ANSI/AWWA C 215 ²¹
Special Requirements for Application of Coating Over the Ditch	ANSI/AWWA C 203 ¹⁰ NACE Standard RP0375 ¹¹ ANSI/AWWA C 214 ¹² ANSI/AWWA C 209 ¹³ <i>Peabody's Control of Pipeline Corrosion</i> ¹⁴ ANSI/AWWA C 213 ¹⁵ API RP 5L7 ¹⁶ CSA Z245.20M ¹⁷
Backfill Resistance	ASTM G 13 ³¹ ASTM G 14 ³²
Resistance to Thermal Effects	ASTM G 8 ²⁴ ASTM G 19 ²⁵ ASTM G 42 ²⁶ ASTM G 95 ²⁷ ASTM D 2304 ³⁸ ASTM D 2454 ³⁹ ASTM D 2485 ⁴⁰
Suitability of Joint Coatings and Field Repairs	<i>Peabody's Control of Pipeline Corrosion</i> ¹⁴ ANSI/AWWA C 213 ¹⁵ API RP 5L7 ¹⁶ CSA Z245.20M ¹⁷ ASTM G 8 ²⁴ ASTM G 19 ²⁵ ASTM G 42 ²⁶ ASTM G 95 ²⁷ ASTM G 9 ²⁸ ASTM G 18 ⁴¹ ASTM G 55 ⁴²

^(A) No specific criteria are available. Comparative tests are recommended for use and evaluation as supplementary information only.

TABLE 5
Methods for Evaluating In-Service Field Performance of External Coatings

Title or Subject of Method	Reference	Basis for Rating
(1) Rate of Change in Current Required for CP	<i>Underground Corrosion</i> ³³	Comparison of initial current requirement with subsequent periodic determination of current requirement
(2) Inspection of Pipeline Coating	NACE Standard RP0274 ²³	(a) With CP: no active corrosion found (b) Without CP: no new holidays showing active corrosion
(3) Cathodic Disbondment	ASTM G 8 ²⁴ ASTM G 19 ²⁵ ASTM G 42 ²⁶ ASTM G 95 ²⁷	Purpose is to obtain data relative to specific conditions for comparison with laboratory data

5.2.2 Inspection

5.2.2.1 Qualified personnel should keep every phase of the coating operation and piping installation under surveillance.

5.2.2.2 Surface preparation, primer application, coating thickness, temperature, bonding, and other specific requirements should be checked periodically, using suitable test procedures, for conformance to specifications.

5.2.2.3 The use of holiday detectors is recommended to detect coating flaws that would not be observed visually. The holiday detector should be operated in accordance with the manufacturer's instructions and at a voltage level appropriate to the electrical characteristics of the coating system.

5.2.3 Installation

5.2.3.1 Joints, fittings, and tie-ins must be coated with a material compatible with the existing coating.

5.2.3.2 Coating defects should be repaired.

5.2.3.3 Materials used to repair coatings must be compatible with the existing pipe coating.

5.2.3.4 The ditch bottom should be graded and free of rock or other foreign matter that could damage the external coating or cause electrical shielding. Under difficult conditions, consideration should be given to padding the pipe or the ditch bottom.

5.2.3.5 Pipe should be lowered carefully into the ditch to avoid external coating damage.

5.2.3.6 Care should be taken during backfilling so that rocks and debris do not strike and damage the pipe coating.

5.2.3.7 Care shall be exercised when using materials such as loose wrappers, nonconducting urethane foam, and rock shield around pipelines as protection against physical damage or for other purposes, because these materials may create an electrical shielding effect that would be detrimental to the effectiveness of CP.

5.2.3.8 When a pipeline comes above ground, it must be cleaned and externally coated, or jacketed with a suitable material, for the prevention of atmospheric corrosion.

5.3 Methods for Evaluating External Coating Systems

5.3.1 Established Systems Proven by Successful Use

5.3.1.1 Visual and electrical inspection of in-service pipeline coatings should be used to evaluate the performance of an external coating system. These inspections can be conducted wherever the pipeline is excavated or at bell holes made for inspection purposes.

5.3.2 Established or Modified Systems for New Environments

5.3.2.1 This method is intended for use when external coating systems will continue to be used and are qualified under Paragraph 5.3.1, but when application will be extended to new environments or when it is desired to revise a system to make use of new developments, one of the following should be used:

5.3.2.1.1 The use of applicable material requirements, material specifications, standards, and recommended practices for application, as given in Table 1, is recommended.

5.3.2.1.2 The use of applicable references in Table 2 is recommended unless previously covered in applicable references in Table 1.

5.3.3 New External Coating System Qualification

5.3.3.1 The purpose of this method is to qualify a new external coating material by subjecting it to laboratory tests appropriate for the intended service. After laboratory tests have been conducted and indicate that the external coating system appears to be suitable, application and installation are conducted in accordance with recommended practices. In-service field performance tests are made to confirm the success of the previous steps. The steps of the method are (1) laboratory tests, (2) application under recommended practices, (3) installation under recommended practices, and (4) in-service field performance tests. If good results are obtained after five years, only Steps 2 and 3 are required thereafter.

5.3.3.1.1 Applicable sections of Tables 3 and 4 are recommended for the initial laboratory test methods.

5.3.3.1.2 Applicable sections of Tables 1 and 2 are recommended for conditional use during Steps 2 and 3.

5.3.3.1.3 During a period of five years or more, the use of the evaluation methods given in Table 5, Item 1 or 2 are recommended. The test method in Item 3 may be used as a supplementary means for obtaining data for correlation with laboratory tests.

5.3.4 Method for Evaluating an External Coating System by In-Service Field Performance Only

5.3.4.1 The purpose of this method is to qualify an external coating system when none of the first three methods given in Paragraph 5.3 has been or will be used. It is intended that this method should be limited to minor pilot installations.

5.3.4.1.1 The use of at least one of the first two methods given in Table 5 is recommended on the basis of at least one investigation per year for five consecutive years.

Section 6: Criteria and Other Considerations for CP

6.1 Introduction

6.1.1 This section lists criteria and other considerations for CP that indicate, when used either separately or in combination, whether adequate CP of a metallic piping system has been achieved (see also Section 1, Paragraphs 1.2 and 1.4).

6.1.2 The effectiveness of CP or other external corrosion control measures can be confirmed by visual observation, by measurements of pipe wall thickness, or by use of internal inspection devices. Because such methods sometimes are not practical, meeting any criterion or combination of criteria in this section is evidence that adequate CP has been achieved. When excavations are made for any purpose, the pipe should be inspected for evidence of corrosion and coating condition.

6.1.3 The criteria in this section have been developed through laboratory experiments or verified by evaluating data obtained from successfully operated CP systems. Situations in which a single criterion for evaluating the effectiveness of CP may not be satisfactory for all conditions may exist. Often a combination of criteria is needed for a single structure.

6.1.4 Sound engineering practices shall be used to determine the methods and frequency of testing required to satisfy these criteria.

6.1.5 Corrosion leak history is valuable in assessing the effectiveness of CP. Corrosion leak history by itself, however, shall not be used to determine whether adequate levels of CP have been achieved unless it is impractical to make electrical surveys.

6.2 Criteria

6.2.1 It is not intended that persons responsible for external corrosion control be limited to the criteria listed below. Criteria that have been successfully applied on existing piping systems can continue to be used on those piping systems. Any other criteria used must achieve corrosion control comparable to that attained with the criteria herein.

6.2.2 Steel and Cast Iron Piping

6.2.2.1 External corrosion control can be achieved at various levels of cathodic polarization depending on the environmental conditions. However, in the absence of specific data that demonstrate that adequate CP has been achieved, one or more of the following shall apply:

6.2.2.1.1 A negative (cathodic) potential of at least 850 mV with the CP applied. This potential is measured with respect to a saturated copper/copper sulfate reference electrode contacting the electrolyte. Voltage

drops other than those across the structure-to-electrolyte boundary must be considered for valid interpretation of this voltage measurement.

NOTE: Consideration is understood to mean the application of sound engineering practice in determining the significance of voltage drops by methods such as:

- 6.2.2.1.1.1 Measuring or calculating the voltage drop(s);
- 6.2.2.1.1.2 Reviewing the historical performance of the CP system;
- 6.2.2.1.1.3 Evaluating the physical and electrical characteristics of the pipe and its environment; and
- 6.2.2.1.1.4 Determining whether or not there is physical evidence of corrosion.
- 6.2.2.1.2 A negative polarized potential (see definition in Section 2) of at least 850 mV relative to a saturated copper/copper sulfate reference electrode.
- 6.2.2.1.3 A minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of polarization can be measured to satisfy this criterion.

6.2.2.2 Special Conditions

6.2.2.2.1 On bare or ineffectively coated pipelines when long-line corrosion activity is of primary concern, the measurement of a net protective current at predetermined current discharge points from the electrolyte to the pipe surface, as measured by an earth current technique, may be sufficient.

6.2.2.2.2 In some situations, such as the presence of sulfides, bacteria, elevated temperatures, acid environments, and dissimilar metals, the criteria in Paragraph 6.2.2.1 may not be sufficient.

6.2.2.2.3 When a pipeline is encased in concrete or buried in dry or aerated high-resistivity soil, values less negative than the criteria listed in Paragraph 6.2.2.1 may be sufficient.

6.2.2.3 PRECAUTIONARY NOTES

6.2.2.3.1 The earth current technique is often meaningless in multiple pipe rights-of-way, in high-resistivity surface soil, for deeply buried

pipe, in stray-current areas, or where local corrosion cell action predominates.

6.2.2.3.2 Caution is advised against using polarized potentials less negative than -850 mV for CP of pipelines when operating pressures and conditions are conducive to stress corrosion cracking (see references on stress corrosion cracking at the end of this section).

6.2.2.3.3 The use of excessive polarized potentials on externally coated pipelines should be avoided to minimize cathodic disbondment of the coating.

6.2.2.3.4 Polarized potentials that result in excessive generation of hydrogen should be avoided on all metals, particularly higher-strength steel, certain grades of stainless steel, titanium, aluminum alloys, and prestressed concrete pipe.

6.2.3 Aluminum Piping

6.2.3.1 The following criterion shall apply: a minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of this polarization can be used in this criterion.

6.2.3.2 PRECAUTIONARY NOTES

6.2.3.2.1 Excessive Voltages: Notwithstanding the minimum criterion in Paragraph 6.2.3.1, if aluminum is cathodically protected at voltages more negative than -1,200 mV measured between the pipe surface and a saturated copper/copper sulfate reference electrode contacting the electrolyte and compensation is made for the voltage drops other than those across the pipe-electrolyte boundary, it may suffer corrosion as the result of the buildup of alkali on the metal surface. A polarized potential more negative than -1,200 mV should not be used unless previous test results indicate that no appreciable corrosion will occur in the particular environment.

6.2.3.2.2 Alkaline Conditions: Aluminum may suffer from corrosion under high-pH conditions, and application of CP tends to increase the pH at the metal surface. Therefore, careful investigation or testing should be done before applying CP to stop pitting attack on aluminum in environments with a natural pH in excess of 8.0.

6.2.4 Copper Piping

6.2.4.1 The following criterion shall apply: a minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of this polarization can be used in this criterion.

6.2.5 Dissimilar Metal Piping

6.2.5.1 A negative voltage between all pipe surfaces and a stable reference electrode contacting the electrolyte equal to that required for the protection of the most anodic metal should be maintained.

6.2.5.2 PRECAUTIONARY NOTE

6.2.5.2.1 Amphoteric materials that could be damaged by high alkalinity created by CP should be electrically isolated and separately protected.

6.3 Other Considerations

6.3.1 Methods for determining voltage drop(s) shall be selected and applied using sound engineering practices. Once determined, the voltage drop(s) may be used for correcting future measurements at the same location, provided conditions such as pipe and CP system operating conditions, soil characteristics, and external coating quality remain similar. (Note: Placing the reference electrode next to the pipe surface may not be at the pipe-electrolyte interface. A reference electrode placed at an externally coated pipe surface may not significantly reduce soil voltage drop in the measurement if the nearest coating holiday is remote from the reference electrode location.)

6.3.2 When it is impractical or considered unnecessary to disconnect all current sources to correct for voltage drop(s) in the structure-to-electrolyte potential measurements, sound engineering practices should be used to ensure that adequate CP has been achieved.

6.3.3 When feasible and practicable, in-line inspection of pipelines may be helpful in determining the presence or absence of pitting corrosion damage. Absence of external corrosion damage or the halting of its growth may indicate adequate external corrosion control. The in-line inspection technique, however, may not be capable of detecting all types of external corrosion damage, has limitations in its accuracy, and may report as anomalies items that are not external corrosion. For example, longitudinal seam corrosion and general corrosion may not be readily detected by in-line inspection. Also, possible thickness variations, dents, gouges, and external ferrous objects may be detected as corrosion. The appropriate use of in-line inspection must be carefully considered.

6.3.4 Situations involving stray currents and stray electrical gradients that require special analysis may exist. For additional information, see Section 9, "Control of Interference Currents."

6.4 Alternative Reference Electrodes

6.4.1 Other standard reference electrodes may be substituted for the saturated copper/copper sulfate reference electrode. Two commonly used reference electrodes are listed below along with their voltage equivalent (at 25°C [77°F]) to -850 mV referred to a saturated copper/copper sulfate reference electrode:

6.4.1.1 Saturated KCl calomel reference electrode: -780 mV; and

6.4.1.2 Saturated silver/silver chloride reference electrode used in 25 ohm-cm seawater: -800 mV.

6.4.2 In addition to these standard reference electrodes, an alternative metallic material or structure may be used in place of the saturated copper/copper sulfate reference electrode if the stability of its electrode potential is ensured and if its voltage equivalent referred to a saturated copper/copper sulfate reference electrode is established.

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Section 7: Design of Cathodic Protection Systems

7.1 Introduction

7.1.1 This section recommends procedures for designing CP systems that will provide effective external corrosion control by satisfying one or more of the criteria listed in Section 6 and exhibiting maximum reliability over the intended operating life of the systems.

7.1.2 In the design of a CP system, the following should be considered:

7.1.2.1 Recognition of hazardous conditions prevailing at the proposed installation site(s) and the selection and specification of materials and installation practices that ensure safe installation and operation.

7.1.2.2 Specification of materials and installation practices to conform to the latest editions of applicable codes, National Electrical Manufacturers Association (NEMA)⁽⁷⁾ standards, National Electrical Code (NEC),⁽⁸⁾ appropriate international standards, and NACE standards.

7.1.2.3 Selection and specification of materials and installation practices that ensure dependable and economical operation throughout the intended operating life.

7.1.2.4 Selection of locations for proposed installations to minimize currents or earth potential gradients, which can cause detrimental effects on foreign buried or submerged metallic structures.

7.1.2.5 Cooperative investigations to determine mutually satisfactory solution(s) of interference problems (see Section 9).

7.1.2.6 Special consideration should be given to the presence of sulfides, bacteria, disbonded coatings, thermal insulating coatings, elevated temperatures, shielding, acid environments, and dissimilar metals.

7.1.2.7 Excessive levels of CP that can cause external coating disbondment and possible damage to high-strength steels as a result of hydrogen evolution should be avoided.

7.1.2.8 When amphoteric metals are involved, care should be taken so that high-pH conditions that could cause cathodic corrosion of the metal are not established.

7.2 Major objectives of CP system design include the following:

7.2.1 To provide sufficient current to the structure to be protected and distribute this current so that the selected criteria for CP are effectively attained;

⁽⁷⁾ National Electrical Manufacturers Association (NEMA), 1300 North 17th St., Suite 1752, Rosslyn, Virginia 22209.

⁽⁸⁾ National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

7.2.2 To minimize the interference currents on neighboring underground structures (see Section 9);

7.2.3 To provide a design life of the anode system commensurate with the required life of the protected structure, or to provide for periodic rehabilitation of the anode system;

7.2.4 To provide adequate allowance for anticipated changes in current requirements with time;

7.2.5 To install anodes when the possibility of disturbance or damage is minimal; and

7.2.6 To provide adequate monitoring facilities to test and evaluate the system performance.

7.3 Information Useful for Design

7.3.1 Useful piping system specifications and information include the following:

7.3.1.1 Route maps and atlas sheets;

7.3.1.2 Construction dates;

7.3.1.3 Pipe, fittings, and other appurtenances;

7.3.1.4 External coatings;

7.3.1.5 Casings;

7.3.1.6 Corrosion control test stations;

7.3.1.7 Electrically isolating devices;

7.3.1.8 Electrical bonds; and

7.3.1.9 Aerial, bridge, and underwater crossings.

7.3.2 Useful information on piping system site conditions includes the following:

7.3.2.1 Existing and proposed CP systems;

7.3.2.2 Possible interference sources (see Section 9);

7.3.2.3 Special environmental conditions;

7.3.2.4 Neighboring buried metallic structures (including location, ownership, and corrosion control practices);

7.3.2.5 Structure accessibility;

7.3.2.6 Power availability; and

7.3.2.7 Feasibility of electrical isolation from foreign structures.

7.3.3 Useful information from field surveys, corrosion test data, and operating experience includes the following:

7.3.3.1 Protective current requirements to meet applicable criteria;

7.3.3.2 Electrical resistivity of the electrolyte;

7.3.3.3 Electrical continuity;

7.3.3.4 Electrical isolation;

7.3.3.5 External coating integrity;

7.3.3.6 Cumulative leak history;

7.3.3.7 Interference currents;

7.3.3.8 Deviation from construction specifications; and

7.3.3.9 Other maintenance and operating data.

7.3.4 Field survey work prior to actual application of CP is not always required if prior experience or test data are available to estimate current requirements, electrical resistivity of the electrolyte, and other design factors.

7.4 Types of CP Systems

7.4.1 Galvanic Anode Systems

7.4.1.1 Galvanic anodes can be made of materials such as alloys of magnesium, zinc, or aluminum. The anodes are connected to the pipe, either individually or in groups. Galvanic anodes are limited in current output by the anode-to-pipe driving voltage and the electrolyte resistivity.

7.4.2 Impressed Current Anode Systems

7.4.2.1 Impressed current anodes can be of materials such as graphite, high-silicon cast iron, lead-silver alloy, precious metals, or steel. They are connected with an insulated cable, either individually or in groups, to the positive terminal of a direct-current (DC) source, such as a rectifier or generator. The pipeline is connected to the negative terminal of the DC source.

7.5 Considerations influencing selection of the type of CP system include the following:

7.5.1 Magnitude of protective current required;

7.5.2 Stray currents causing significant potential fluctuations between the pipeline and earth that may preclude the use of galvanic anodes;

7.5.3 Effects of CP interference currents on adjacent structures that may limit the use of impressed current CP systems;

7.5.4 Availability of electrical power;

7.5.5 Physical space available, proximity of foreign structures, easement procurement, surface conditions, presence of streets and buildings, river crossings, and other construction and maintenance concerns.

7.5.6 Future development of the right-of-way area and future extensions to the pipeline system;

7.5.7 Costs of installation, operation, and maintenance; and

7.5.8 Electrical resistivity of the environment.

7.6 Factors Influencing Design of CP Systems

7.6.1 Various anode materials have different rates of deterioration when discharging a given current density from the anode surface in a specific environment. Therefore, for a given current output, the anode life depends on the environment and anode material, as well as the anode weight and the number of anodes in the CP system. Established anode performance data may be used to calculate the probable deterioration rate.

7.6.2 Data on the dimensions, depth, and configuration of the anodes and the electrolyte resistivity may be used to calculate the resultant resistance to electrolyte of the anode system. Formulas and graphs relating to these factors are available in the bibliography literature and from most anode manufacturers.

7.6.3 Design of galvanic anode systems should consider anode-to-pipe potential, electrolyte resistivity, current output, and in special cases, anode lead-wire resistance. A separate design for each anode or anode system may not be necessary.

7.6.4 Galvanic anode performance in most soils can be improved by using special backfill material. Mixtures of gypsum, bentonite, and anhydrous sodium sulfate are most commonly used.

7.6.5 The number of impressed current anodes required can be reduced and their useful life lengthened by the use of special backfill around the anodes. The most common materials are coal coke,

calcined petroleum coke, and natural or manufactured graphite.

7.6.6 In the design of an extensive distributed-anode impressed current system, the voltage and current attenuation along the anode-connecting (header) cable should be considered. In such cases, the design objective is to optimize anode system length, anode spacing and size, and cable size in order to achieve efficient external corrosion control at the extremities of the protected structure.

7.6.7 When it is anticipated that entrapment of gas generated by anodic reactions could impair the ability of the impressed current groundbed to deliver the required current, suitable provisions should be made for venting the anodes. For the same current output of the system, an increase in the surface area of the special backfill material or an increase in the number of anodes may reduce gas blockage.

7.6.8 When it is anticipated that electroosmotic effects could impair the ability of the impressed current groundbed to deliver the required current output, suitable provisions should be made to ensure adequate soil moisture around the anodes. Increasing the number of impressed current anodes or increasing the surface area of the special backfill materials may further reduce the electroosmotic effect.

7.7 Design Drawings and Specifications

7.7.1 Suitable drawings should be prepared to designate the overall layout of the piping to be protected and the location of significant items of structure hardware, corrosion control test stations, electrical bonds, electrical isolation devices, and neighboring buried or submerged metallic structures.

7.7.2 Layout drawings should be prepared for each impressed current CP installation, showing the details and location of the components of the CP system with respect to the protected structure(s) and to major physical landmarks. These drawings should include right-of-way information.

7.7.3 The locations of galvanic anode installations should be recorded on drawings or in tabular form, with appropriate notes on anode type, weight, spacing, depth, and backfill.

7.7.4 Specifications should be prepared for all materials and installation practices that are to be incorporated in construction of the CP system.

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Section 8: Installation of CP Systems

8.1 Introduction

8.1.1 This section recommends procedures that will result in the installation of CP systems that achieve protection of the structure. The design considerations recommended in Sections 4 and 7 should be followed.

8.2 Construction Specifications

8.2.1 All construction work on CP systems should be performed in accordance with construction drawings and specifications. The construction specifications should be in accordance with recommended practices in Sections 4 and 7.

8.3 Construction Supervision

8.3.1 All construction work on CP systems should be performed under the surveillance of trained and qualified personnel to verify that the installation is in strict accordance with the drawings and specifications. Exceptions may be made only with the approval of qualified personnel responsible for external corrosion control.

8.3.2 All deviations from construction specifications should be noted on as-built drawings.

8.4 Galvanic Anodes

8.4.1 Inspection, Handling, and Storage

8.4.1.1 Packaged anodes should be inspected and steps taken to ensure that backfill material completely surrounds the anode. The individual container for the backfill material and anode should be intact. If individually packaged anodes are supplied in waterproof containers, the containers must be removed before installation. Packaged anodes should be kept dry during storage.

8.4.1.2 Lead wire must be securely connected to the anode. Lead wire should be inspected for assurance that it is not damaged.

8.4.1.3 Other galvanic anodes, such as the unpackaged "bracelet" or ribbon type, should be inspected to ensure that dimensions conform to

design specifications and that any damage during handling does not affect application. If a coating is used on bands and the inner side of bracelet anode segments, it should be inspected and, if damaged, repaired before the anodes are installed.

8.4.2 Installing Anodes

8.4.2.1 Anodes should be installed according to construction specifications.

8.4.2.2 Packaged galvanic anodes should be backfilled with appropriately compacted material. When anodes and special chemical backfill are provided separately, anodes should be centered in special backfill, which should be compacted prior to backfilling. Care should be exercised during all operations so that lead wires and connections are not damaged. Sufficient slack should exist in lead wires to avoid strain.

8.4.2.3 When anodes in bracelet form are used, external pipe coating beneath the anode should be free of holidays. Care should be taken to prevent damage to the external coating when bracelet anodes are installed. After application of concrete (if used) to pipe, all coating and concrete should be removed from the anode surface. If reinforced concrete is used, there must be no metallic contact between the anode and the reinforcing mesh or between the reinforcing mesh and the pipe.

8.4.2.4 When a ribbon-type anode is used, it can be trenched or plowed in, with or without special chemical backfill as required, generally parallel to the section of pipeline to be protected.

8.5 Impressed Current Systems

8.5.1 Inspection and Handling

8.5.1.1 The rectifier or other power source should be inspected to ensure that internal connections are mechanically secure and that the unit is free of damage. Rating of the DC power source should comply with the construction specification. Care should be exercised in handling and installing the power source.

8.5.1.2 Impressed current anodes should be inspected for conformance to specifications concerning anode material, size, length of lead cable, anode lead connection, and integrity of seal. Care should be exercised to avoid cracking or damaging anodes during handling and installation.

8.5.1.3 All cables should be carefully inspected to detect defects in insulation. Care should be taken to avoid damage to cable insulation. Defects in the cable insulation must be repaired.

8.5.1.4 Anode backfill material should conform to specifications.

8.5.2 Installation Provisions

8.5.2.1 A rectifier or other power source should be installed so that the possibility of damage or vandalism is minimized.

8.5.2.2 Wiring to rectifiers shall comply with local and national electrical codes and requirements of the utility supplying power. An external disconnect switch should be provided in the AC circuit. A rectifier case shall be properly grounded.

8.5.2.3 On thermoelectric generators, a reverse current device should be installed to prevent galvanic action between the anode bed and the pipe if the flame is extinguished.

8.5.2.4 Impressed current anodes can be buried vertically, horizontally, or in deep holes (see NACE Standard RP0572¹) as indicated in construction specifications. Backfill material should be installed to ensure that there are no voids around anodes. Care should be exercised during backfilling to avoid damage to the anode and cable.

8.5.2.5 The cable from the rectifier negative terminal to the pipe should be connected to the pipe as described in Paragraph 8.6. Cable connections to the rectifier must be mechanically secure and electrically conductive. Before the power source is energized, it must be verified that the negative cable is connected to the structure to be protected and that the positive cable is connected to the anodes. After the DC power source has been energized, suitable measurements should be made to verify that these connections are correct.

8.5.2.6 Underground splices on the header (positive) cable to the groundbed should be kept to a minimum. Connections between the header and anode cables should be mechanically secure and electrically conductive. If buried or submerged, these connections must be sealed to prevent moisture penetration so that electrical isolation from the environment is ensured.

8.5.2.7 Care must be taken during installation of direct-burial cable to the anodes (positive cable) to avoid damage to insulation. Sufficient slack should be left to avoid strain on all cables. Backfill material around the cable should be free of rocks and foreign matter that might cause damage to the insulation when the cable is installed in a trench. Cable can be installed by plowing if proper precautions are taken.

8.5.2.8 If insulation integrity on the buried or submerged header cable, including splices, is not

maintained, this cable may fail because of corrosion.

8.6 Corrosion Control Test Stations, Connections, and Bonds (see Paragraph 4.5)

8.6.1 Pipe and test lead wires should be clean, dry, and free of foreign materials at points of connection when the connections are made. Connections of test lead wires to the pipe must be installed so they will remain mechanically secure and electrically conductive.

8.6.2 All buried or submerged lead-wire attachments should be coated with an electrically insulating material, compatible with the external pipe coating and wire insulation.

8.6.3 Test lead wires should be color coded or otherwise permanently identified. Wires should be

installed with slack. Damage to insulation should be avoided and repairs made if damage occurs. Test leads should not be exposed to excessive heat and sunlight. Aboveground test stations are preferred. If test stations are flush with the ground, adequate slack should be provided within the test station to facilitate test connections.

8.6.4 Cable connections at bonds to other structures or across isolating joints should be mechanically secure, electrically conductive, and suitably coated. Bond connections should be accessible for testing.

8.7 Electrical Isolation

8.7.1 Inspection and electrical measurements should ensure that electrical isolation is adequate (see NACE SP0286⁵).

Section 9: Control of Interference Currents

9.1 Introduction

9.1.1 This section recommends practices for the detection and control of interference currents. The mechanism and its detrimental effects are described.

9.2 Mechanism of Interference-Current Corrosion (Stray-Current Corrosion)

9.2.1 Interference-current corrosion on buried or submerged metallic structures differs from other causes of corrosion damage in that the direct current, which causes the corrosion, has a source foreign to the affected structure. Usually the interfering current is collected from the electrolyte by the affected structure from a DC source not metallically bonded to the affected structure.

9.2.1.1 Detrimental effects of interference currents usually occur at locations where the currents transfer between the affected structures and the electrolyte.

9.2.1.2 Structures made of amphoteric metals such as aluminum and lead may be subject to corrosion damage from a buildup of alkalinity at or near the metal surface collecting interference currents.

9.2.1.3 Coatings may become disbonded at areas where voltage gradients in the electrolyte force current onto the affected structure. However, as the external coating becomes disbonded, a larger area of metal may be exposed, which would increase the demand for a CP current. This disbondment may create shielding problems.

9.2.2 The severity of external corrosion resulting from interference currents depends on several factors:

9.2.2.1 Separation and routing of the interfering and affected structures and location of the interfering current source;

9.2.2.2 Magnitude and density of the current;

9.2.2.3 Quality of the external coating or absence of an external coating on the structures involved; and

9.2.2.4 Presence and location of mechanical joints having high electrical resistance.

9.2.3 Typical sources of interference currents include the following:

9.2.3.1 Direct current: CP rectifiers, thermoelectric generators, DC electrified railway and transit systems, coal mine haulage systems and pumps, welding machines, and other DC power systems;

9.2.3.2 Alternating current: AC power systems and AC electrified railway systems; and

9.2.3.3 Telluric current.

9.3 Detection of Interference Currents

9.3.1 During external corrosion control surveys, personnel should be alert for electrical or physical observations that could indicate interference from a foreign source such as the following:

9.3.1.1 Pipe-electrolyte potential changes on the affected structure caused by the foreign DC source;

9.3.1.2 Changes in the line current magnitude or direction caused by the foreign DC source;

9.3.1.3 Localized pitting in areas near or immediately adjacent to a foreign structure; and

9.3.1.4 Damage to external coatings in a localized area near an anode bed or near any other source of stray direct current.

9.3.2 In areas in which interference currents are suspected, appropriate tests should be conducted. All affected parties shall be notified before tests are conducted. Notification should be channeled through corrosion control coordinating committees, when they exist (see NACE Publication TPC 11⁸). Any one or a combination of the following test methods can be used.

9.3.2.1 Measurement of structure-electrolyte potentials with recording or indicating instruments;

9.3.2.2 Measurement of current flowing on the structure with recording or indicating instruments;

9.3.2.3 Development of beta curves to locate the area of maximum current discharge from the affected structure (see Appendix A); and

9.3.2.4 Measurement of the variations in current output of the suspected source of interference current and correlations with measurements obtained in Paragraphs 9.3.2.1 and 9.3.2.2.

9.4 Methods for Mitigating Interference Corrosion Problems

9.4.1 Interference problems are individual in nature and the solution should be mutually satisfactory to the parties involved. These methods may be used individually or in combination.

9.4.2 Design and installation of electrical bonds of proper resistance between the affected structures is a technique for interference control. The bond electrically conducts interference current from an affected structure to the interfering structure or current source.

9.4.2.1 Unidirectional control devices, such as diodes or reverse current switches, may be required in conjunction with electrical bonds if

fluctuating currents are present. These devices prevent reversal of current flow.

9.4.2.2 A resistor may be necessary in the bond circuit to control the flow of electrical current from the affected structure to the interfering structure.

9.4.2.3 The attachment of electrical bonds can reduce the level of CP on the interfering structure. Supplementary CP may then be required on the interfering structure to compensate for this effect.

9.4.2.4 A bond may not effectively mitigate the interference problem in the case of a cathodically protected bare or poorly externally coated pipeline that is causing interference on an externally coated pipeline.

9.4.3 CP current can be applied to the affected structure at those locations at which the interfering current is being discharged. The source of CP current may be galvanic or impressed current anodes.

9.4.4 Adjustment of the current output from interfering CP rectifiers may resolve interference problems.

9.4.5 Relocation of the groundbeds of cathodic protection rectifiers can reduce or eliminate the pickup of interference currents on nearby structures.

9.4.6 Rerouting of proposed pipelines may avoid sources of interference current.

9.4.7 Properly located isolating fittings in the affected structure may reduce or resolve interference problems.

9.4.8 Application of external coating to current pick-up area(s) may reduce or resolve interference problems.

9.5 Indications of Resolved Interference Problems

9.5.1 Restoration of the structure-electrolyte potentials on the affected structure to those values that existed prior to the interference.

9.5.2 Measured line currents on the affected structure that show that the interference current is not being discharged to the electrolyte.

9.5.3 Adjustment of the slope of the beta curve to show that current discharge has been eliminated at the location of maximum exposure (see Appendix A).

Section 10: Operation and Maintenance of CP Systems

10.1 Introduction

10.1.1 This section recommends procedures and practices for energizing and maintaining continuous, effective, and efficient operation of CP systems.

10.1.1.1 Electrical measurements and inspection are necessary to determine that protection has been established according to applicable criteria and that each part of the CP system is operating properly. Conditions that affect protection are subject to change. Correspondingly, changes may be required in the CP system to maintain protection. Periodic measurements and inspections are necessary to detect changes in the CP system. Conditions in which operating experience indicates that testing and inspections need to be made more frequently than recommended herein may exist.

10.1.1.2 Care should be exercised in selecting the location, number, and type of electrical measurements used to determine the adequacy of CP.

10.1.1.3 When practicable and determined necessary by sound engineering practice, a detailed (close-interval) potential survey should be conducted to:

- (a) assess the effectiveness of the CP system;
- (b) provide base line operating data;
- (c) locate areas of inadequate protection levels;
- (d) identify locations likely to be adversely affected by construction, stray currents, or other unusual environmental conditions; or
- (e) select areas to be monitored periodically.

10.1.1.4 Adjustments to a CP system should be accompanied by sufficient testing to assure the criteria remain satisfied and to reassess interference to other structures or isolation points.

10.2 A survey should be conducted after each CP system is energized or adjusted to determine whether the applicable criterion or criteria from Section 6 have been satisfied.

10.3 The effectiveness of the CP system should be monitored annually. Longer or shorter intervals for monitoring may be appropriate, depending on the variability of CP factors, safety considerations, and economics of monitoring.

10.4 Inspection and tests of CP facilities should be made to ensure their proper operation and maintenance as follows:

10.4.1 All sources of impressed current should be checked at intervals of two months. Longer or shorter intervals for monitoring may be appropriate. Evidence of proper functioning may be current output, normal power consumption, a signal indicating normal operation, or satisfactory CP levels on the pipe.

10.4.2 All impressed current protective facilities should be inspected annually as part of a preventive maintenance program to minimize in-service failure. Longer or shorter intervals for monitoring may be appropriate. Inspections may include a check for electrical malfunctions, safety ground connections, meter accuracy, efficiency, and circuit resistance.

10.4.3 Reverse current switches, diodes, interference bonds, and other protective devices, whose failures would jeopardize structure protection, should be inspected for proper functioning at intervals of two months. Longer or shorter intervals for monitoring may be appropriate.

10.4.4 The effectiveness of isolating fittings, continuity bonds, and casing isolation should be evaluated during the periodic surveys. This may be accomplished by electrical measurements.

10.5 When pipe has been uncovered, it should be examined for evidence of external corrosion and, if externally coated, for condition of the external coating.

10.6 The test equipment used for obtaining each electrical value should be of an appropriate type. Instruments and related equipment should be maintained in good operating condition and checked for accuracy.

10.7 Remedial measures should be taken when periodic tests and inspections indicate that CP is no longer adequate. These measures may include the following:

10.7.1 Repair, replace, or adjust components of CP systems;

10.7.2 Provide supplementary facilities in which additional CP is necessary;

10.7.3 Thoroughly clean and properly coat bare structures if required to attain CP;

10.7.4 Repair, replace, or adjust continuity and interference bonds;

10.7.5 Remove accidental metallic contacts; and

10.7.6 Repair defective isolating devices.

10.8 An electrical short circuit between a casing and carrier pipe can result in inadequate CP of the pipeline outside the casing due to reduction of protective current to the pipeline.

10.8.1 When a short results in inadequate CP of the pipeline outside the casing, steps must be taken to restore CP to a level required to meet the CP criterion. These steps may include eliminating the short between the casing and carrier pipe, supplementing CP, or

improving the quality of the external coating on the pipeline outside the casing. None of these steps will ensure that external corrosion will not occur on the carrier pipe inside the casing; however, a shorted casing does not necessarily result in external corrosion of the carrier pipe inside the casing.

10.9 When the effects of electrical shielding of CP current are detected, the situation should be evaluated and appropriate action taken.

Section 11: External Corrosion Control Records

11.1 Introduction

11.1.1 This section describes external corrosion control records that will document in a clear, concise, workable manner data that are pertinent to the design, installation, operation, maintenance, and effectiveness of external corrosion control measures.

11.2 Relative to the determination of the need for external corrosion control, the following should be recorded:

11.2.1 Corrosion leaks, breaks, and pipe replacements; and

11.2.2 Pipe and external coating condition observed when a buried structure is exposed.

11.3 Relative to structure design, the following should be recorded:

11.3.1 External coating material and application specifications; and

11.3.2 Design and location of isolating devices, test leads and other test facilities, and details of other special external corrosion control measures taken.

11.4 Relative to the design of external corrosion control facilities, the following should be recorded:

11.4.1 Results of current requirement tests;

11.4.2 Results of soil resistivity surveys;

11.4.3 Location of foreign structures; and

11.4.4 Interference tests and design of interference bonds and reverse current switch installations.

11.4.4.1 Scheduling of interference tests, correspondence with corrosion control coordinating committees, and direct communication with the concerned companies.

11.4.4.2 Record of interference tests conducted, including location of tests, name of company involved, and results.

11.5 Relative to the installation of external corrosion control facilities, the following should be recorded:

11.5.1 Installation of CP facilities:

11.5.1.1 Impressed current systems:

11.5.1.1.1 Location and date placed in service;

11.5.1.1.2 Number, type, size, depth, backfill, and spacing of anodes;

11.5.1.1.3 Specifications of rectifier or other energy source; and

11.5.1.1.4 Cable size and type of insulation.

11.5.1.2 Galvanic anode systems:

11.5.1.2.1 Location and date placed in service;

11.5.1.2.2 Number, type, size, backfill, and spacing of anodes; and

11.5.1.2.3 Wire size and type of insulation.

11.5.2 Installation of interference mitigation facilities:

11.5.2.1 Details of interference bond installation:

11.5.2.1.1 Location and name of company involved;

11.5.2.1.2 Resistance value or other pertinent information; and

11.5.2.1.3 Magnitude and polarity of drainage current.

- 11.5.2.2 Details of reverse current switch:
- 11.5.2.2.1 Location and name of companies;
 - 11.5.2.2.2 Type of switch or equivalent device; and
 - 11.5.2.2.3 Data showing effective operating adjustment.
- 11.5.2.3 Details of other remedial measures.
- 11.6 Records of surveys, inspections, and tests should be maintained to demonstrate that applicable criteria for interference control and CP have been satisfied.
- 11.7 Relative to the maintenance of external corrosion control facilities, the following information should be recorded:
- 11.7.1 Maintenance of CP facilities:
- 11.7.1.1 Repair of rectifiers and other DC power sources; and
- 11.7.1.2 Repair or replacement of anodes, connections, wires, and cables.
- 11.7.2 Maintenance of interference bonds and reverse current switches:
- 11.7.2.1 Repair of interference bonds; and
 - 11.7.2.2 Repair of reverse current switches or equivalent devices.
- 11.7.3 Maintenance, repair, and replacement of external coating, isolating devices, test leads, and other test facilities.
- 11.8 Records sufficient to demonstrate the evaluation of the need for and the effectiveness of external corrosion control measures should be maintained as long as the facility involved remains in service. Other related external corrosion control records should be retained for such a period that satisfies individual company needs.

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Appendix A—Interference Testing

A beta curve is a plot of dynamic (fluctuating) interference current or related proportional voltage (ordinate) versus values of corresponding structure-to-soil potentials at a selected location on the affected structure (abscissa). If the correlation is reasonably linear, the plot will indicate whether the affected structure is receiving or discharging current at the location where the structure-to-soil potential was measured. Dynamic interference investigation involves

many beta curve plots to search for the point of maximum interference-current discharge. Interference is resolved when the correlation of maximum current discharge has been changed to a correlation that shows that current pickup is being achieved in the exposure area by the corrective measures taken. These corrective measures may be accomplished by metallic bonding or other interference control techniques.

Appendix B—Method for Determining Probable Corrosion Rate and Costs of Maintaining Service

Maintenance of a piping system may include repairing corrosion leaks and reconditioning or replacing all or portions of the system.

In order to make estimates of the costs involved, it is necessary to determine the probability of corrosion or the rate at which corrosion is proceeding. The usual methods of predicting the probability or rate of corrosion are as follows:

(a) Study of corrosion history on the piping system in question or on other systems of the same material in the same general area or in similar environments. Cumulative leak-frequency curves are valuable in this respect.

(b) Study of the environment surrounding a piping system: resistivity, pH, and composition. Redox potential tests may also be used to a limited extent. Once the nature of the environment has been determined, the probable corrosiveness is estimated by reference to actual corrosion experience on similar metallic structures, when environmental conditions are similar. Consideration of

possible environmental changes such as might result from irrigation, spillage of corrosive substances, pollution, and seasonal changes in soil moisture content should be included in such a study.

(c) Investigation for corrosion on a piping system by visual inspection of the pipe or by instruments that mechanically or electrically inspect the condition of the pipe. Condition of the piping system should be carefully determined and recorded each time a portion of the line is excavated for any reason.

(d) Maintenance records detailing leak locations, soil studies, structure-to-electrolyte potential surveys, surface potential surveys, line current studies, and wall thickness surveys used as a guide for locating areas of maximum corrosion.

(e) Statistical treatment of available data.

(f) Results of pressure testing. Under certain conditions, this may help to determine the existence of corrosion.

Appendix C—Contingent Costs of Corrosion

In addition to the direct costs that result from corrosion, contingent costs include:

- (a) Public liability claims;
- (b) Property damage claims;

(c) Damage to natural facilities, such as municipal or irrigation water supplies, forests, parks, and scenic areas;

(d) Cleanup of product lost to surroundings;

(e) Plant shutdown and startup costs;

- (f) Cost of lost product;
 - (g) Loss of revenue through interruption of service;
 - (h) Loss of contract or goodwill through interruption of service; and
 - (i) Loss of reclaim or salvage value of piping system.
-

Appendix D—Costs of Corrosion Control

The usual costs for protecting buried or submerged metallic structures are for complete or partial CP or for external coatings supplemented with cathodic protection. Other corrosion control costs include:

- (a) Relocation of piping to avoid known corrosive conditions (this may include installing lines above ground);
- (b) Reconditioning and externally coating the piping system;

- (c) Use of corrosion-resistant materials;
- (d) Use of selected or inhibited backfill;
- (e) Electrical isolation to limit possible galvanic action; and
- (f) Correction of conditions in or on the pipe that might accelerate corrosion.



Level 2

Chapter 32

Case Study E

Case Study

It's Monday morning and John has another new inspection job to start; the contractor is starting on Wednesday of this week. Arriving at the office he sees that his boss has laid the specification on his desk with a simple note stating, "Let me know what you need."

In reading the specification John notices right away that it is very vague as to what inspection procedures and documentation are going to be required. Simply put, it says, new rail car interiors to be lined with two full coats of an amine epoxy coating of 4 to 6 mils per coat and is to be holiday-free. All work is to be performed at the fabricators yard in Tulsa, OK, between February 12 and March 15. Surface preparation shall be in accordance with NACE No. 1/SSPC-SP 5 over a surface accepted by the coating inspector to be adequate for immersion service. No salts are allowed to be present, the welds are to be rounded, and the humidity in the cars is to be maintained between 40 to 50% with temperatures held to coating manufacturers' requirements until final cure. Hardness readings are to meet ASTM requirements and pull-off adhesion testing shall be performed to meet a minimum of 900 pounds per square inch and "X" cuts shall be a minimum reading of 5. The contractor will touch up all areas where destructive testing is performed.

There will be a pre-job on Wednesday morning before work begins, and John has plenty of questions. What does your team consider should be included in John's list of standards, reference materials, and equipment required for him to adequately perform and back up his job with only the information provided?

Please list your team's response on a flip chart and be ready to present in ____ minutes. It is now ____; be ready to present at ____.

Your Team's List



Level 2

Chapter 33

Coating Types and

Inspection Criteria

Coating Types and Inspection Criteria

Introduction

In Level 1 of the Coating Inspector Program, two vital topics that were discussed were:

- An introduction to coatings
- Coating curing mechanisms

Throughout this course references to coatings types and material components have been made, including:

- Composition of coatings: pigment and vehicle
- Coatings: named according to the resin used, for example, alkyds
- How coatings cure: evaporation; polymerization by heat, oxygen, or catalyst; coalescence, etc.
- How coatings are applied: brush, roller, spray, electrostatic, cloud chamber, hot dipped, etc.
- Coating defects and coating failures

Earlier we discussed hot-dip galvanizing with zinc and spray metallizing of aluminum and zinc. Now we will focus on coatings by:

- Reviewing coating types, categorized by curing mechanisms
- Noting some advantages and disadvantages of each generic type
- Listing some typical uses for each type of coating
- Exploring some inspection criteria for each generic type.

The coating inspector must have a clear understanding of how various coatings cure and should become familiar with the specific surface treatment and application requirements for each coating that might be used.

Inspection criteria may be coating-type specific and the inspector would want to consider them in the following manner:

- What do I see? Is the coating uniform, with good integrity and pinhole free, or does it have blisters, runs, sags, dry spray, mudcracking, etc.?
- What are the probable causes of defects that can be seen?
- As the inspector, what do I do about it?

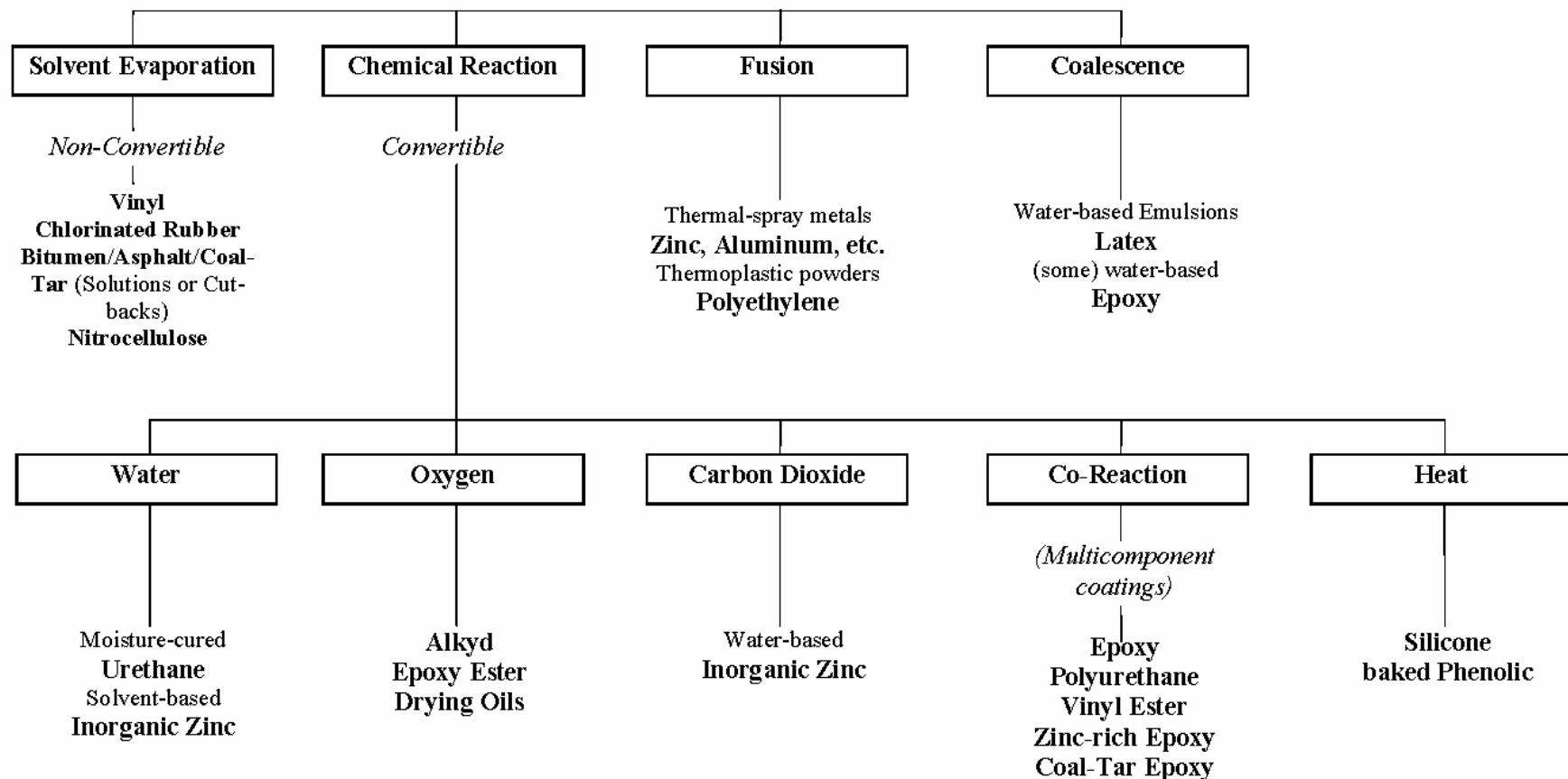
We will discuss some inspection criteria for each curing mechanism and will identify other inspection criteria for specific coatings.

Curing Mechanisms

The curing mechanisms to be reviewed include:

- Solvent evaporation
- Polymerization
 - Oxygen-induced
 - Catalyst- (activator or converter) induced
 - Heat-induced
 - Water-induced (hydrolysis)
- Coalescence

Film-Forming Mechanisms (Drying and / or Curing)



Solvent-Evaporation Cure (Nonconvertible) Coatings

Coatings that cure by solvent evaporation are made by dissolving a resin, such as chlorinated rubber or vinyl in a suitable solvent, or blend of solvents.

When one of these materials is applied, it cures by simple evaporation of the solvent. The resin remains unchanged and can be redissolved by its original hydrocarbon solvent, no matter how old the film is.

Evaporation cure coatings should not be topcoated with a different type of coating that contains a strong solvent. The solvent may attack the base coating, causing it to redissolve. In addition, coatings that cross-link develop greater film stresses. For example, alkyds and oil-based coatings should not be topcoated with epoxy because, as the epoxy cures, significant internal stresses develop, causing the coating system to delaminate (peel).

Evaporation-type coatings generally may be applied over a different type of coating. For example, a vinyl coating can be applied to an epoxy. However, if the epoxy coating is fully cured, and has become relatively hard and slick, poor intercoat adhesion may result.

Since all the solvent must evaporate for the coating to be properly cured, evaporation-type coatings should not be applied too thickly. If applied too thickly, the coating is likely to have solvents entrapped within the film, and these trapped solvents ultimately weaken coating integrity.

Coatings that cure by solvent evaporation include:

- Chlorinated rubber
- Vinyl
- Acrylics
- Bitumens (asphalt and coal-tar cutbacks)

General Inspection Criteria for Solvent Evaporation Cure Coatings

Chlorinated rubber and vinyl coatings contain high amounts of volatile solvents. If applied to a hot surface, these coatings may not be able to wet the surface adequately before the solvents flash off, resulting in a dry, poorly formed film being deposited. The coating film may be porous, with poor film integrity, have low gloss, and be useless as a protective coating.

Asphalt and coal-tar coatings contain less volatile solvents; however, if applied to a hot surface, these materials may develop pinholes in the film, resulting in a porous surface. Also, if they are applied in too thick of a film at higher ambient temperatures, the coating surface may *skin set*, causing solvent entrapment. The film underneath will remain soft, prolonging or preventing total cure.

Chlorinated Rubber Coatings

Chlorinated rubber is an elastomer formed when natural rubber or a polyolefin reacts with chlorine. These materials must be modified by other resistant resins to obtain higher solids, decrease brittleness, and increase adhesion.

Chlorinated rubber coatings generally are low in solids (typically 15 to 25% by volume) and must be applied in thin coats of 25 to 75 μm (1 to 3 mils) dry-film thickness per coat. Modified chlorinated rubber coatings are often applied at a higher DFT, 100 to 175 μm (4 to 7 mils), for example.

Chlorinated rubber begins to break down at about 80°C (175°F) and decompose at about 134°C (275°F).

Chlorinated rubber coatings are especially resistant to alkalis and acids and have good chemical and water resistance.

Chlorinated rubber coatings have poor resistance to:

- Aromatic solvents
- Esters
- Ketones
- Animal and vegetable oils and fats
- Heat

Chlorinated rubber coatings are used wherever resistance to water, acids, and alkalis is required, especially in:

- Chemical plants
- Water treatment plants
- Breweries

Vinyl Coatings

Vinyl is made by dissolving polyvinyl chloride (PVC) copolymers, such as vinyl acetate, and vinyl acrylic, etc., in a suitable solvent such as methyl ethyl ketone (MEK). Toluene and xylene are used as diluents with the MEK.

The long-chain molecules of vinyl resin make them thermoplastic and also make them physically strong and highly resistant to a wide variety of materials, such as:

- Acids
- Alkalies
- Oil and greases
- Alcohols
- Chemical salts
- Water

Vinyls have good weather resistance, also good gloss and color retention. They are most resistant to aging, but can become brittle with age due to the breakdown or migration of the plasticizer.

Vinyl coatings have been used widely in:

- Marine environments: atmospheric, immersion, and offshore
- Chemical plants
- Paper mills
- Oil refineries
- Dam gates and penstocks
- Food processing plants
- Water tanks
- Water and wastewater treatment plants

Like chlorinated rubber, vinyl coatings degrade at elevated temperatures (80°C [175°F]).

Vinyl coatings are typically applied at low DFTs, with as many as seven coats being used to achieve long-term protection.

Inspection Criteria—Chlorinated Rubber and Vinyl Coatings

The inspection criteria for chlorinated rubber and vinyl are quite similar, and they are combined in the following table.

Chlorinated Rubber and Vinyl Inspection Criteria

What might the inspector see?	What is the probable cause?	What should the inspector do?
Dry spray, cob webbing, poor appearance	1. Insufficient or wrong thinner 2. Application at high ambient temperature	Request proper thinner in correct amount Seek guidance from coating manufacturer or postpone coating application
Film softens and/or disintegrates upon short term exposure	Film applied to surfaces exposed to strong solvents	Suggest owner use more solvent resistant coatings or eliminate exposure to solvents
Film deteriorates when placed in service	Application to surfaces exposed to temperatures above 80°C (175°F)	Measure temperature and report

Acrylic Coatings

Acrylic coatings are a class of coatings in which the binder is an acrylic resin. The resin is similar to urethane, in that it is more resistant to ultraviolet exposure than epoxy resins.

Generally, acrylics are one-package coatings that cure by solvent evaporation; however, acrylic resins can be fashioned into emulsion coatings. We will discuss acrylic emulsions in the section on Waterborne Coatings.

Solvent-evaporation-cure acrylics are frequently used over epoxy intermediate coatings and provide very good appearance. They are easily recoated and are easy to maintain.

When used over epoxies, the acrylic should be applied before the underlying epoxy cures hard, that is, within several days to one month, depending on the epoxy and acrylic formulation.

Acrylic coatings are commonly used in atmospheric service and find wide use on marine vessels. They are used on the exterior hull above the waterline, on the exterior decks, the superstructure and other areas where good appearance is important.

Bituminous Coatings

Both asphalt and coal tar are frequently referred to as *bitumens*, though they are derived from different sources. Asphalt, or gilsonite, occurs in nature and is also derived from the residuals of refined crude oil. Asphalt coatings are made by dissolving the base material in an aliphatic solvent such as mineral spirits.

Coal tar is derived from coal-tar pitch, a residue of the coking process (destructive distillation of coal) in a steel mill. Coal-tar coatings are made by dissolving the coal-tar pitch in an aromatic solvent such as xylol or toluol.

Since these coatings are made by dissolving or *cutting back* the base material with a solvent, they frequently are referred to as *cutback coatings*.

Asphalt cutback coatings have:

- Limited water resistance
- Good weather and sunlight resistance

Generally, asphalt coatings are used aboveground as roofing materials or as a maintenance coating where color is not a factor.

In general, coal-tar coatings have:

- Excellent water resistance
- Excellent bond to steel or concrete
- Limited resistance to sunlight
- Resistance to aliphatic solvents but are dissolvable with aromatic solvents

Coal-tar-cutback coatings may be used:

- As a base coat for coal-tar emulsions in atmospheric service
- On steel or concrete, buried or submerged
- As a membrane in vessels to be lined with tile or brick

Both coal-tar and asphalt coatings are high-solids materials and can be applied in thicker films, 400 to 600 μm (15 to 25 mils) wet per coat. Both products will withstand service temperatures (dry) up to 92°C (200°F). Asphalt and coal tar can also be fashioned into trowelable mastic coatings.

Both materials are thermoplastic and can be applied after heating the solid enamel until it is liquid. The noxious fumes associated with hot asphalt or coal tar are thought by some to be carcinogenic, and the material is less commonly applied as a result.

Polymerization-Cured Coatings

Polymerization occurs when two or more resin molecules combine to form a single, more complex molecule.

Polymerization is a chemical reaction in which a compound is formed from the joining of many similar chemical groups called *monomers*. The major characteristics of monomers are:

- Inherently stable
- Capable of linking together chemically

This joining together of monomers within a resin in the process called *polymerization* is the most common curing method of today's coatings.

Three main types of chemical reaction are commonly used to induce polymerization:

- Oxygen-induced
- Chemically induced
- Heat-induced

It should be noted that other forms of induction reactions do exist; for example, ultraviolet light is used to induce curing in some glues to bond glass together.

The polymerization may form long-chain molecules (one-dimensional linking) or a more complex three-dimensional molecule (cross-linking).

The end result of such cross-linking is a rigid, three-dimensional molecular structure formed as a coating film on the substrate.

The more effective the cross-linking polymerization process is the stronger and more chemical-resistant the cured resin becomes.

One example of polymerization is the joining of the monomer ethylene (C_2H_4) into the common polymer polyethylene, in which up to 1,400 ethylene monomer groups may be joined.

Polyethylene comprises various thermoplastic materials that may be used for coating buried pipes as an extruded sheath, as a sintered (heated) powder, or as a preformed tape wrap.

Polymerization can describe the reaction used to produce synthetic resins, or it can describe the cure process of a coating after mixing and application.

Many resins used in coatings are partially developed polymers, which cure by completing the polymerization.

With age, some additional polymerization develops, and the coating film becomes more glass-like, harder, and less resilient.

Oxygen-Induced Polymerization Coatings

Oxygen-induced polymerization coatings form a solid film by a process called *oxidative cross-linking* using atmospheric oxygen. There is some evaporation because solvents are added for ease of application.

The main ingredients in many oxidation types, such as alkyd coatings, are:

- Vegetable oils,
 - linseed
 - tung
 - soy bean
 - dehydrated castor oil
- Fish oils
 - menhaden

Film formation depends on the oil reacting with oxygen to form a cross-linked structure. To speed up the reaction between the oil and oxygen, small amounts of metallic catalysts, called *driers*, are added during manufacturing. The usual driers are cobalt, lead, and manganese compounds.

Because film formation depends on oxygen in the air entering the wet film and reacting with the oil, curing can take a considerable amount of time. The time taken to form a solid film can vary from two days to several days. Some drying oils probably never complete their potential cure cycle.

Because the oxygen in the air can enter the film only at the surface, there is a limit to the wet-film thickness (WFT) that may be applied. In general, WFT should not be greater than 50 to 75 μm (2 to 3 mils). If the WFT is greater, the film becomes solid at the top and remains liquid underneath. This can cause the film to pucker and

wrinkle at the top and take a very long time to solidify at the bottom if ever.

Like most chemical reactions, the speed of the reaction increases with an increase in temperature. Thus, the coating will dry and cure faster in warmer temperatures. Because the reaction depends on oxygen from the air reaching the surface, a regular change of air over the surface will also speed up the reaction.

On the other hand, if a thin film of moisture forms on the surface because of humidity or other factors, the oxygen uptake will be slowed, extending the drying time. Wax and oil contaminants will have a similar, but more pronounced, effect.

Manufacturers of oxidation-type coatings usually add a small amount of a material that prevents the oxygen reaction while the coating is stored in the can. This is usually effective only while the can is full and only for a stated shelf life. If some of the coating is removed and the can resealed, the coating will react with oxygen in the can to form a solid film on the top of the remaining coating. This film must be entirely removed and the coating strained before the coating is used.

The oils used in oxidation-type coatings may react with alkali to form soap, a process known as *saponification*.

Generally oxidation-type coatings are not suitable for use in conditions where severe corrosion may be encountered. Oxidation-type coatings also are not suitable for application on alkaline surfaces, such as new concrete, or over zinc coatings, such as inorganic zinc or hot-dip galvanizing, because they may saponify and delaminate from the substrate.

Oxidation-type coating films can be attacked by strong solvents, such as acetone, MEK, and ethyl acetate. These solvents cause the film to swell and wrinkle. It is generally not recommended that a dry film of an oxidation-type coating be overcoated with a coating that contains strong solvents, such as vinyl or epoxy.

Types of coatings that cure by oxidation include:

- Drying oils
- Alkyds
- Epoxy ester
- Oil-modified phenolic
- Uralkyd (oil-modified urethane)
- Silicone alkyd

Some inspection criteria that are common for drying oils, alkyds, epoxy esters, and oil-modified phenolics, may be found in the table below.

Inspection Criteria of Coatings That Cure by Oxidative Polymerization

What might the inspector see?	What is the probable cause?	What should the inspector do?
Softened coating, with loss of adhesion at coating/substrate interface	Application over alkaline surfaces such as, concrete, galvanizing, inorganic zinc	Ensure coating applied to non-alkaline substrate, or use proper tie coat.
Wrinkling, sagging, coating not cured, or cure very slow, spot rusting	Material past shelf life, failure to mix in pigment	Report use of old coating Observe and ensure proper mixing
Slow drying, runs, sags, wrinkling, outer surface harder than body of coating	Application in excessively thick coats	Ensure application in thinner wet coats to allow proper cure before next coat
Early failure, coating resin disintegrates, loss of adhesion	Application to surfaces exposed to strong solvents, mineral acids, alkalis, water immersion, or high temperature	Report; suggest client confine coatings to moderate exposure Do not apply to high-temperature surfaces
Peeling or alligatoring, and/or cracking, poor adhesion, poor longtime performance	Application to solvent evaporation type primer	Ensure use of proper primer or tie coat

Drying Oils

Drying oils (vegetable oils and fish oils) are commonly used in the production of synthetic resins such as alkyds, and are raw materials for many synthetic resins, such as phenolic varnishes.

Drying oils are film-formers, and may be used in their natural state as crude protective coatings. When used as coatings, they:

- Have good wetting ability and can penetrate some light rust to the substrate
- May be slow to develop a solid film
- Have poor solvent resistance
- Will saponify when in contact with alkaline environments such as zinc galvanizing or concrete
- Are rarely used in modern coating applications

Alkyd Coatings

Alkyd coatings are oil-modified resins that dry to a tough, hard film. The proportion of oil used will determine what the alkyd is called:

- Long-oil alkyd
- Medium-oil alkyd
- Short-oil alkyd

Alkyds are used for making moderately fast-drying enamels for both interior and exterior architectural and industrial coatings. Alkyd coatings may also be modified with other types of resins including:

- Acrylic
- Phenolic
- Silicone

- Urethane
- Vinyl

Like other coatings that cure by oxygen-induced polymerization, alkyds should not be used directly on concrete, masonry, or galvanized surfaces, except over an alkali-resistant primer, sealer, or proper tie coat.

Some advantages of alkyds are:

- Minimal surface preparation
- Ease of application
- Easily maintained
- Excellent exterior durability
- Low cost
- Excellent flexibility
- Good appearance and gloss retention

Some limitations of alkyds include:

- Variable color retention
- Low film build per coat
- Poor chemical and solvent resistance
- Fair water resistance
- Limited heat resistance that becomes brittle at temperatures higher than 81°C (180°F)

Alkyds are good general-purpose coatings for such aboveground structures, as tanks, structural steel, etc. They also are used for decorative topcoats in power plants, refineries etc.

Epoxy Ester Coatings

Epoxy esters are epoxy resins modified with oil to produce a one-package coating that cures by oxygen-induced polymerization.

Epoxy esters are not as hard or chemically resistant as two-component epoxies. They do have an intermediate degree of chemical resistance and can be used on areas subjected to occasional chemical spillage.

Since epoxy esters are single-package materials, they do not require a catalyst, and do not have pot life restrictions like two-component epoxy coatings.

Typically, epoxy esters are used as primers for steel and on:

- Indoor steel surfaces, machinery, and equipment
- Plant floors

Used outdoors, these coatings chalk rapidly and excessively.

Oil-Modified Phenolic Coatings

Oil-modified phenolic coatings should not be confused with epoxy phenolic coatings that are used extensively in industrial applications.

Phenolic coatings have good interior and exterior resistance to water and chemicals, but are softened by strong solvents. Phenolics discolor with age, and the film becomes very hard and brittle.

Aged phenolic films are most difficult to recoat because of poor adhesion to the aged, oxidized surface. Intercoat adhesion can be improved if the old coated surface is properly scarified or roughened to provide some amount of profile.

Oil-modified phenolics are used most commonly for:

- Interior and exterior protection of wood
- A vehicle in some barrier-type primers
- Interior floor coatings
- Oil-resistant shop primer

Oil-modified phenolic resins are used by some coating manufacturers to formulate what is called a *universal primer*. The coating inspector should recognize that these types of primers are not truly universal, that is, they cannot be used on all substrates nor with all types of coatings.

In addition to general inspection criteria previously discussed, other criteria are shown in the following table.

Inspection Criteria for Oil Modified Phenolic Coatings

What might the inspector see?	What is the probable cause?	What can the inspector do?
Lifting of the coating, peeling from substrate	Recoat time too short	Observe required recoat interval. Allow coating to dry/cure properly before recoating
Poor intercoat adhesion, delamination	Recoat time too long	Observe proper recoat time. Apply overcoating before surface hardens too much

Uralkyd (Oil-Modified Urethane) Coatings

Uralkyds are urethanes modified with drying oils and alkyds. They are available as clear varnishes or as pigmented, one-package, air-dry coatings. Uralkyds look and handle somewhat like high-spar varnishes, and performance is similar to that of epoxy esters.

Uralkyds are very abrasion resistant and have good weatherability and gloss retention. They are frequently

used on commercial, institutional, and residential wood floors, furniture, and trim, and have been widely used on the exterior of aboveground tanks.

Silicone Alkyd Coatings

Silicone alkyds are much more resistant than pure alkyds to general weathering conditions and particularly to high temperatures.

These modified alkyds are made by reacting a silicone polymer with the solid alkyd resin, and then cooking it with a drying oil, such as tung, linseed, or soy.

Silicone alkyds are used increasingly as maintenance coatings and marine finishes because of their improved properties. Silicone alkyds are also used extensively for surfaces operating at moderately high temperatures.

Chemically Induced Polymerization Coatings

Chemically induced polymerization coatings are formed when the resin is reacted with a curing agent (also called an activator or catalyst).

A wide assortment of coating and lining materials are included under this heading for discussion today. All the coatings listed require the addition of an activator to the base material in order to form a cured film.

Chemically cured coatings to be discussed include:

- Epoxy
- Coal-tar epoxy
- Zinc-rich epoxy
- Polyesters/vinyl esters
- Two-component urethane

- Vinyl wash primers
- Epoxy-modified phenolic

Chemically induced polymerization coatings are the most versatile modern coatings. The many formulations can be modified to provide specific properties. These coatings, and epoxies in particular, are the workhorses of the protective coating industry.

Before the discussion of specific coating types begins, some important application precautions with the application of most co-reaction cure coatings should be mentioned. These include:

- Add converter to base before application. If the converter is not added to the base before application, the coating will appear to dry but will not completely cure.
- Ensure proportion of base to converter is correct. If the proportion of base to converter is incorrect, the polymer formed will not be the correct one expected. The pot life may be affected, and the applied film may have poor chemical resistance and poor overall corrosion resistance. The coating may even set up in the spray pot and lines.
- Do not over mix. Over mixing of the separate components before combining and/or over mixing after combining them, can result in blistering, bubbling, and poor film formation due to the entrapped air in the coating. Rapid cure may also occur.
- Allow sufficient digestion or sweat-in time. The coating manufacturer may recommend that before application, the coating be allowed to sit for a period of time after the converter and base are combined.

This allows the combined material to become compatible and the polymerization reaction to proceed uniformly throughout the blended coating materials.

Defects such as crawling, fisheyes, and cratering may occur as a result of insufficient digestion time, and the cure may not be uniform.

- Use the correct thinner (if thinning is allowed or required). If the incorrect thinner is used, the coating tends to coagulate in the paint pot (container) and gel in the fluid hoses. If the product can be sprayed at all, it generally will have poor spray characteristics and film formation can be so disrupted that early failure is almost certain.
- Do not apply at too low of a temperature. Unless specially formulated for low-temperature application, most chemically cured materials must be applied when the surface temperature and the adjacent air is at or above 10°C (50°F) and rising to achieve proper cure. Generally, vinyl esters must be applied at temperatures above 16°C (60°F), polyesters above 7°C (45°F), and aliphatic and aromatic polyurethanes above 4°C (40°F).
- Provide some air movement across coated surface. In confined spaces, it is especially important to have proper air movement across the coated surface to avoid solvent entrapment and prolonged cure of the coating.
- Do not exceed pot life. Once the base and converter are blended, polymerization begins and continues until it is complete. To protect the user, the coating manufacturer indicates the pot life at given temperatures on the product data sheet.

The pot life is defined as that limited period of time during which the product, once combined, must be applied for optimum results.

As the mixed coating approaches its pot life, its viscosity increases. When its pot life expires, the coating may still be a liquid, but with increased viscosity.

Coatings exceeding their stated pot life should not be applied. An applicator may be tempted to try to apply

such a coating, sometimes thinning it to reduce the viscosity for spraying. If this is done, the coating may:

- Have poor sprayability
- Develop low film build
- Sag
- Not cure properly

The finished film may have:

- Entrapped air
- Pinholes
- Sags
- Inferior film thickness
- Poor service performance
- Poor film integrity

Epoxy Two-Component (Co-Reactive) Coatings

Two-component epoxies are coatings activated by adding a curing agent (also sometimes called *converter*, *activator*, *hardener*, or *catalyst*) to a resin base.

There are several general types of curing agents including:

- Polyamide, which produces a film with less tendency to blush than polyamine, and generally has better wetting characteristics to the substrate. Polyamine-cured epoxy coatings generally have better chemical resistance than polyamide epoxies, but are more toxic.
- Polyamine, which produces a film with excellent chemical and immersion resistance. Polyamine-cured coatings tend to have short pot lives and care must be taken to apply the coating soon after mixing. In addition, polyamine systems are sensitive to moisture

and, in combination with cool temperatures, will *blush* and generate amine bloom, which degrades adhesion of successive coats of material.

- Isocyanate, which produces a film that cures at lower temperatures (below 10°C [50°F]) than the polyamine or polyamide types, while having a shorter pot life, typically one to two hours.

Other curing agents include:

- Ketimines
- Amine adducts
- Polyimides
- Amido-amines

Epoxy coatings generally provide:

- Excellent chemical and solvent resistance
- Good water resistance
- High film build per coat
- Good exterior durability (except for chalking)
- Excellent adhesion to steel or concrete

Epoxy coatings are widely used in:

- Interiors of potable water tanks
- Lining vessels and equipment
- Structural steel
- Chemical and petrochemical plants
- Marine vessels and offshore facilities
- Water and wastewater facilities
- Food-processing plants

Epoxy coatings are susceptible to chalking in exterior exposures, and do not have good long-term gloss appearance.

Some types of epoxy coatings may develop amine blush when exposed to high humidity and moisture during the cure phase.

Amine blush appears as an oily, waxy, or milky film, clear or amber in color, on the surface of the coating, and generally occurs as the film cures during cool, damp conditions. The amine component of the coating reacts with atmospheric carbon dioxide and water at the coating surface to form amine carbamate. The effect may not be readily visible, but can still interfere with successful adhesion of succeeding coats. Inspectors should carefully and closely examine surfaces that are known to have been exposed to damp moist conditions during the early curing phase.

The amine carbamate (blush) may be removed by washing the coating surface with water or with a solvent recommended by the manufacturer. If the coating is to be overcoated, the amine blush must be removed, otherwise intercoat adhesion failure may occur. If the coating is not to be overcoated, removal of the amine blush may be optional.

Coal-Tar-Epoxy Coatings

Coal-tar-epoxy coatings are made by blending an epoxy resin with selected coal-tar resins. The resultant coating is synergistic in that it combines the excellent water resistance and adhesion of the coal tar with the chemical and solvent resistance of a pure epoxy to yield a product for heavy-duty use on buried or submerged structures.

Some typical uses for coal-tar-epoxy coatings include:

- Primer for antifouling coatings
- Oil tank interiors
- Ballast tanks (ships)
- Pipelines, steel or concrete
- Docks and pilings
- Ship hulls, at or below waterline
- Sewage and water treatment plants
- Linings for water pipelines
- Oil platforms

Coal-tar epoxy is generally used alone and not in conjunction with other coatings. This coating yields a relatively high film build per coat, and many specifications call for only one or two applications.

Coal-tar epoxy develops a hard, slick film when it cures, which makes it difficult to recoat or repair. Some formulations cure relatively quickly, and the coating inspector should monitor over-coating intervals very closely.

Inspection Criteria for Coal-Tar Epoxy

What might the inspector see?	What is the probable cause?	What can the inspector do?
Amine blush, an amber-colored, oily film bloom on surface	Application and cure during cool, damp conditions	Ensure application at proper temperature and humidity. Ensure blush is removed before overcoating
Delamination between coats	Recoat interval exceeded	Monitor recoat interval. Scarify surface by sweep blast before overcoating

Zinc-Rich Epoxy

Zinc-rich epoxy is available in a two- or three-package formulation containing a moderately high amount by weight of metallic zinc powder (50 to 75% by weight) in the cured film.

The three-package system consists of:

- Epoxy resin (may contain fillers and some color pigments)
- Curing agent (co-reactant)
- Zinc dust

The two-package system consists of:

- Epoxy resin plus zinc dust
- Curing agent (co-reactant)

Zinc-rich coatings left uncoated for a long period of time may form a surface layer of zinc salts, such as zinc oxide or zinc carbonate. These salts must be removed before over coating, otherwise intercoat adhesion may fail.

Zinc-rich epoxy coatings are used for:

- Tank linings
- Primer for high-performance systems
- Marine environments
- For repair of inorganic zinc

Surface preparation requirements, application procedures, and general inspection criteria for zinc-rich converted epoxy are much the same as for other epoxy coatings. Inspection criteria are shown in the table below.

Inspection Criteria for Zinc-Rich Epoxy

What might the inspector see?	What is the probable cause?	What can the inspector do?
Delamination of coating from substrate	Application to inadequately cleaned surface and/or surface with inadequate anchor pattern	Ensure surface preparation and surface/profile are as specified
Loss of film properties (hardness), sagging, not providing galvanic protection when cured	Failure to use agitated spray systems required to keep zinc uniformly dispersed in coating	Monitor application and ensure agitator in constant use to keep zinc properly dispersed
Uncoated peaks showing rust, rust bleed-through	Application over unusually deep surface profile, or DFT less than recommended	Ensure proper surface profile and adequate application. May need to rework zinc application.
Rust bleed-through; mudcracking; some coating peeling	Application thickness below or above that specified	Ensure proper application thickness

Polyester/Vinyl Ester Coatings

Polyesters/vinyl esters make use of polyester or vinyl resins to produce coatings with a relatively high DFT up to 2,540 μm (100 mils) per application. Polyesters/vinyl esters have excellent acid, solvent, water, and abrasion resistance. Vinyl esters also have very good alkali resistance.

Polyesters/vinyl esters are slightly more color stable in exterior exposure than epoxy coatings and are slower to chalk. Some types of polyesters have poor wettability over old coatings. These materials should be applied directly to the metal substrate. They require a higher surface profile (greater than 100 μm [4 mils]) than most other organic coatings.

During application, these coatings give off hazardous fumes containing styrene, and the painter should wear an air-fed respirator when working with them.

Eye protection must be worn when working around these coatings, because both the liquid and fumes can cause permanent damage to the cornea of the eye. Generally, the catalyst used with these type coatings is MEK peroxide, which can be dangerous and should not be allowed to come in contact with metal objects or containers.

The catalyst can decompose and burn spontaneously if not stored at lower temperatures and if not properly handled.

Mixing large quantities (e.g. >19 L [5 gal]) of material may be hazardous. The heat generated by the curing reaction can lead to spontaneous combustion.

Water can be used as a blanket to stop the reaction of the mixed coating, and any catalyzed materials discarded or not used should be placed underwater to prevent combustion.

Polyesters/vinyl esters suffer some shrinkage and unstable reactions. Typical uses include:

- Tank linings
- Glass- and fiber-reinforced plastic products
- Secondary containment

Inspection Criteria for Polyester/Vinyl Ester

What might the inspector see?	What is the probable cause?	What can the inspector do?
Material lumpy or gelled in container	Material has exceeded shelf life or has been subjected to hot storage conditions	Check shelf life of material and determine its usability. Ensure proper material storage
1. Applied coating has very brittle film 2. Applied coating has slow and/or poor cure 3. Material set up in pot, lines, and/or gun	1. High catalyst level shortens pot life, gives brittle film 2. Insufficient catalyst extends pot life, gives slow and poor cure 3. Excessive catalyst, curing too rapid, unable to apply before cure	In all cases shown, monitor mixing and application to ensure catalyst level is in accordance with the material requirements and the specification
No cure response; film if formed will have poor integrity	Catalyst is old, and past useful life	Ensure catalyst material within stated useful shelf life
Coating does not cure or has a poor cure	Coating applied when substrate and ambient temperature too low.	Ensure that substrate and ambient temperatures are within the ranges required by the material manufacturer and the specification. Generally, these materials can be applied as low as 15°C (60°F), but temperature must reach 21°C (70°F) within 24 hours after application for cure reactions to proceed properly.
1. Low cure response, and coating does not cure well into a hard film 2. Coating does not cover peaks of profile; rusting visible	1. Application of film less than 250 µm (10 mils) 2. Application of film less than actual profile	Since polyesters need mass to cure properly and require a profile higher than for most coatings, inspector must ensure correct profile, and proper WFT applied to obtain correct DFT
Poor film build and inferior cure	Use of incorrect thinner	Ensure only correct thinner used
Cure not proceeding	Poor ventilation or air movement across coated surface	Provide adequate ventilation or air movement to remove solvent atmosphere from wet coated surface

Two-Component Urethane Coatings

Catalyzed two-component urethanes come in two forms:

- Aliphatic
- Aromatic

[Note: The terms aliphatic and aromatic refer to the chemical structure of a compound. Aliphatic hydrocarbons comprise three subgroups (1) paraffins, (2) olefins, and (3) acetylenes. Chemically they are characterized by open or straight, or branched-chain arrangement of the constituent carbon atoms. One of the simplest compounds in this group is methane (CH_4); an example of a common aliphatic solvent is mineral spirits.

Aromatic hydrocarbons are chemicals that have a closed-chain six-carbon (hexagonal ring) group or structure as a principal part of the molecule. The simplest chemical of this family is benzene (C_6H_6) and some common aromatic solvents are xylene, and toluene.

Each of these two groups of hydrocarbons exhibit certain chemical properties that are reflected in the characteristics of coatings derived from them. Some of these properties can be seen in the following description of the urethanes.

Aliphatic urethanes exhibit:

- Outstanding abrasion resistance
- Good chemical resistance
- Hardness
- Flexibility
- Excellent exterior gloss and color retention
- Limited resistance in immersion

Aromatic urethanes exhibit many characteristics of the aliphatic group, except:

- They may be used in some immersion service
- They do not have good exterior gloss and color retention

The aromatic group is used for interior service and limited immersion, while the aliphatic group is widely used outdoors. A common system for offshore platforms consists of an inorganic zinc primer, epoxy intermediate coat, and aliphatic urethane as the topcoat.

The fumes generated by these materials are hazardous, and an air-fed respirator should be worn when working around them.

Aromatic urethanes are moisture sensitive, and care should be taken to keep moisture from the material during storage and application.

Typical inspection criteria are seen in the following table.

Inspection Criteria for Two-Component Polyurethanes

What might the inspector see?	What is the probable cause?	What can the inspector do?
Very short pot life; film cheesy—full of bubbles and pinholes; poor gloss	Moisture in lines or equipment	Monitor equipment to ensure no moisture enters application equipment
Poor adhesion of fresh coat to aged coat	Application to aged coat without proper surface preparation	Prepare surface (usually by scarifying) for over coating

Polyureas

Polyurea coatings are similar to two-component polyurethanes but with a different chemical makeup. Polyurethanes are made by reacting an isocyanate with a hydroxyl. Polyureas are made by reacting an isocyanate with an amine. Polyureas are 100%-solids two-component spray systems that react rapidly and cure very fast. They may be aromatic or aliphatic. They require heated plural-component spray equipment for application. Polyureas are relatively insensitive to moisture and have good adhesion to properly prepared surfaces. Temperature stability is good up to 177°C (350°F). Polyureas set in 3 to 5 seconds and can be walked on in as little as 30 seconds. Due to the fast set, polyureas do not have good wetting characteristics. Application costs are higher than some other coatings due to the special equipment required for application. Inspection criteria are much the same as for other two-component coatings.

Vinyl Wash Primer

Vinyl (polyvinyl butyral) wash primer is a modified vinyl vehicle with a rust-inhibitive pigment, such as zinc chromate mixed with phosphoric acid. This coating cures by chemical polymerization. It is used as a specialty primer to promote intercoat adhesion between the substrate and certain topcoats, such as:

- Alkyd
- Chlorinated rubber
- Vinyl
- Epoxy
- Urethane

These primers have a rapid dry and cure time, usually 15 to 20 minutes, and generally should be over coated within 4 to 8 hours. Vinyl wash primers should be applied in very thin coats to achieve DFT of 8 to 12 μm (0.3 to 0.5 mil) maximum.

A rule of thumb is: If it is clearly visible from a distance, such as 6 m (20 ft), it is too thick.

If the primer is applied too thick or if over coating is delayed past the recommended time, proper adhesion between the substrate and the topcoat will be compromised.

The specification may require a solvent rub test, as with all catalyzed coatings to determine the degree of cure.

Inspection Criteria for Vinyl (Polyvinyl/Butyral) Wash Primer

What might the inspector see?	What is the probable cause?	What can the inspector do?
Film dries, but no wash primer mechanism seems to occur	Failure to add converter to base before application	Ensure applicator adds the converter to base before application
Poor spray characteristics—will not displace moisture on damp surface. Material may agglomerate	Incorrect or no thinner used	Ensure correct thinner (if required) is used
Cohesive failure	Coating much thicker than the 12.5 μm (0.5 mil) maximum required.	Monitor application; ensure correct DFT of wash primer
Material gels immediately; gelled coating cannot be applied to surface	Catalyst added to base rapidly without stirring	Observe mixing; ensure catalyst added slowly to base with proper agitation
Delamination of topcoat from aged primer	Wash primer exposed to atmosphere longer than recommended	Ensure topcoat is applied within the required overcoat interval

Epoxy-Modified Phenolic Coatings

Two-component epoxy phenolic coatings contain a significant amount of reactive phenolic resin as well as an epoxy resin. The phenolic resin contributes to improved water and solvent resistance, but it detracts from sunlight resistance.

These epoxy phenolic coatings exhibit a very high cross-link density, which provides excellent resistance to a wide range of chemicals and solvents. These materials can be formulated to cure using an alkaline curing agent, or by using an amine-curing agent.

On exposure to the atmosphere, the epoxy phenolics yellow and chalk more rapidly than polyamide or polyamine epoxy coatings.

The increased solvent resistance requires that the recoat interval be more carefully observed. The major deficiency of this coating is its poor flexibility.

Epoxy phenolic coatings are used on:

- Tank interiors up to 500 µm (20 mils)
- Interior of pipelines
- Containment areas of nuclear plants

Inspection Criteria for Epoxy-Modified Phenolic Coatings

What might the inspector see?	What is the probable cause?	What can the inspector do?
Blistering ranging from very small, 250 to 375 µm (10 to 15 mil) to very large, 12.5 mm (500 mil).	Cross-linking not completed; coating placed in service (immersion) before sufficient cure	Observe curing; ensure coating cured before placing in service

Heat-Induced Polymerization Coatings

Epoxy-Phenolic Coatings

Heat-cured epoxy phenolic coating is very similar in composition to the two-component, chemically cured epoxy-phenolic type, except:

- It is a single-component material.
- It usually contains a higher proportion of phenolic resin.
- It requires a carefully controlled baking schedule to cure and form the protective film.

The heat converting or one-component epoxy-phenolic coatings are very resistant to:

- Water
- Solvents
- Chemicals

These coatings are used mainly:

- On the interior of down-hole oil well tubing
- For drill pipe
- On the interior of process vessels, including beer and storage tanks
- On the interior of cans, pails, and drums

Careful baking is required if the full protective properties of the coating are to be achieved. Inspectors are often required to monitor the baking schedule, which may range from:

- Setup bakes used to drive off solvents and start the cross-linking reaction 95°C (200°F) to final bake (to

complete cross-linking) ranging from about 165°C (325°F) to as much as 200°C (500°F)

Most of these coatings used to protect down-hole tubing require a substrate temperature of about 205 to 235°C (400 to 450°F) for about one hour for proper cure. Different formulations may require different times.

Shop evaluation (i.e., inspection) of cure often uses standard cure panels. As the coating cures, it changes color, generally toward brown. The degree of cure is somewhat reflected in the final color, and the standard panels are used to estimate the degree of cure.

High-bake phenolic coatings have poor flexibility, which limits the potential film thickness. Thin substrates or vibrating surfaces can cause problems for these coatings. Surface cleanliness and surface profile are important because the coating must achieve maximum adhesion to counteract the possibility of *letting go* due to expansion or contraction.

It is important to check the final coating for pinholes, since these coatings are used typically in critical exposures and/or in immersion environments.

Repair of deficient pieces may be difficult and always is a potential weakness in the coating. Defective pieces often are re-blasted and recoated.

Inspection Criteria for Epoxy-Phenolic (Heat Converting) Systems

What might the inspection see?	What is the probable cause?	What can the inspector do?
<ol style="list-style-type: none"> Cross-linking reaction starts in container, increasing viscosity and stickiness. Excessive thinner required for smooth film; severe pinholes during application. Difficult to achieve required DFT. 	Improper and/or lengthy storage. The phenolic component is heat reactive, and may gel in 3 to 6 months even at ambient temperatures.	<p>Inspect very carefully to ensure material has not begun to gel in the container.</p> <p>Monitor storage, suggest storing under refrigeration until needed for application.</p>
<p>Coating does not wet substrate, and crawls during set-up and/or final bake.</p> <p>Coating has blisters, holidays.</p> <p>Film cracks and delaminates.</p>	<p>Surface may not be clean and dry.</p> <p>Inadequate surface profile.</p> <p>These materials require a profile sufficient to prevent disbonding during final bake.</p>	Observe surface preparation to ensure required cleanliness and surface profile are achieved.
<ol style="list-style-type: none"> Unable to attain holiday free film. Blistering during set-up and/or final bake; some cracking of blisters Semi-circular cracking during final bake—no apparent blisters. 	Excessive film thickness.	Monitor application, and ensure coating applied to proper DFT.
Coating sags easily, with solvent left in film. Blisters develop during final bake; film has holidays, and coating is peeled.	Improper set-up bake.	Observe/monitor set-up and final bake procedures to ensure they are proper and as specified.
<ol style="list-style-type: none"> Coating is light colored Coating is very dark colored, film looks chalky, has blisters and is cracking Film has poor adhesion 	<ol style="list-style-type: none"> Insufficient final bake Final bake is excessive 	Carefully observe baking procedure and schedule to ensure they are as specified.
Blistering and bubbling	Inadequate drying time before baking, solvents not completely evaporated	Allow adequate drying time before baking (flash time).

Silicone Coatings

Silicone-based coatings frequently are used in high-temperature environments. They are available in two types:

- Modified
- Unmodified

Modified silicone coatings are produced by blending silicone with other resins. When silicones are applied to a work piece during erection or standby, these modifying resins hold the silicone in place. When the work piece is heated (baked), the silicone coating is heat-cured. These modifying resins burn off, and the silicone portion becomes effective.

This type of coating frequently is used when heat resistance in the range of 200 to 375°C (400 to 700°F) is required, generally on such structures as:

- Furnaces
- Boilers
- Petroleum cracking towers
- Stills

Unmodified silicone coatings frequently are used when heat resistance is required for up to 535°C (1,000°F) continuous exposure, or up to 650°C (1,200°F) intermittent.

Silicones may be applied directly to the clean, cool steel surface. Inorganic zinc often is used as a primer in services up to temperatures of 402°C (750°F). Organic resin-based primers should not be used; they are not formulated to withstand high temperatures.

Successful performance of silicone coatings requires a:

- High standard of surface cleanliness
- Proper bake schedule with careful control of the temperature and baking time

Silicones have limited abrasion resistance.

Inspection Criteria for Silicone Coatings

What might the inspector see?	What is the probable cause?	What can the inspector do?
Pop-ups in coating, film has poor integrity, and coating appears to be disintegrating	Poor application resulting in a heavy uneven coat	Ensure application is as required
Blistering and bubbling in service	Wrong heat (bake) schedule	Ensure proper heat schedule is followed
Aluminum pigment has dull, non-uniform, mottled appearance	Over agitation or mechanical mixing	Ensure mixing is done as required

Zinc-Rich Coatings

There are many formulations of zinc-rich coatings. SSPC has defined two major types of zinc-rich coatings in the standard SSPC-Paint 20.

Type 1-Inorganic

Type 2-Organic

Type 1-Inorganic coatings are further divided into three general types:

- Type 1-A—Inorganic water-soluble, post-cure
- Type 1-B—Inorganic water-reducible, self-cure
- Type 1-C—Inorganic solvent-reducible, self-cure

We will first discuss inorganic zinc and then organic zinc.

Type 1—Inorganic Zinc

Overview

Inorganic zinc coatings are composed of powdered metallic zinc, along with small amounts of other added metals, such as lead mixed into a complex silicate solution.

Inorganic zinc-rich coatings are distinguished by their large amounts (75 to 95%) of zinc dust in the dried film.

Some of the inorganic silicate vehicles used to produce inorganic zinc coatings include:

- Sodium silicate
- Potassium silicate
- Ammonium silicate
- Lithium silicate

Hydrolyzed organic silicates, such as ethyl silicate vehicles, also are used to produce inorganic zinc coatings.

In spite of the different starting points with different silicates, the ultimate reaction product on the steel surface is quite similar for each inorganic zinc coating, with the exception of the post-cure type coating. In the reaction process, silicic and polysilicic acids form and react with the zinc and other added metals.

Each vehicle, water-soluble, water-reducible, or organic silicate reacts with or hydrolyzes to form polymers with the silicic acid, and when the zinc is added to the system, a silica-oxygen-zinc (S-O-Zn) polymer is created.

This combination is very insoluble and forms a strong matrix surrounding the zinc powder particles to produce a coating. Silicic acid, a weak acid, reacts with both the zinc ions from the zinc and the iron ions formed from the reaction with the moisture on the steel surface, to form an

insoluble reaction product at the interface of the metal and silicate coating.

Coatings based on sodium, potassium, silicate, or ethyl silicate react as follows:

In the initial reaction the ingredients are concentrated as the solvent (organic solvent for solvent-based, water for water-based zincs) evaporates from the coating. This concentration brings the zinc and the silica compounds into close relationship and allows initial deposition of the coating on the steel surface.

In the second reaction, which takes place shortly after the coating is applied, the coating becomes insoluble when the zinc ions react with the silicic acid to form the initial zinc silicate.

The coating now is a solid, insoluble coating on the metal surface, but is not completely reacted. At this point, most of the coating is somewhat porous, largely because of the packing quality of the spherical zinc particles.

- Frequently, when inorganic zinc coatings are overcoated with organic coatings, within a short time after application the organic coating bubbles. This is due to the penetration of solvents into the zinc coating creating a vapor pressure that then causes the bubbling.
- The third part of the reaction occurs over a period of many days or even months, and is the continuing activity of carbonic acid formed by carbon dioxide and moisture in the air acting on and within the exposed zinc coating to complete the formation of the zinc-silicate matrix. (Note: This does not occur with a zinc that has been topcoated).

Inorganic zinc coatings continue to cure over a long period of time and become much harder and more abrasion resistant, and develop a greater adhesion to the steel surface. When exposed, they protect the steel surface by acting as a sacrificial anode, corroding in place of the steel.

Inorganic zinc coatings can be used alone as true one-coat systems, or as primers for many other types of organic coatings. When exposed to the atmosphere for any period of time, the inorganic zinc-rich coatings develop a passive film (much like the zinc from galvanizing) consisting of zinc carbonate and zinc oxide, which tend to inhibit further corrosion.

General Precautions

Surface Preparation

Inorganic zinc coatings require a high standard of surface cleanliness. All existing coatings or contaminants must be removed and the surface abrasive blast cleaned to NACE No. 1/SSPC-SP 5 (white metal) for immersion service, or to NACE No. 2/SSPC-SP 10 (near white metal) for atmospheric service. Some manufacturers have allowed preparation to NACE No. 3/SSPC-SP 6 (commercial blast) when atmospheric service is intended, but generally speaking, better surface preparation provides better long-term performance.

Mixing and Handling

Inorganic zinc-rich coatings should be mixed by mechanical agitation. These coatings should not be mixed by shaking, as this could cause rapid heating, resulting in gel formation, or in some cases, the container bursting due to the build up of internal pressure of hydrogen gas.

The zinc powder should be strained through a 30/60 mesh screen or a vacuum paint strainer. If more than 113 g (0.25 lbs) of zinc dust per mixed 4 L (1 gal) is removed by this 30/60 mesh screen, it is an indication of old or contaminated materials. In such cases, that container of material should be discarded.

Application

Generally, inorganic zinc coatings properly applied to the required DFT do not shrink while drying or curing like organic coatings do. Once applied, the inorganic material

follows the configuration of the surface. This is a major advantage when applying these materials over rough, pitted surfaces or over rough welds. These coatings, if applied too thickly, will shrink and mudcrack.

Features of Inorganic Zinc Coatings

The very strong, rock-like film and chemical adhesion of the inorganic zinc coatings form a base with outstanding friction characteristics. This means, for example, the coatings can be used for faying surfaces on bridges, towers, tanks, etc., when allowed by the specification.

The inorganic zinc coatings are unaffected by organic solvents and fuels such as:

- Ketone
- Aromatic hydrocarbons
- Gasoline
- Diesel oil and lubrication oil
- Jet fuel

These zincks also have good heat resistance and are relatively unaffected by temperatures up to, or even beyond the melting point (419°C [785°F]) of zinc.

Inorganic zinc coatings are widely used for:

- Power plants
- Chemical plants
- Oil refineries
- Transmission towers
- Bridges
- Offshore structures
- Ships

Types of Inorganic Zinc-Rich Coatings

Type 1-A inorganic post-curing vehicles are water soluble and include alkali-metal (sodium, potassium, lithium) silicates, phosphates, and modifications thereof. These coatings must be cured by application of heat or a solution of an acid-curing agent.

Since this type is water-soluble, it may be applied under cool or warm, but dry conditions, wherever the water can evaporate within minutes to two hours. After a couple of hours, the zinc tends to separate in the vehicle and makes a poor coating with little resistance.

The acid-curing agent, usually an acid amine phosphate, must be applied to the coating as soon as the water evaporates. A rain shower on a Type 1-A coating prior to application of the curing agent will break up the gel, rendering the coating useless.

This type of zinc coating is most effective when used as a true one-coat system without topcoats. If the coating is to be topcoated with an organic coating, the curing solution must be removed or neutralized by water washing.

Type 1-B inorganic self-curing vehicles are water reducible and include water-soluble alkali-metal (sodium, lithium, etc.) silicates, phosphates, and modifications thereof. These coatings cure when water evaporates from the film, and the zinc crystallizes by reacting with the carbon dioxide and moisture in the air.

They are most effective when applied under warm, dry conditions, which allows the water to evaporate quickly, leaving a hard metallic coating that becomes insoluble in water in a short time.

Over a period of days, months, even years, the coating continues to cure as the zinc reacts with the silicate in the presence of moisture in the air or on the coated surface. Some of these types of coatings require more humidity to cure than other coatings.

Over a period of time, and with continued exposure to atmospheric moisture, zinc carbonate and zinc hydroxide form on and within the coating to decrease any porosity and to develop the coating into a continuous film.

Type 1-C inorganic self-curing vehicles are solvent-reducible and include titanates, organic silicates (such as ethyl), and polymeric modifications of these silicates. These systems are primarily dependent upon moisture in the atmosphere to complete hydrolysis and form the polysilicate.

They are best applied under cool, reasonably humid (50 to 90% relative humidity) conditions since moisture from the air is required for a complete cure. They do not cure well or completely under hot, dry conditions; in such climates it may be necessary to spray the coating with water mist to achieve complete cure.

In the curing process, moisture reacts with the organic ethyl silicate, releasing ethyl alcohol as a byproduct. If this type coating is topcoated before completely curing, severe delamination could occur. One inspection method for assessing cure of this type coating is to merely scratch the surface and sniff to detect the odor of alcohol. If alcohol is detected, it may indicate incomplete cure.

In a sense, self-cure solvent-based zinks are self-inspecting regarding DFT. If the coating is applied too heavily, generally more than 125 μm (5 mils), it will mudcrack; if topcoated, the low shear of the film will allow delamination.

Since this type of coating is solvent-based, it is more likely to overspray under warm, windy conditions than water-based products.

Cure Tests

ASTM has published a solvent-rub test method for assessing cure of inorganic zinc coatings, ASTM D 4752, *Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc-rich Primers by Solvent Rub*. The test method defines rubbing a 2.5- x 15-cm (1- x 6-in.) test area with

the index finger using a solvent saturated rag, with 50 double-rubs, then provides a scale to assess the resistance of the cured coating.

A more subjective site test is often performed, in which the surface of the zinc silicate coating is scarred with the edge of a quarter or similar coin held perpendicular to the surface. The coating should show a bright, silver scar, and remain intact. If coatings are chipped and removed by the single stroke, then the cure is not acceptable.

Type 2—Organic Zinc

We have already discussed the most common zinc-rich organic coating type, zinc-rich epoxy. The use of other coating binders, while not common, can be found in some specialized uses.

Type 2—Organic vehicles include phenoxy-catalyzed epoxy, urethane, chlorinated rubber, styrene, silicone, vinyl, and other suitable resinous binders. The organic vehicles included in this group may be chemically cured or may dry by solvent evaporation. Under certain conditions, heat may be used to facilitate or accelerate hardening.

The chemistry in the formation of this type of zinc coating is quite simple compared with the complex chemical reactions of the various inorganic zinc coatings.

Basically, the organic zinc coatings are a mixture of zinc dust or metallic zinc pigment (typically 50 to 75% by weight in the dried film) in an organic vehicle, such as those noted above. Two requirements are essential for the effective performance of organic zinc-rich coatings:

- The zinc in the vehicle, in order to provide cathodic protection, must be in particle-to-particle contact or must contain a conductive filler such as iron phosphide to make an electrically conductive path through the organic matrix to the steel substrate.

If the organic vehicle surrounds the zinc and prevents particle-to-particle contact, the zinc cannot go into solution to provide cathodic protection.

- The organic vehicle or carrier for the metallic zinc pigment must be alkali resistant, because zinc, particularly in chloride environments, reacts to form a strong alkali which would adversely affect any alkali-sensitive resin or binder.

Generally organic zinxs are more easily applied than the inorganic zinxs. They are less porous and more easily top-coated with a variety of organic materials.

Inspection Criteria for Inorganic Zinc—Post-Cure Water-Soluble

What might the inspector see?	What is the probable cause?	What can the inspector do?
Coating does not cure or does not cure uniformly; coating still water-soluble, in streaks or totally	Failure to apply curing agent (wash coat) or curing agent not applied uniformly	Monitor application to ensure curing agent uniformly applied
Non-uniform cure; mudcracking; coating flaking in heavy areas; rust-bleed in thin areas	DFT above or below that specified	Monitor application to ensure DFT is as specified
Spot rusting, sagging, greater tendency to mudcrack	Failure to use all of zinc powder or powder not uniformly blended in vehicle	Monitor mixing to ensure proper amount of zinc powder is added and properly blended
Coating peeling, crawling, or fish eyeing	Contaminants on surface	Ensure surface cleanliness before coating
Peeling or loss of adhesion of intermediate or finish coats	Failure to remove curing agent before top coating	Monitor application to ensure wash coat adequately removed
Loss of film properties (hardness); sagging; some mudcracking	Failure to use agitated spray containers	Ensure agitation is used for mixing coatings throughout application
Rain on applied primer before application of wash coat	Coating softens; may completely wash off	Try to ensure primer is not applied when rain appears imminent
Coating softens; may wash off completely	Rain on applied coating before application of wash coat	Ensure coating applied under proper ambient conditions

Inspection Criteria for Inorganic Zinc—Self-Cure, Water-Reducible

What might the inspector see?	What is the probable cause?	What can the inspector do?
Poor adhesion to surface; coating easily removed	Surface not properly cleaned; contamination not totally removed	Observe surface preparation; ensure contamination is removed
Film will not cure; may become friable and/or powdery	Application when humidity is below required level	Ensure application only under required ambient conditions
Coating blistering, bubbling; film is very porous, and has poor integrity	Application to hot surfaces	Ensure substrate temperature within application limits of specified coating
Rust bleed-through, poor film integrity. Topcoats may not adhere	Not enough powder mixed or not mixed properly	Ensure proper amount of powder and proper mixing

Inspection Criteria for Inorganic Zinc—Self-Cure, Solvent Reducible

What might the inspector see?	What is the probable cause?	What can the inspector do?
Film not cured, is friable and powdery	Application when relative humidity is low	Ensure application when humidity level is adequate
Poor film formation and poor adhesion	Application over condensation on surface or under very warm, dry conditions	Ensure no condensation and ambient conditions proper for application
Product gels in pail, pressure pot, or lines	Premature cure because moisture enters equipment before application	Observe equipment; keep moisture out until material applied
Film is powdery and dry	Application in warm area with considerable air movement	Apply when ambient conditions are proper

Coatings that Cure by Hydrolysis

Moisture-Cured Urethane

Moisture-cured urethanes are one-package coatings, either clear or pigmented, and are available in aliphatic or aromatic form (most are the aromatic form).

Moisture-cured urethanes cure by reacting with the moisture in the air and require 30 to 80% relative humidity to achieve total cure.

These coatings have:

- Excellent flexibility
- Toughness with excellent resistance to chipping and abrasion
- Good acid, alkali, and solvent resistance
- Limited adhesion
- Some problems with package stability

Moisture-cured urethanes have limited pot life once the package has been opened. The coating inspector should be alert to any attempts to use coatings left over from the previous day.

These materials are used:

- For wood and concrete floors subjected to heavy wear and occasional strong chemical spills
- On offshore platforms
- As a topcoat for certain epoxy coatings

Inspection Criteria for Moisture-Cured Urethane

What might the inspector see?	What is the probable cause?	What can the inspector do?
Coating gels in container; bubbles and pinholes are visible in coating film	Aged coating exhibits excess thickness or has absorbed moisture before application	Ensure coating is within useful shelf life and has not prematurely absorbed moisture
Poor intercoat adhesion	Over coating aged film without abrading surface	Abrade or scarify surface before over coating

Waterborne Coatings

Waterborne coatings are highly desirable in industry, being preferred over solvent-borne coatings because of environmental concerns and legislation which has created VOC restrictions.

The protective coatings industry faces many changes as a result of recent legislation, particularly on the subject of Volatile Organic Compounds (VOCs). In this respect, the continuing development of waterborne coatings represents a significant step toward universal compliance.

Waterborne coatings are broadly defined as those materials that use water as part of the vehicle. Waterborne coatings can be organic or inorganic.

Water is probably the most common solvent, but is a relatively weak solvent. None of the commonly used natural or synthetic coating resins are soluble in water, unless specifically treated or modified.

With present-day coating technology, most generic coating types can be formulated as waterborne, water-soluble, or water-reducible coatings.

Waterborne coatings can be separated into two groups:

- Those using water-soluble resins. We will call these *water soluble*.

- Those using resins not soluble in water, but suspended in water (usually labeled *latex* or *emulsion coatings*). The resin is a separate phase of the coating vehicle. We will call these *suspensions*.

Coatings using Water-Soluble Resins

Organic coating resins, including alkyds, acrylics, and vinyl acrylics, can be modified chemically to be water soluble. Resins which have been modified to create the water-soluble form generally retain the characteristics of their solvent-borne cousins. Water-soluble acrylic coatings, for example, are used for their general toughness, good color, and for exceptional resistance to UV light, all characteristics which are typical of solvent-borne acrylics.

Waterborne inorganic coatings consist of inorganic silicate binders, such as sodium and potassium, dissolved in water. Once applied to a steel surface, the silicate binders react with the atmosphere to create an inorganic film.

Water-soluble and water-reducible inorganics will be discussed in the chapter on inorganic zines.

Coatings using Resins Suspended in Water

Water-suspensions are coatings in which water acts as a diluent or dispersant. Latex and emulsion coatings are probably the best known examples of water-dispersion coatings.

Latex materials are often called *latex emulsions*. Although latex coatings and emulsions are different, they have similar film-forming mechanisms. The terms *latex* and *emulsion* frequently are used synonymously in the paint industry.

Latex

Latex is a stable dispersion of a fine polymeric material, (such as rubber or resin) in water. The term *latex* was given to the first emulsion paints developed in the 1940s, and generally are used as house paints.

Synthetic latexes are made by emulsion polymerization techniques from:

- Styrene–butadiene copolymer
- Acrylate resins
- Polyvinyl acetate

Note: Emulsion polymerization is a polymerization reaction carried out with the reactants in emulsified form. Many copolymers, such as synthetic rubber, are made in this way.

Emulsion

An emulsion is a stable mixture of two or more *immiscible* liquids held in suspension by a small amount of emulsifiers. Common examples include milk, butter, and salad dressing.

Immiscible: descriptive of two or more fluids that are not mutually soluble.

Both latex and emulsion are liquid-phase materials, that is, a (liquid) dispersion or solution with distinct and mechanically separable portions:

- The major component is called the *continuous* or *external* phase.
- The minor component is called the *disperse* or *internal* phase. This component may or may not be uniformly dispersed in the continuous phase.

In milk, water is the major component and is therefore the continuous phase. Butter fat is the minor component and

is the disperse phase. In butter, fat is the continuous phase, and water is the disperse phase.

Emulsion coating resins may include:

- Polyvinyl acetates
- Acrylic resins
- Bitumens
- Water-based co-reactive coating types, such as epoxy

The technology used to create emulsion coatings is extremely complex, and is in a phase of rapid development.

Film Formation—The Drying and Curing Process

Emulsion coatings generally cure by:

- Coalescence
- Various co-reaction or polymerization reactions, depending on the type of material

Different types of waterborne coatings have different physical characteristics, but all of them must coalesce from the water dispersion and form a film. During this stage of film formation, the liquid phase, which is primarily water, evaporates, together with any organic solvent in the coating.

Generally, emulsions form a film by the process of coalescence. In this cure mechanism, water, then solvent, evaporate from the film, allowing discrete, liquid particles to move together on the surface. As the evaporation continues, these particles increase their contact and begin to fuse, or coalesce, into a somewhat continuous film. Evaporation of water and solvents continues until the film reaches its final state.

During the film-formation period, waterborne coatings are likely to be sensitive to water. For many materials, this means that they are unlikely to be reliable when applied in

a high-humidity environment (e.g., tropical shipyards), or in a cold, wet environment (North Sea oil platforms). The period of sensitivity may last up to a month or more after application, depending on temperature and humidity.

Co-Reactant Suspension Coatings

Epoxy emulsion coatings are, for the most part, two-component epoxy-polyamide systems, treated to allow suspension in water. Some diluents are added to the liquid-epoxy resin and the polyamide-curing agent.

These diluents lower the viscosity and aid coalescence of the material as water and solvents evaporate. As the epoxy and polyamide-curing agent coalesce, they begin a cross-link polymerization reaction that completes the cure.

The two-part epoxy and curing agent are packaged separately and, when mixed, have a reasonable pot life. Proper coalescence of the water-dispersed resin particles is essential to complete the cure process and, hence, for the full service life of these materials to be achieved.

If the atmosphere is hot and dry, the coating may dry too rapidly, with the result that the particles do not coalesce properly. If the atmosphere is cold and damp, the water evaporates sufficiently slowly that the resin particles agglomerate but do not coalesce properly. Then, proper cross-linking is not possible. Again, the coating is improperly cured and will not be effective.

For proper cure of these materials in atmospheric service, the temperature should be between 10 and 27°C (50 and 80°F) with a relative humidity between 30% and 60%.

Advantages

Some advantages of waterborne coatings include:

- Little or no odor
- Low VOCs (vehicle is mostly water)
- Ease of application and cleanup

- Relatively high flash point because of slow solvents used (water evaporates first, then the solvent)

Disadvantages

Some disadvantages of waterborne coatings are:

- Generally low gloss, except in electro-coats
- Must be stored, transported, and applied at temperatures above freezing
- Generally need low humidity (30 to 60%) for proper cure
- Film is less dense and more porous to water and ions
- May cause rust on surface in adverse conditions
- More expensive per mil per square foot than conventional solvent-reduced counterparts due to lower effective volume solids
- Strong polar solvents in some materials may cause lifting and peeling of previously aged coating
- Slower to develop cure than solvent-based coatings

Typical Uses

Waterborne coatings are widely used for atmospheric service in:

- Bridges
- Oil refineries
- Storage tanks
- Petrochemical plants, etc.

Some of the co-reactive types, such as epoxy, may be used on floors.

In the past, waterborne coatings were rarely appropriate for immersion service, but with improving formulations, some are now used in immersion service.

Most water-borne coatings formulations have been developed by modification of familiar resin types. Each resin was initially chosen for use in protective coatings for specific physical and/or chemical properties. In general, at this time the performance characteristics of waterborne coatings are unlikely to match the performance of their solvent-borne equivalents.

It is important to recognize that waterborne coating formulations are in a state of rapid development. They are likely to behave differently from the solvent-borne coatings they will ultimately replace.

Inspection Criteria for Waterborne Coatings

What might the inspector see?	What is the probable cause?	What can the inspector do?
Coating gelled or separated completely; suspension is destroyed	Coating exposed to freezing temperatures	Ensure gelled coating not used. Ensure material is not allowed to freeze
Coating sags or crawls; slow to dry; film not properly formed	Application at low temperatures (below 10°C [50°F])	Ensure application at warmer temperatures (above 10°C [50°F])
Coating smells bad; may contain gel-like particles; coating skins over	Liquid paint past shelf life; bacteria may have attacked anti-sag polymer	Ensure material is well within the stated shelf life. Do not allow paint past shelf life to be used.
Cracking, shrinkage	Excessive thickness may cause shrinkage and cracking	Ensure coating applied at recommended thickness
Liquid coating gels or kicks out	Addition of organic thinner such as xylol	Allow only recommended thinners be used
Coating streaking, running, or washing off substrate	Exposure to moisture (dew, rain, spray, etc.) before fully cured	Ensure coating not exposed to rain, spray, or dew



Level 2

Chapter 34

Specialized Coatings

Specialized Coatings

Introduction

We will discuss:

- Special coatings
- Corrosion coatings and coating inspection in specific environments and situations

The coatings that we will cover include:

- Heat-resistant finishes
- Antifouling paints
- Fireproof coatings
- Temporary protectives
- Polyvinyl chloride (PVC) dispersion
- Foams
- Chemical conversion coatings
 - Phosphating
 - Chromating
 - Anodizing

We will start with heat-resistant finishes.

As inspectors we may be called upon to inspect any and all types of coatings and applications. Heat-resistant coatings are used extensively throughout the industry.

Most organic coatings tend to degrade at temperatures around 65°C (150°F). Fluorocarbons and silicones have been found to be quite resistant to heat and are used for exposures up to 650°C (1,200°F). In addition to good

heat resistance these resins exhibit good chemical resistance. They are, however, quite expensive.

Most heat-resistant finishes require heat to cure. Often the coatings are applied and the structure is put into service. The coating cures as the service temperature is reached.

Obviously heat-resistant finishes are selected with regard to both operating temperatures and end-use requirements.

Antifouling Paints

Underwater surfaces are subject to attachment and growth of marine plants and animals. The resultant increase in resistance to movement results in increased fuel cost which can be quite expensive.

In order to prevent these growths, which are known as fouling, various methods have been tried. Special compositions, known as antifouling paints, have proven to be the most successful. These paints contain chemicals that are poisonous to marine plants and animals. Materials such as cuprous oxide, copper salts, mercury, arsenic, tin, lead, or zinc have been used. The use of most of these materials is now restricted due to the harmful effects on marine life.

A new range of antifouling compositions is being developed. Some of these are based on acrylic, vinyl, and synthetic rubber binders with organo-metallic compounds that form solid solutions with the binders. The poisons diffuse through the binder, maintaining a uniform concentration throughout the film. As poison is leached from the surface of the film, a fresh supply is diffused from deeper down. This process continues until the poisons are depleted. Research is also being done on ablative type coatings using modified silicone resins.

Periodic renewal of antifouling coatings is essential and is a major feature of dry-docking programs for commercial shipping.

Research and development continues in this field to try to overcome the problem of marine growth on seagoing vessels without harming the marine environment.

Fireproof Paints

Before going further, the distinction between the terms fire-inert, flame-retardant, and fire-resistive needs to be made.

A fire-inert material will not support combustion (burn).

A flame-retardant material slows the rate of burning across a surface but may itself burn.

A fire-resistive material retards heat penetration through a substrate.



Figure 34.1: Intumescent Epoxy Smoothing with Roller

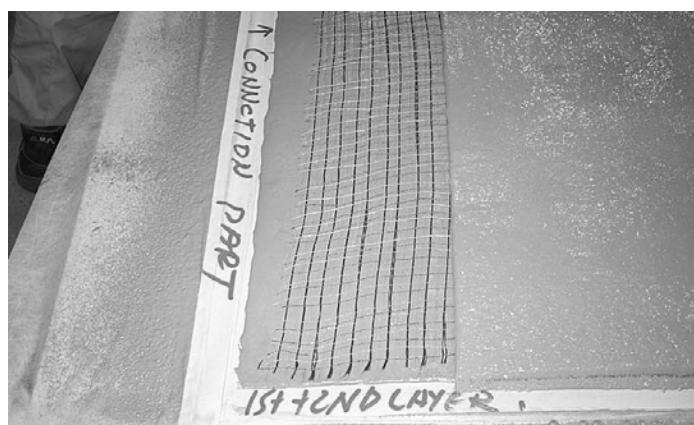


Figure 34.2: Middle Layer of Reinforcement in Epoxy Intumescent Coating



Figure 34.3: Taking DFT measurements of PFP Epoxy Epoxy Intumescent Coating

Fire-inert paints simply use specially formulated resins as binders and pigments that will not support combustion.

Flame-retardant paints contain pigments that will retard the spread of fire by:

- Providing a heat barrier
- Forming a barrier that excludes oxygen
- Evolving noncombustible gases
- Forming a thermally insulating layer of foam; that is, an intumescent coating

It is important to note that intumescent paints are flame-retardant and not fire-resistive.

The above paints are tested and given a rating based upon the lowest time segment during which the tested unit withstands fire exposure prior to reaching the failure point. Ratings are published for 1, 2, 3, and 4 hours.

Temporary Protectives

Temporary protectives, also known as thin-film protectives, are coatings that are used to provide temporary protection to the surfaces over which they are applied. Examples are:

- Machined surfaces
- Motor shafts
- Coiled steel
- Wire, bar, and cast

The primary requirements of a temporary protective are that it be easy to apply and easy to remove.

Some types of temporary protectives are:

- Lubricants
- Oils
- Paint coating systems

Polyvinyl-Chloride Dispersions

Polyvinyl-chloride dispersions find wide use for products manufactured from pre-coated strip. Some properties of these coatings are:

- Excellent salt-spray resistance
- Excellent humidity resistance
- Excellent abrasion resistance
- Excellent resistance to fats and oils

They have good tolerance to deep drawing and to severe forming.

The polyvinyl-chloride-dispersion-type coatings may be categorized as either organosols or plastisols. Organosols may be thermoplastic or thermoset. Plastisols are thermoplastic. Both types exhibit low solvent resistance and chalk upon exterior exposure.

Organosols are used on cold-rolled steel, black plate, hot-dip galvanized steel, electrogalvanized steel, hot-dip aluminum-coated steel, tin plate, and aluminum.

Plastisols are used on the same type substrates in the appliance industry.

Fluoropolymer Coatings

Fluoropolymer coatings are commonly referred to by their trade names such as KynarTM (PVDF), HalarTM (ECTFE), and TeflonTM (PTFE). The temperature and chemical resistance of fluoropolymers increases as the fluorine content increases, with PVDF on the low end and PTFE on the high end. The chemical names of the various coatings are as follows:

PFA—Per Fluoro Alkoxy

PTFE—Polytetrafluoroethylene

FEP—Fluorinated Ethylene Propylene

ECTFE—Ethylene Chlorotrifluoroethylene

PVDF—Polyvinyl Fluoride

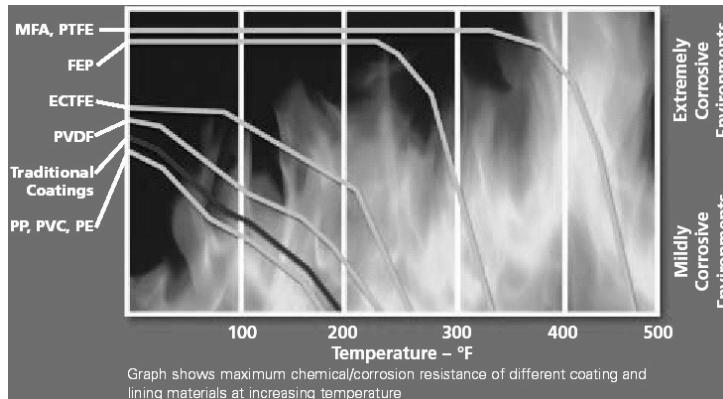


Figure 34.4: Temperature and Chemical Resistance of Fluoropolymer Coatings

Fluoropolymers exhibit good flexibility, solubility, gloss, and hardness, and excellent weather resistance. Fluoropolymers are often used as coil coatings and metal cladding on roofs and walls. They exhibit good adhesion on plastics, copper, aluminum, galvanized steel, concrete, and glass. They are commonly plant-applied under strict quality controls. The coating inspector should read the

manufacturer's product data sheets and application instructions very carefully when performing inspection on fluoropolymer coatings.

Additional Special Coatings

In addition to the coatings described here, several others should be mentioned:

- Foams
- Chemical conversion coatings
 - Phosphating
 - Chromating
 - Anodizing

Foams

Foaming formulations, among the most common of which are the epoxy, urethane-based, or silicone systems, can be sprayed to required thicknesses on properly prepared surfaces. Foams are used for a variety of purposes, including:

- Thermal insulation
- Soundproofing
- Joints at girth welds on weight-coated pipe.

The density of foams varies, but is usually within a range of 16 to 240 kg/m³ (1 to 15 lbs/ft³).

There are open-cell foams and closed-cell foams. Open-cell foams are like a sponge: they will absorb water and other liquids. Closed-cell foams can be buoyant and do not absorb liquids as readily as open-cell foams.

Some foam formulations may produce potentially hazardous byproducts such as nitrosamines, isocyanates, and formaldehyde. Safety rules should be observed.

Chemical Conversion Coatings

There are three types of chemical conversion coatings that should be mentioned very briefly:

- Phosphating
- Anodizing
- Chromating

Phosphating

Phosphate coatings are applied by immersing the object to be coated in a hot bath of the coating material, although they may be applied cold.

The three principal phosphating compositions—iron, zinc, and manganese—have phosphoric acid as their active ingredient.

The phosphoric acid interacts with the substrate to produce a surface layer that consists almost entirely of a crystalline complex of the phosphoric acid, iron, zinc, or manganese component.

The thickness of the surface layer is determined by the bath composition, temperature, and length of immersion.

Anodizing

Anodizing, or anodic oxidation, produces an oxide coating on the base metal by electrolytic action in a suitable solution. The metal being coated is the anode. Aluminum is the most frequently anodized metal.

Anodizing is done to enhance the corrosion-resistant qualities of the metal and to impart decorative effects.

Chromating

The addition of chromates to many corrosive liquids reduces or prevents corrosion attack on metals. There are some restrictions on the use of chromates.

Chromate treatments are most often applied to aluminum and steel.

What are the responsibilities of the coating inspector in regard to these specialized coating applications?

- Read and understand the specifications.
- Make yourself familiar with the coatings and the process.
- Conduct all tests required by the specification or owner.
- Ensure that the specifications are followed.
- Record and document.



Level 2

Chapter 35

Specialized Applications

Special Shop Application Methods

Introduction

This section deals with some methods of coating application that are perhaps not ones which the typical coating inspector is likely to come across, like the various spray methods discussed in earlier courses.

These application methods include:

- Dip
- Flow
- Flood
- Barrel
- Curtain
- Roller
- Electrocoating

The two most primitive methods of applying liquid coating to a surface are either to dip the article into a container of paint, or to pour the paint over the article and allow the surplus to drain off. Both these methods are surprisingly in common use.

Dipping

The simplest method is to immerse the article totally in the paint in a suitable container, withdraw the article, and allow the excess paint to drain off. The paint must be thinned down so the solids content is low, resulting in a thin dry film.

In many cases, however, dipping paints become more viscous than they would be if used in a spray operation. The rate of withdrawal of the dipped article must be

constant. To ensure that it is, some mechanical device is used.

Paints for dipping should be especially formulated for this method of application. A slow-drying oil paint will produce runs and sags, while a paint that dries too fast will not flow properly and may skin over in the tank.

The shape of the work piece is also very important when considering dip application. Obviously, an article with many recesses will retain paint in these areas. In the motor car industry, this problem is overcome by rotating the whole car body, mounted on a giant spit, while it is in the dipping tank.

Articles commonly coated by dipping include bar joists, automobile bodies, angle iron, wrought iron fencing, etc.

Flow Coating

Flow coating is a modification of the dipping process. In this case, work pieces are carried by conveyor through an enclosed chamber containing suitably placed low-pressure jets which spray them with paint. Work-pieces then pass into a solvent chamber where the solvent vapor/air mixture conditions are controlled to give good flow and early setting of the film. Paint drainings from both chambers are returned for reuse.

Flood Coating

Flood coating is a technique used for the coating of large complex work-pieces, with inaccessible areas. In principle, paint is pumped over the article so that it is completely flooded and the excess is allowed to drain into a reservoir, where it is filtered and returned to the main reservoir for reuse.

As in the case of dipping, careful adjustment of the paint viscosity is necessary to insure proper film thickness.

Flood coating is primarily used for large transformers that are too large and too heavy for dipping or flow coating.

Curtain Coating

Another flow method used in large-scale production is called curtain coating. In this case, the work-piece is placed on one conveyor, then passed through a curtain of paint on to a second conveyor. For any given paint, the applied film thickness is dependent upon the speed of the conveyor and the width of the paint curtain.

Solvent vapor is lost, so regular additions of thinners are necessary to maintain the correct viscosity. Production rate is very high and coating utilization is very good, since there is little loss of material.

Curtain coating is used on wide flat stock such as tennis table tops and wood panels.

Barrel Coating

From the coating of large sheets of flat material, let us turn to the coating of very small articles such as buttons, screws, clips, stress studs, etc. These are coated by barrelling, or barrel coating.

The articles are loaded into a rotatable barrel inclined at about 45° and the calculated quantities of paint and thinners are added. The barrel is then rotated until all the articles are coated over their whole surface. The barrel has a facility for tipping, rather like a concrete mixer.

After sufficient time to ensure complete coating, warm air is blown in to remove the solvent. The articles are then tipped out on to a tray. They are then allowed to air dry or they are baked according to the type of paint used.

The speed of barreling is usually 20 to 40 revolutions per minute. Speeds in excess of this will cause the articles to stick together by centrifugal force.

Roller Coating

Roller coating is a process specific to the application of high viscosity paints. The process is very similar to printing, in that the coating is transferred to the surface to be coated by means of a roller which is itself fed with paint from a feed roller. This application method is only suitable for flat surfaces such as sheet or strip.

Roller coating machines are designed to coat either one side only or both sides of the sheet simultaneously. The production rate of roller coating is extremely high and it is, therefore, quite economical.

Coil Coating

An important development of roller coating is the process known as coil coating. This is used for large volume coating of raw material such as steel, galvanized steel, and aluminum, supplied in the form of coils.

The metal is received by the coater in the form of a coiled continuous sheet. The metal is then cleaned, passivated, painted, baked, and recoiled in one continuous operation at speeds up to 400 feet (120 meters) per minute.

The coil-coated sheet is used for a wide range of fabricated products such as roof and side cladding sheets, kitchen and office furniture, and domestic appliances. The applied coatings must be of very high quality to stand up to the subsequent stamping and pressing operations required to form the end product.

Electrophoretic Painting

Another interesting method of paint application in large volumes is the process known as electrophoretic painting, or electropainting as it is commonly known. The process in its simplest form consists of passing an electric current through a bath of water soluble paint so that the paint is

deposited onto the article by a process similar to, but much more complicated than, electroplating.

There are three mechanisms involved in this process. The first is electrophoresis, or movement of charged molecular size particles. When these particles arrive at the electrode of opposite charge, their ion charge is given up to the electrode, a process known as *electrolysis*.

Finally, water is squeezed out from the organic molecule on the electrode, under the influence of the electrical potential, a process known as electro-osmosis. The cumulative effect of these three processes is termed electropainting.

Electropainting has gone through several development stages since its conception as coating technology evolved. Today's systems utilize cathodic, rather than anodic, deposition resulting in a higher quality finish. The deposited film is very uniform and the solids are around 90% due to electro-osmosis even though it is deposited from a bath containing only 10% to 15% solids.

Electro-deposition is used in the automobile industry, steel furniture, tractor sheet metal, aluminum windows, dust control equipment, aircraft components, refrigerator bodies, etc.

Advantages of electro-painting include:

- Very high efficiency
- Absence of toxic solvents and fire hazards
- Uniform coating with excellent coverage of edges
- Good throwing power into less accessible areas

Inspection Issues

Inspection issues for the above application methods include:

- Surface preparation

- Viscosity control
- Correct solvent
- Proper mixing
- Proper equipment
- Proper cure
- Proper handling

Discussion

Have any of you been involved with any of these methods?

What are the inspection points you look for when these operations are performed?



Level 2

Chapter 36

Coating Survey

Coating Survey

A Coating Survey is a task performed in an organized, rational manner, to gather information about the condition of equipment, plants (i.e. facilities) or structures.

To be meaningful, it should be performed by knowledgeable individuals, and should provide information that can be used by the company for the purpose for which it was intended.

There is often a need to perform coating surveys. The economic climate and the rising pressure to preserve assets leads to increased emphasis on maintenance. At the same time, the cost of maintenance must be kept to a minimum, which requires careful planning.

Management groups, particularly in large companies, are aware of the need to develop appropriate long-term strategies for the benefit of the company. Painting is a major maintenance item, and can account for huge annual expenditures.



Figure 36.1: Coating Surveys Provide Baseline Information that Allows Planning to Proceed

While some companies have been haphazard in their approach to painting in the past, there is an increasing

recognition that planning and performance monitoring can be beneficial to the company.

Coating surveys are often commissioned to provide the baseline information that allows planning to proceed.

Another change that has caused companies to look more closely at their facilities is the increased attention paid to safety, both for the workers and the public. Accidents caused by corrosion, which are by no means rare, lead to significant loss of profit, dissatisfaction in the work force, and bad publicity.



Figure 36.2: Production Plant

Coating surveys may be conducted to evaluate the condition of existing coatings on:

- Individual pieces of equipment
- Structures
- Ships
- Tanks, pressure vessels, rail cars
- Offshore platforms
- Processing units
- Entire production plants, manufacturing facilities, etc.

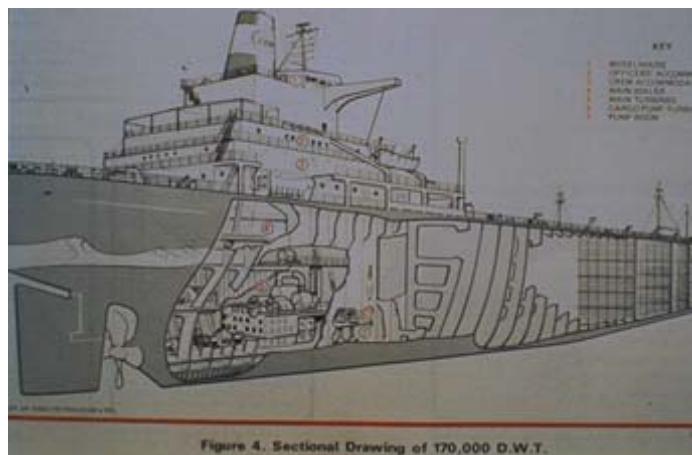


Figure 36.4. Sectional Drawing of 170,000 D.W.T.

Figure 36.3: Coating Surveys May Be Mandatory

In some cases, coating surveys may be mandatory. Ships, for example, must be inspected at regular intervals to comply with class regulations, and thus maintain their insurance rating. Offshore platforms are treated in the same way.

Objectives of Survey

What, then, is a coating survey *intended* to achieve for the company that has commissioned it?

Knowledgeable management should establish the objectives and goals of the survey process. The coating survey may:

- Evaluate the existing coating
- Judge the overall appearance of the facility
- Provide enough information to allow budgets to be calculated for proposed remedial work
- Consider the need for environmental compliance

Who performs coating survey?

Coatings surveys are performed by knowledgeable individuals. It is important that the surveyors possess the skill to follow the survey plan and gather meaningful information. The individuals may be a:

- Certified NACE Coating Specialist
- NACE-Certified Coating Inspector—Level 3
- Coating inspector, not Level 3 but qualified by field experience
- Coating manufacturer's technical representative with adequate field experience
- Maintenance Engineer with extensive knowledge of the plant or facility

Ideally, a coating survey is conducted by team effort. If the team leader is suitably qualified, then some of the support members may be required only to work with clearly defined tasks, and extensive individual skills may not be required.

The steps in the survey process may include:

- Conducting the survey gathering all data according to the survey plan
- Organizing the data gathered according to structures, units, etc., and analyze the data
- Looking for trends or patterns of coating performance (or failure)
- Summarizing the data and ensure that they are accurate, factual and correspond to reference standards used
- Preparing plans for performing the maintenance work required, based on the survey results



Level 2

Chapter 37

Specialized Tests and

Test Equipment

Specialized Tests and Test Equipment

Thus far in the Coating Inspector Program, we have explored tests and test equipment that a coating inspector may expect to encounter in the field.

Now we will briefly review some tests frequently performed in the laboratory. This is to provide you with some idea of the equipment that might be used for special purposes in coatings being formulated by the manufacturer, for example, or on samples collected during the course of a failure investigation.

Tests for coatings to be reviewed are:

Optical properties that include:

- Color
- Gloss
- Hiding power

Mechanical properties such as:

- Hardness
- Abrasion resistance
- Adhesion
- Flexibility

Special laboratory instruments including:

- Atomic Absorption/Emission (AA/AE) and Induction Coupled Plasma (ICP) Spectrophotometers
- Gas Liquid Chromatographs (GLC)
- Infrared Spectrophotometers (IR and FT-IR)
- Differential Scanning Calorimeters (DSC)

Optical Properties

Optical properties of coatings include color, gloss, and hiding power.

Color

The prime responsibility of the coating inspector regarding color is to ensure that the coating being applied is the color specified. The inspector should be aware that there is a wide variety of tests relating to color that have been designed to measure various properties of a coating's color including:

Permanence

This is the ability of a color to resist change due to exposure to the environment. The color is measured before and after exposure to a particular environment, such as UV radiation.

Metamerism

Metamerism is the phenomenon exhibited by a pair of colors that match only under a particular light source. They are often called a metameric pair. A color sample of a coating may appear different under different types of light (sunlight, fluorescent, tungsten light bulbs, etc.). In addition, different pigment systems react differently to light sources, so that samples of color with different pigment systems that appear to match under sunlight, for example, may appear entirely dissimilar under another type of light, such as fluorescent. ASTM D 4086, *Standard Practice for Visual Evaluation of Metamerism*, describes visual methods for detecting metamerism and for estimating the magnitude of a metameric color difference.

Goniochromatism

Goniochromatism, also called "Flop" is the phenomenon exhibited by a coating which changes color when the angle of illumination, or angle of viewing, is changed. This effect is often seen on high-end automobile finishes.

Specialized equipment has been developed to evaluate matches of these types of colors to ASTM Standard E 2175.

Color Definition

In the United States, colors are usually defined by three numerical coordinates: L, a, and b. This is known as the CIELab system. Differences between two shades of color are computed and quantified as delta E (ΔE). For example, a painting specification for a large project may limit shade variation between batches of topcoats to a maximum of five ΔE CIELab Units.

Similar numeric systems for defining colors exist in other parts of the world; for example, the Munsell system is widely used in Europe.

Color Spectrophotometers

These instruments, which are often called “color meters,” can measure the reflectance, transmission, or absorption of color of a coating. The instrument optics are either coupled to an external computer or to a microprocessor embedded in the instrument. They may be large bench-top units as used in laboratories and in retail paint outlets for matching paint colors to customer requirements, or small, hand-held instruments that can be taken into the field by an inspector.



Figure 37.1 Spectrophotometer

The larger instruments have multiple types of light sources that comply with different published standards. The light is reflected from the coated specimen, focused onto a diffraction grating and then onto a band of photoelectric sensors that determine the intensity of each wavelength of the reflected light in the red to violet visible region.

These instruments can give a readout defining a color by either CIELab or Munsell values and can compare one color against another. They can also present a color spectrum plotting absorbance versus wavelength. Metamerism can be detected by making measurements using different light sources.

Instruments exist that determine color by the tristimulus method in which light is shone onto the coating through three different-colored filters and the color is computed from the reflected energy of each light color. The development of low cost microelectronics has resulted in the spectrophotometers becoming the preferred instruments.

If the inspector in the field is required to evaluate a match of a sample to a standard, then, without access to a hand-held instrument, he/she should view the color outdoors under indirect *north* light. This may not exactly replicate a standardized *daylight* light source; however, it should be close enough to help the inspector make a fairly accurate field evaluation.

Gloss

Gloss is the *ratio* of light reflected from the surface to light incident on the surface, that is, it is a measure of how well a surface functions as a mirror.

Trade practice recognizes various stages of increasing gloss using the following terminology:

- Flat (matte), practically free of sheen
- Eggshell
- Semi-Gloss



- Full Gloss

Equipment is available for use in the laboratory as well as in the field for measuring the gloss of a coating.



Figure 37.2 Portable Gloss Meter

Gloss is measured quantitatively with an imaginary value of 100% for a perfect mirror. Gloss meters must be calibrated against at least two known standards. Typically, two or three standard plates will be supplied with the instrument having gloss values of about 96%, 50%, and 10%.

Meters for measuring gloss of paints are generally set for angles 20°, 60°, and 85° to normal, or combinations thereof. Measurements at 85° are significant primarily for paints of very low gloss.

Measurements at 60° are significant for all gloss levels, while measurements at 20° are useful for finer distinctions among high-gloss finishes, generally in the OEM category.

When making a gloss test, the inspector, or tester, should conduct the test at the specified angle of incidence, and this angle should be stated in reporting the test results.

Gloss may be affected by:

- Smoothness and uniformity of film
- Moisture on the surface

Hiding Power

Hiding power is the ability of a coating to hide or obscure a surface over which it has been applied uniformly.

Several methods for testing and evaluating hiding power have been developed. Perhaps the most common method employs a chart with lines partially black and partially white (or black and red). A paint film applied over this chart gives a visual evaluation of the degree of hiding.



Figure 37.3 Hiding Power Check Pattern

If a measurement of the *reflectance* of the film over the black portion is divided by the measurement of *reflectance* over the white portion, the contrast ratio (opacity) is obtained.

Mechanical Properties

Hardness

There are several methods available for measuring hardness of a coating. The method selected usually depends on the type of material, the particular circumstances, and the specification requirements.

The apparent or measured hardness of a coating film may be influenced by:

- Film thickness
- Service conditions
- Substrate hardness
- Temperature
- Degree of cure

The hardness of a coating film, as distinct from its substrate, is defined as its ability to resist cutting, indentation, or penetration by a hard object.

A coating is considered hard if it is not easily scratched; however, the trend seems to be toward the increasing use and adaptation of the indentation hardness test as a measure of the hardness of a coating.

Some methods of determining hardness of an organic coating include:

- Scratch
- Pendulum rocker
- Indentation
- Impressor

Scratch hardness tests indicate the measure of coating hardness based on scratching the coating film with a pointed instrument, under pressure. The ASTM D 3363 pencil hardness test describes this test.

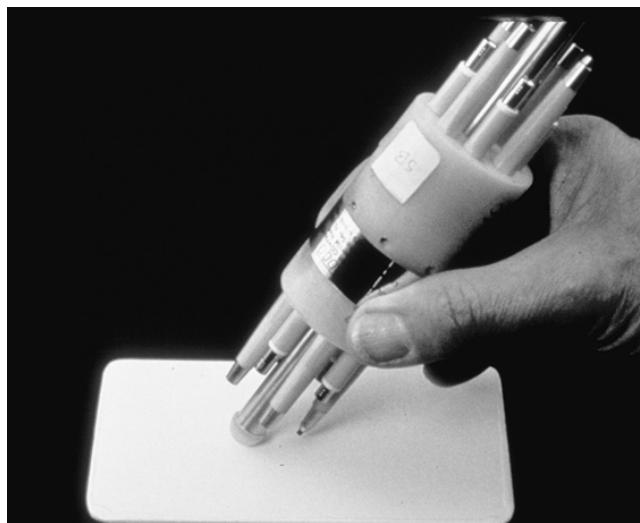


Figure 37.4 ASTM D 3363 Pencil Hardness Test

In the Pendulum Hardness test, either a König or a Persoz pendulum is set into motion on a test panel prepared with the subject coating. The pendulum is made to swing and the time for the oscillation amplitude to decrease by a specified amount is measured. The shorter the damping time, the lower the hardness of the coating. ASTM D 4366 describes this test.

The Sward Rocker is one of the best known, and widely used and copied, instruments for measuring hardness of an organic coating. The rocker is set in oscillation (rocking motion) on the test specimen. The number of complete oscillations multiplied by two gives the hardness value. ASTM D 2134 describes this test.

Indentation hardness is the resistance of a material to indentation (penetration). In this procedure, a loaded indentor presses into the surface of the organic coating at right angles to the coating. ASTM D 1474 describes Knoop and Pfund indentation tests. Pendulum, rocker, and indentation hardness tests are laboratory test procedures.

Impressor hardness has been described this week. The instrument used for this test on fiberglass-reinforced organic materials is the Barcol Impressor Hardness Tester. Shore hardness testers may be used on elastomeric coatings and linings.

Abrasion Resistance

Abrasion resistance is related to other properties of a coating including:

- Hardness
- Mar resistance
- Elasticity
- Toughness
- Thickness

Abrasion resistance is a complex combination of physical properties. It is not surprising that several test methods and instruments have been developed to measure abrasion resistance of a coating.

Abrasion resistance is the ability of a coating to resist being worn away and to maintain its original appearance and structure when subjected to rubbing, scraping, or erosion.

Some difficulties in testing for abrasion resistance are in finding tests that are:

- Equivalent to the service condition
- Reproducible from operator to operator, lab to lab, and equipment to equipment

We will mention two methods that appear to meet the above criteria, those being Falling Sand and Air Blast.

We will also look at a third method using the Taber Abraser, which is commonly used and has been found to produce satisfactory lab results.

Falling Sand

The falling sand method is described both by ASTM and United States Federal test methods. Various abrasives have been used for this test procedure, but the ASTM procedure requires the use of a particular grade and type

of silica sand, which is available from only one source in the United States. ASTM D 968 describes this test.

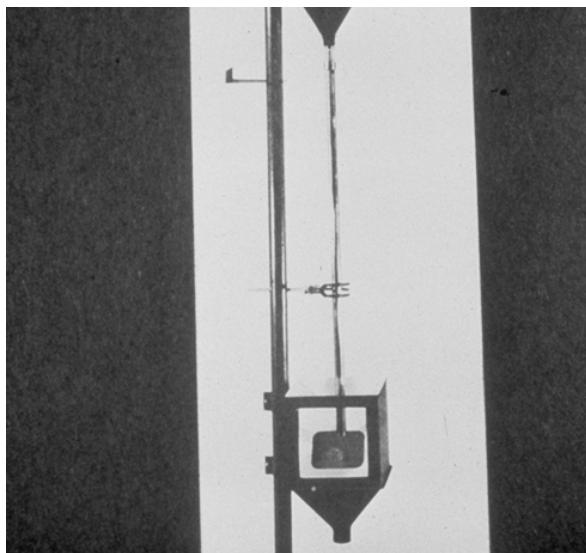


Figure 37.5 ASTM D 968 Falling Sand Test

Abrasion resistance of the coating is expressed in terms of volume of abrasives (liters of sand) required to wear through a unit thickness of coating when the abrasive falls from a specified height through a guide tube. The method is extremely laborious except for relatively soft, thin-film coatings, and is too costly to be practical for most modern protective coating systems.

Air Blast

In this method, an abrasive under the action of a controlled stream of air, is allowed to strike a coated panel until the substrate is visible. The amount of abrasive used per unit of film thickness is reported as the abrasion resistance of the coating. ASTM D 658 describes this test.

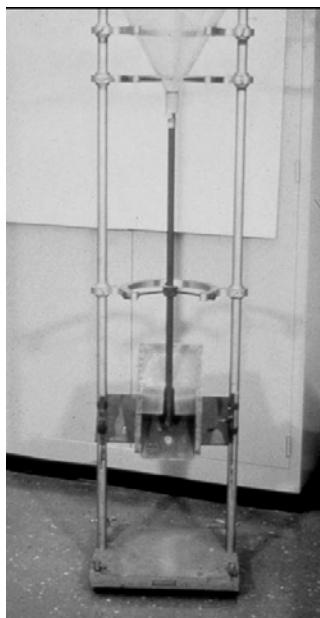


Figure 37.6 ASTM D 658 Air Blast Abrasion Test

Taber Abraser

This method (ASTM D 4060) of measuring abrasion resistance is well recognized by the coatings industry and is widely specified.



Figure 37.7 ASTM D 4060 Taber Abraser Test

The reproducibility of this test is relatively poor and the average of at least three separate tests should be used. In this test, the coating is applied at a uniform thickness to a flat, rigid panel. After the coating cures, the panel is:

- Weighed
- Placed on a Taber Abraser where it is abraded by rotating the panel under weighted abrasive wheels
- Reweighed

The type of abrasive wheel to be used and required weight loading must be specified. Abrasion resistance may be expressed as either:

- Wear index—1,000 times the loss in weight in milligrams per cycle
- Weight loss—loss in weight in milligrams at a specified number of cycles
- Wear cycle per mil—the number of cycles of abrasion required to wear a film through to the substrate per mil of film thickness.

Adhesion

Adhesion is “the state in which two surfaces are held together by interfacial attraction, which may be due to either chemical or short-range physical forces.”

In a more practical sense, adhesion may be defined as the force required to remove a coating.

Two test methods of interest to the coating inspector are:

- Tape pull-off (ASTM D 3359) X-cut and Cross-Hatch
- Portable tester, dolly pull-off (ASTM D 4541)

Flexibility

Flexibility is the degree to which a coating, after drying/curing, is able to conform to movement or deformation of its supporting surface, without cracking or flaking.

Flexibility of a coating is not necessarily a constant characteristic of a specific coating film and it may be affected by:

- Substrate
- Humidity
- Temperature
- Strain rate
- Age of coating

Coatings should be flexible enough to withstand splitting or cracking in service following shrinkage of the film or movement of the substrate due to certain service conditions.

Flexibility is particularly important when flat stock is coated before stamping in assembly-line procedures.

Flexibility may be tested in several ways. One of the most familiar is bending a coated panel over a mandrel as illustrated on this slide.

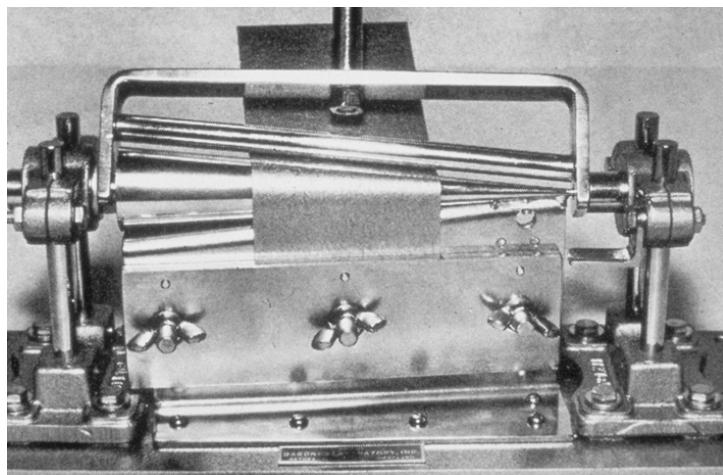


Figure 37.8 Mandrel Test for Flexibility

Special Laboratory Test Instruments

There are some sophisticated tests and test equipment that may be encountered by the coating inspector, particularly if involved in the investigation of coating failures.

In sending samples of coatings to the lab, the inspector should provide the lab with as much specific information as possible. Unlike laboratories shown on popular

television crime series, laboratory instruments do not allow the technician to simply put a sample into them and conveniently receive a printed answer in a matter of seconds. Most instruments require frequent tuning and calibration. In many cases samples require laborious preparation before the instrument can analyze them. Instrument output may require expert interpretation.

Information provided to the laboratory should include the following:

- The identity of the materials to be analyzed

The inspector should ensure that the samples are properly packed and labeled. A chain-of-custody form should accompany the samples. A copy of this should be retained by the inspector.

- The type of analysis required

For example, leachable lead in spent abrasive. Type and concentration of retained solvents in coating chips. Generic identification of coating type.

- Expected concentrations or concentrations of interest

For example, lead in paint is of interest in parts per million but in potable water this changes to parts per billion. This enables the lab technician to select the best instrument for the job.

Generally, the lab technician at the testing lab will have access to several sophisticated instruments and should be able to perform a number of special tests for the inspector.

Some of these test instruments are:

- Atomic Absorption/Emission (AA/AE) and Induction Coupled Plasma (ICP) Spectrophotometers
- Gas Liquid Chromatographs (GLC)
- Infrared Spectrophotometers (IR and FT-IR)
- Differential Scanning Calorimeters (DSC)



The following brief discussion will serve to acquaint you with these instruments, in the event you encounter them during the course of your inspection activities.

Atomic Absorption/Emission (AA/AE) and Induction Coupled Plasma (ICP) Spectrophotometers

These instruments are used to quantify concentrations of metallic compounds. Examples are:

- Hazardous heavy metals in spent abrasives
- Lead concentration in paints
- Titanium dioxide pigment in coatings
- Silicon concentration in silicone/alkyd resins

AA/AE instruments are being replaced by ICP instruments for routine high-volume analysis as the latter offer faster operation speeds.



Figure 37.9 AA/AE Spectrophotometer

Gas Liquid Chromatography

This test instrument/process may be used to analyze the composition of an organic liquid, such as the liquid solvent portion of a coating where there may be doubt as to its composition.

A sample is injected into a heated packed column or a specially lined capillary. The sample is separated into its individual components by what closely resembles a mini-fractional distillation process. The individual components are measured by a detector as they leave the other end of the column or capillary. There are many different types of GLC instruments and detectors. A special type of detector is a Mass Spectrograph (MS) which identifies the individual components by fragmenting their molecules and measuring their respective molecular masses. Both the GLC instruments and their detectors require careful calibration. MS detectors have to be tuned using known standards in order to give meaningful results.



Figure 37.10 GLC with 30-m Long Capillary in Oven

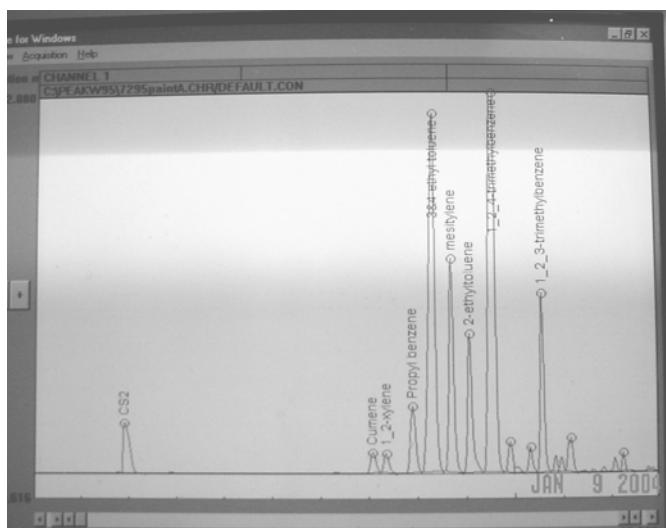


Figure 37.11 GLC Output Screen

Gas Liquid Chromatography may be used to determine the presence of particular solvents in a paint thinner mixture. For example, this test could be used to confirm or negate that the contents of a container of solvent is what is claimed on the label. It can also identify and quantify solvents retained in coating films. Some instruments are so sensitive that they were able to identify residual solvents in paint films that were over 100 years old.

Infrared Spectrophotometer

These instruments can be used to analyze the composition of a coating or identify many chemical compounds. Infrared radiation is made to interact with the material to be analyzed. The wave numbers at which the radiation is absorbed, and the intensity of the absorptions, reflect the molecular structure of the matter being analyzed.

This slide shows the infrared spectrum of the binder resin from the epoxy component of a coating. The spectra are often very complex and correct interpretation of them requires specialized training as well as a thorough knowledge of the types of material being analyzed, in this case coatings and coating raw materials. There are computer programs that assist with interpretation of spectra and searching libraries of infrared spectra.

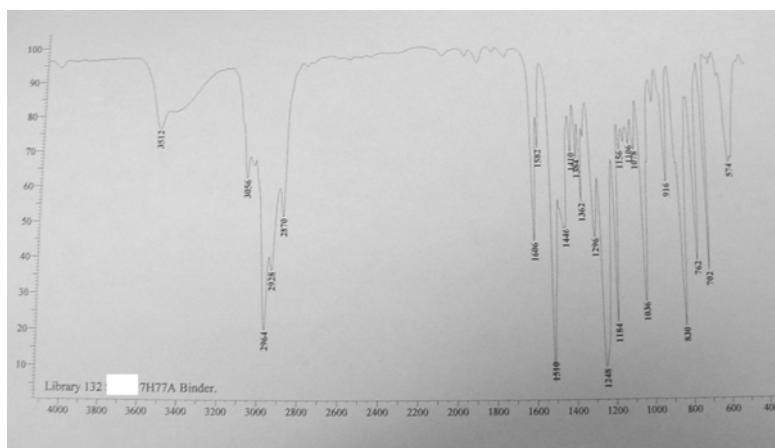


Figure 37.12 Infrared Spectrum

Modern infrared spectrophotometers used for routing analysis generate digital signals using interferometers and Fourier Transform circuitry. These Fourier Transform

Infrared Spectrophotometers (FT-IR) are more powerful and operate faster than the older dispersive instruments. This slide shows an FT-IR instrument equipped with an infrared microscope that is capable of analyzing particles that are too small to be seen with unaided vision.



Figure 37.13 FT-IR Spectrophotometer

Differential Scanning Calorimeter (DSC)

The DSC is used to measure heat gained or lost in a chemical reaction. They are used as quality-control instruments for powder coatings such as fusion-bond epoxies. They are also used to measure the degree of cure of chemically cured coatings such as epoxies and to monitor the quality of plastics such as polyethylene and polypropylene.



Figure 37.14 Thermal Analysis Equipment

Another use for DSC is to measure the amount of metallic zinc in a zinc primer, based on the heat of fusion of the zinc. This is described in ASTM D 6580.

Boroscopes

Boroscopes are useful for inspection of enclosed spaces where the coating inspector cannot personally enter. The two general types of Boroscopes are rigid and flexible.

The rigid boroscope, as illustrated here, can be useful for inspecting long lengths of coated pipe, new pipe, or that which is involved in failure investigation. Extension rods may be added to enable the inspector to survey longer lengths of piping.

The flexible, or fiber-optic boroscope, as illustrated here, operates on the principle of light being transmitted through optical glass fibers.

Various attachments are available to change direction of rays, vary the light source, or attach 35-mm, or video cameras, to make permanent records of any observation.

These are but a few of the many instruments that are available to aid the inspector. It is not possible to train you to use all of the instruments described in this course. Many of these instruments are very specialized and require intensive training and education to become proficient in their use. Our purpose here is simply to make you aware of some of the tools used in the coatings industry.



Level 2

Chapter 38

Self-Study Questions

Chapter 31—Cathodic Protection

1. Cathodic protection uses the flow of electric current through the _____ or _____ metallic structures to protect them from the _____.
2. _____ are often used in conjunction with cathodic protection.
3. Two types of cathodic protection discussed here are:
 - a. _____
 - b. _____
4. The galvanic anode _____ preferentially to the protected structure.
5. Metals suitable for use as galvanic anodes include:
 - a. _____
 - b. _____
 - c. _____
6. Problem areas in cathodic protection include:
 - a. _____/throw
 - b. cathodic _____
7. Cathodic disbondment generally occurs at the areas closest to the _____.
8. The potential of _____ volts is the established minimum for cathodic protection.

Chapter 33—Coating Types and Inspection Criteria

1. Solvent evaporation cure coatings cure when the solvent(s) evaporate and the resin is _____ on the surface.
2. A coating containing a strong _____ should not be applied on top of an evaporation cure coating.
3. Asphalt cutback coatings have good sunlight resistance but generally poor _____ resistance, especially in immersion.

4. Polymerization cure mechanisms include:
 - a. _____ induced
 - b. _____ induced
 - c. _____ induced
5. The main ingredients in oxygen-induced polymerization coatings are vegetable and fish oils and it should be realized that the coating may _____ in contact with alkaline surfaces.
6. Oxidative cure coatings can be attacked by strong _____.
7. Epoxy esters do not require a _____ to cure.
8. Epoxy esters _____ rapidly outdoors.
9. Oil modified phenolic coatings are often used as _____ shop primers.
10. Silicone alkyds are resistant to _____ and to weathering.
11. With chemically cured coatings, if the _____(_____) is not added to the base resin, the coating will appear to _____ but will not _____.
12. Amine blush is a waxy, oily film that may form on an uncured epoxy in _____, _____ conditions.

Chapter 34—Specialized Coatings

1. One type of antifouling paint contains chemicals that are poisonous to _____ and _____.
2. A _____ material is non-burning—it will not support combustion.
3. A _____ material slows down the rate of burning across a surface, when applied to a combustible substrate; however, it will itself _____.
4. A _____ material retards heat penetration through a substrate.
5. Intumescent or swelling paints are not fire-_____, they are fire-_____.

6. Three types of chemical conversion coatings are:
 - a. _____
 - b. _____
 - c. _____
7. Chromate treatments can be applied to a wide variety of metals, but the coating inspector generally would encounter them with _____ and _____.

Chapter 35—Specialized Application Methods

1. In dip coating, the rate of _____ must be controlled.
2. The _____ of a workpiece is important in considering dip application.
3. In flow coating operations, the paint is _____ on through _____ jets.
4. _____ coating is used for coating large, complex, pieces such as transformers.
5. _____ coating is used for small articles, such as buttons, screws, clips, stress studs, etc.
6. _____ is used for large volume coating of steel, galvanized steel, and aluminum supplied in coils.

Chapter 36—Coating Survey

1. A coating survey is a task performed in an organized, rational manner to _____ about the condition of equipment, structure, or facility.
2. _____ must be inspected at regular intervals to comply with _____ and to maintain their insurance rating.
3. The coating survey may:
 - a. _____ existing coating
 - b. Judge overall _____ of the facility
 - c. Identify _____ coatings _____

4. Generally, a coating survey is the first step in developing a _____.
5. The survey team should summarize the data and ensure that they are accurate, factual, and correspond to _____ used.

PRINTED NAME: _____

I affirm that:

1. I understand that I am **solely** responsible for making sure that all necessary work experience documentation is completely submitted in good order to, and on hand at NACE Headquarters not less than 60 days prior to the first day of the Peer Review I wish to attend, and that failure to do so may result in my not being able to take the Peer Review.
2. I understand that if I knowingly provide, or cause to be provided, any false information in connection with my recognition under the NACE International Coating Inspector Program, that it will be grounds for action against my standing in the program.
3. It is the responsibility of the individual to complete the renewal or update process, and to notify NACE International of address changes. Each level successfully completed expires on the date noted on the wallet card issued (or three years from the completion date). Failure to receive notices from NACE does not alleviate the individual's responsibility to contact NACE to complete the renewal or update process.
4. With respect to the Peer Review examination;
 - a. I understand that passing the Peer Review examination is significantly more difficult than passing any of the training courses and that successful completion of the training courses does not guarantee successful completion of the Peer Review examination. I also understand that in the event that I do not pass the Peer Review examination I must wait not less than one week before making a second attempt.
 - b. I understand that in the event that I fail the Peer Review examination twice, I must wait not less than six months before a third or additional retake, and that any person who fails the second or subsequent attempts must wait a minimum of six months between additional attempts.
5. I understand that the names of the categories within the NACE International Coating Inspector Program are as follows:

Highest Level Successfully Completed	Category Title
CIP Level 1	NACE Coating Inspector Level 1—Certified
CIP Level 2	NACE Coating Inspector Level 2—Certified
CIP Levels 1, 2 and Peer Review Examination	NACE-Certified Coating Inspector—Level 3

6. NACE has a firm policy regarding the use of its logos and certification numbers and titles. The certification number and category title may be used only by individuals who are NACE Coating Inspector Level 1—Certified, NACE Coating Inspector Level 2—Certified, or NACE-Certified Coating Inspector—Level 3 and may not be used by any other persons. All active CIP card holders are permitted to use the term **NACE Coating Inspector Level 1—Certified**, **NACE Coating Inspector Level 2—Certified**, or **NACE-Certified Coating Inspector—Level 3** (whichever level of certification is attained), and their certification number on business cards. This example illustrates how this information can be used someone who has achieved the status of **NACE Coating Inspector Level 1—Certified**:

John Smith
NACE Coating Inspector Level 1—Certified, Cert. No. 9650
ACE Inspections, Inc., Knoxville, TN

This example illustrates how this information can be used by a **NACE-Certified Coating Inspector—Level 3**:

John Smith
NACE-Certified Coating Inspector—Level 3, Cert. No. 9650
ACE Inspections, Inc., Knoxville, TN

Those who have achieved any level of certification and who are members in good standing of NACE International may display the NACE Logo for the purpose of identifying the individual as having achieved NACE certification.

I understand that violation of these rules will result in action against my standing in the program on the basis of violation of the NACE International Coating Inspector Program Attestation.

7. I (re) affirm the NACE International Coating Inspector Program attestation and agree to abide by its provisions as long as I hold any level of certification under the program.

Signature: _____

Date: _____

ATTESTATION: Requirements for certification under the NACE International Coating Inspector Program include the signing of the following Attestation. In order to maintain your certification as a NACE International Coating Inspector, you must, on an ongoing basis, fully comply with the NACE International Coating Inspector Program Code of Professional Conduct and the standards contained in this Attestation. Failure to fully comply with the Code of Professional Conduct and/or the Attestation constitutes unprofessional conduct and is a sufficient reason for a reprimand, suspension, revocation, or for the denial of the initial certification or recertification, which will be determined at the sole discretion of NACE.

I, the undersigned, recognize and acknowledge that:

1. Proper coating inspection can be critical to the safety and welfare of the general public and industrial facilities.
2. Coating inspection is obligatory to maximize conservation of our material resources and to reduce economic losses.
3. The entire field of coatings encompasses many diverse skills and disciplines and level of technical competence which must often be taken into consideration.
4. Through continual association and cooperation with others in the coatings field, the safest and most economical solutions may be found to many types of coating problems.
5. The quality of work and personal conduct of each coating inspector reflect on the entire profession of coating inspection.

Therefore, I hereby agree to:

1. Give first consideration in my coating inspection work to safety and public welfare.
2. Apply myself with diligence and responsibility to my coating inspection work.
3. Pursue my work with fairness, honesty, integrity, and courtesy, ever mindful of the best interests of the public, my employer and my fellow workers.
4. Not represent myself to be proficient or make recommendations concerning coatings-related work for which I am not qualified by knowledge and experience.
5. Avoid and discourage untrue, sensational, exaggerated, or unwarranted statements regarding my work.
6. Treat as confidential my knowledge of the business affairs or technical processes of clients, employers, or customers.
7. Inform clients or employers of any affiliations, interests, or connections which might influence my judgment.
8. Accept no money gratuities of any kind or other gratuities whose value could cause a question as to whether they may have influenced my inspection activities, decisions, or reports.
9. Be fair, reasonable, and objective in my work, not allowing myself to be influenced by personalities or other individual considerations.
10. Completely, accurately, and honestly fulfill the reporting requirements of the specifications for any coating operation I may be responsible for inspecting.
11. Take it upon myself to determine from my superiors the scope of my authority and work within it.
12. Ensure, to the best of my ability, that the terms, language, and requirements of the coating specification are clearly understood and agreed to by all parties involved.
13. Strive to obtain the best possible results under given conditions within a given coating specification.

I hereby agree to uphold and abide by the NACE International Coating Inspector Program Code of Professional Conduct and the standards contained in this Attestation as an applicant under this Program, and so long as I am a participant in the NACE International Coating Inspector Program. I understand that failure to fully comply with the Code of Professional Conduct and/or the Attestation will be deemed to constitute unprofessional conduct and is a sufficient reason for a reprimand, suspension, revocation, or for the denial of the initial certification or recertification, which will be determined at the sole discretion of NACE.

Signature: _____

Date: _____

Printed Name: _____

CIP Work Experience Assessment Procedure

1. Two years of coatings-related work experience is required in order to take peer review. Completed work experience forms **must** be received at NACE Headquarters at least two months in advance of the date of peer review in order to be sent to a review board for verification and approval. If you plan to take the peer review in the next year, it is to your benefit to complete and send the forms to NACE Headquarters as soon as possible.
2. At this time, there is no waiting period between levels of the CIP. This means that:
 - a. No matter how much or how little experience you have in the coatings industry, you can take CIP Level 1 and CIP Level 2 with no waiting period in between.
 - b. You do not have to complete any work experience forms in order to attend the two (2) CIP training courses.
3. Thirty-six (36) field-related work experience points are strongly recommended before you take the Peer Review and receive Certification under the CIP. Peer Review is significantly more difficult without the field experience of 36 points.

How the Work Experience Assessment Procedure Operates

Your work experience documentation must provide documentation of field-related work experience points.

Only **coatings-related field work experience** (defined as coatings-related field work in a place where protective coatings are applied or inspected). Experience points are assigned as follows when the work experience has been uninterrupted:

Type of Coatings-Related Work Experience	Points Awarded Per Month of Uninterrupted Work Experience
Coating Inspection	2.0
Other Field Experience	1.5
Non-Field Experience	1.0

Points are not given for non-field coatings-related experience. The following lists, while neither definitive nor exhaustive, indicate what kinds of experience would and would not be considered **coatings-related field work experience**.

Accepted	Not Accepted
•Coating Inspector	•Laboratory technician without field-related responsibilities
•Paint Crew Foreman	•Specification writing without field-related responsibilities
•Industrial Maintenance Painter	•Protective coatings sales without field-related responsibilities
•Blast cleaning operator	
•Protective coating sales with field-related responsibilities	
•Site manager of coatings operation	

When coatings-related work experience has been interrupted for two years or longer, the points awarded for the work experience prior to interruption are reduced, as follows:

Length of Interruption in Continuity of Coatings-Related Work	Factor for Reduced Points Awarded for Coatings-Related Work Prior to Interruption
Up to 2 years	No reduction factor
2 years to 3 years	80%
3 years to 4 years	70%
4 years to 5 years	60%
5 years and more	50%

For example: An applicant worked 24 months as a painter applying industrial maintenance coatings, then worked in a job not at all related to protective coatings for 2 years, then most recently worked 12 months as a coating inspector. The coatings-related total work points awarded are calculated as follows:

$$\begin{aligned} 24 \text{ months} \times 1.5 \text{ points per month} \times 80\% &= 28.8 \text{ points for work as a painter} \\ 12 \text{ months} \times 2.0 \text{ points per month} \times 100\% &= \underline{24.0} \text{ points for inspection work} \\ \text{Total Work Points} &= 52.8 \end{aligned}$$

How to fill out the forms

Disregard of these instructions may seriously delay your application process. NACE cannot be responsible, and accepts no responsibility for delays caused by incomplete, inaccurate, or illegible information.

1. Carefully read these directions, and look over the sample forms, before proceeding.
2. Make as many copies of Form 2: Individual Job Documentation as you need to document the 36 work experience points you need to take the Peer Review.

NOTE: For the purpose of these forms, **job** is defined as **a position in which you are regularly employed for a period of time**. For example: *I had a job for AAA Painters for two years as a helper, then for two years as a painter; then I had a job for 3 years with ZZZ Inspection as a coating inspector.*

3. Completely fill out one copy of Form 2 for each job you want included in your work experience assessment. You must provide complete information. If you are self employed, provide names and addresses of specific individuals at major clients who can verify your work history.
4. Summarize the information from each copy of Form 2 you completed onto Form 1: Summary of Protective Coatings-Related Work Experience.
5. Arrange your forms in order of most recent experience first, followed by less recent experience. Number pages consecutively. If you have 12 pages of forms, the first page is page 1, and the other pages should be numbered 2 through 12.
6. Write only on one side of each page.
7. Read and sign the Affirmation and Attestation.
8. Make and keep a copy of your forms for your records.
9. When your forms are complete, send them to:

NACE Education Division	Phone:	281/228-6244
Attention: Carol Steele	FAX:	281/228-6344
1440 South Creek Drive	E-Mail:	Carol.Steele@nace.org
Houston, TX 77084-4906 USA		

Note: You do not need to return the instructions or sample copies, only your completed forms.

10. If you require assistance, contact NACE at the above address or phone.

Your forms must be received at NACE Headquarters not less than 60 days from the first day of the Peer Review you plan to attend.

S A M P L E

Form 1: Summary of Protective Coatings-Related Work Experience

Instructions: Make and use as many copies of this form as needed. Please provide all information requested. Forms must be printed legibly in black ink or typed. Illegible information can delay the application process. For assistance with this form, contact the Education Division at NACE International Headquarters.

Applicant Information:

Name: A. Sample

Phone: 409/111-4321

Company: ZZZ Coating Inspection Inc.

Fax: 409/111-1234

Address: 987 Gage Avenue

City: Millspec

State/Province: TX

Zip/Postal Code: 77987

Country: USA

Please summarize below the information on each copy of Form 2, Individual Job Documentation. List your experience beginning with the most recent, followed by less recent experience.

From Month/Year	To Month/Year	Number of months in this job	Points for this job	Job Title	Company Name
1/92	1/95	36	72	Coating Inspector	ZZZ Inspection Inc.
12/89	12/91	24	36	Painter	AAA Painters
12/87	12/89	24	36	Helper	AAA Painters
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				
		TOTAL POINTS:	144		

Applicant Affidavit: I understand that if I knowingly provide false information in connection with my recognition under this program, it will be grounds for disciplinary procedures.

Signed: _____

Date: _____

S A M P L E

Form 2: Individual Job Documentation

Use one of these forms for each job; that is, each period of work experience you wish to document. Note that for this form, *job* is defined as *a position in which you are regularly employed for a period of time*. Make and use as many copies of this form as you need. Please provide all information requested in the form. Applications must be printed legibly in black ink or typed. Illegible information can delay the application process. For assistance with this form, contact the Education Division at NACE International Headquarters.

JOB INFORMATION:

Job Title:	Painter	
<hr/>		
AAA Painters		
<hr/>		
From:	Month	1
To:	Year	92
<hr/>		
Who can NACE contact to verify this experience?		
Name:	Bob Roberts	
Company:	AAA Painters	
Address:	123 Coating St.	
<hr/>		
<hr/>		
City:	Paintersville	
State/Province:	TX	Zip/Postal Code 77123
Country:	USA	
Phone:	409/123-4567	
Fax:	409/123-7654	

WORK EXPERIENCE POINT CALCULATION:

- a. Number of months in this job: 24

b. Experience Points (check one):

Field, coating inspection (2 points)

Field, other than inspection (1.5 points)

Non-field experience (1.0 points)

Write the point value here: 1.5

c. Points for this job 1.5

Multiply a. (number of months)
by b. (experience points).

Write results in this box: 36

Describe in detail what are/were your specific coatings-related duties in this job. NOTE: Do not write on the back of this form, attach additional sheets if necessary, writing only on one side of each page.

Experience with conventional airspray and airless spray equipment. Responsible for making sure that equipment was set up right, and cleaned up at end of day.

Responsible for correctly applying the coating as directed by supervisor. Took wet-film readings as directed.

Worked mainly on offshore structure during this time, but also had a couple of projects in refineries.

Applicant Affidavit: I understand that if I knowingly provide false information in connection with my certification under this program, it will be grounds for disciplinary procedures.

Signed: _____

Date: _____

Form 1: Summary of Protective Coatings-Related Work Experience

Instructions: Make and use as many copies of this form as needed. Please provide all information requested. Forms must be printed legibly in black ink or typed. Illegible information can delay the application process. For assistance with this form, contact the Education Division at NACE International Headquarters.

Applicant Information:

Name: _____

Phone: _____

Company: _____

Fax: _____

Address: _____

City: _____

State/Province: _____

Zip/Postal Code: _____

Country: _____

Please summarize below the information on each copy of Form 2, Individual Job Documentation. List your experience beginning with the most recent, followed by less recent experience.

From Month/Year	To Month/Year	Number of months in this job	Points for this job	Job Title	Company Name
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				
		TOTAL POINTS:			

Applicant Affidavit: I understand that if I knowingly provide false information in connection with my certification under this program, it will be grounds for disciplinary procedures.

Signed: _____

Date: _____

MAKE A COPY OF ALL PAGES OF THIS APPLICATION FOR YOUR RECORDS

Form 2: Individual Job Documentation

Use one of these forms for each job; that is, each period of work experience you wish to document. Note that for this form, *job* is defined as *a position in which you are regularly employed for a period of time*. Make and use as many copies of this form as you need. Please provide all information requested in the form. Applications must be printed legibly in black ink or typed. Illegible information can delay the application process. For assistance with this form, contact the Education Division at NACE International Headquarters.

JOB INFORMATION:

Job Title: _____

From: Month _____ Year _____

To: Month _____ Year _____

Who can NACE contact to verify this experience?

Name: _____

Company: _____

Address: _____

City: _____

State/Province: _____ Zip/Postal Code _____

Country: _____

Phone: _____

Fax: _____

WORK EXPERIENCE POINT CALCULATION:

a. Number of months in this job:

b. Experience Points (check one):

- Field, coating inspection (2 points)
 Field, other than inspection (1.5 points)
 Non-field experience (1.0 points)

Write the point value here:

c. Points for this job

Multiply a. (number of months)

by b. (experience points).

Write results in this box:

PLEASE DESCRIBE IN DETAIL what are/were your specific coating-related duties in this job. Your application will NOT be accepted if this section is not completed. NOTE: Do not write on the back of this form. Attach additional sheets if necessary, writing only on one side of page.

Applicant Affidavit: I understand that if I knowingly provide false information in connection with my certification under this program, it will be grounds for disciplinary procedures.

Signed: _____ Date: _____

MAKE A COPY OF ALL PAGES OF THIS APPLICATION FOR YOUR RECORD

Standard Recommended Practice

Application, Performance, and Quality Control of Plant-Applied, Fusion-Bonded Epoxy External Pipe Coating

This NACE International standard represents a consensus of those individual members who have reviewed this document, its scope, and provisions. Its acceptance does not in any respect preclude anyone, whether he has adopted the standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not in conformance with this standard. Nothing contained in this NACE International standard is to be construed as granting any right, by implication or otherwise, to manufacture, sell, or use in connection with any method, apparatus, or product covered by Letters Patent, or as indemnifying or protecting anyone against liability for infringement of Letters Patent. This standard represents minimum requirements and should in no way be interpreted as a restriction on the use of better procedures or materials. Neither is this standard intended to apply in all cases relating to the subject. Unpredictable circumstances may negate the usefulness of this standard in specific instances. NACE International assumes no responsibility for the interpretation or use of this standard by other parties and accepts responsibility for only those official NACE International interpretations issued by NACE International in accordance with its governing procedures and policies which preclude the issuance of interpretations by individual volunteers.

Users of this NACE International standard are responsible for reviewing appropriate health, safety, environmental, and regulatory documents and for determining their applicability in relation to this standard prior to its use. This NACE International standard may not necessarily address all potential health and safety problems or environmental hazards associated with the use of materials, equipment, and/or operations detailed or referred to within this standard. Users of this NACE International standard are also responsible for establishing appropriate health, safety, and environmental protection practices, in consultation with appropriate regulatory authorities if necessary, to achieve compliance with any existing applicable regulatory requirements prior to the use of this standard.

CAUTIONARY NOTICE: NACE International standards are subject to periodic review, and may be revised or withdrawn at any time without prior notice. NACE International requires that action be taken to reaffirm, revise, or withdraw this standard no later than five years from the date of initial publication. The user is cautioned to obtain the latest edition. Purchasers of NACE International standards may receive current information on all standards and other NACE International publications by contacting the NACE International Membership Services Department, 1440 South Creek Drive, Houston, Texas 77084-4906 (telephone +1 [281] 228-6200).

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Foreword

This standard recommended practice presents guidelines for establishing requirements to ensure proper application and performance of plant-applied, fusion-bonded epoxy (FBE) coatings to the external surfaces of pipe. It is intended for use by corrosion control personnel concerned with mitigation of corrosion on buried and submerged piping used for transportation and storage of oil, gas, water, and similar products.

This standard was originally prepared in 1994 by NACE Task Group T-10D-10, a component of Unit Committee T-10D on Protective Coating Systems. It was revised in 2002 by NACE Task Group 031. This Task Group was administered by Specific Technology Group (STG) 03 on Protective Coatings and Linings—Immersion/Buried. Sponsoring STGs also included STG 05 on Cathodic/Anodic Protection; and STG 35 on Pipelines, Tanks, and Well Casings. This standard is issued by NACE International under the auspices of STG 03.^(1, 2)

In NACE standards, the terms *shall*, *must*, *should*, and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. The term *should* is used to state something considered good and is recommended but is not mandatory. The term *may* is used to state something considered optional.

⁽¹⁾ With permission of Canadian Standards Association (CSA), portions of this standard have been reproduced from CSA Standard Z245.20-M 98, "External Fusion Bonded Epoxy Coated Steel Pipe," (Copyright CSA, 1986). Copies of Z245.20-M 98 may be purchased from CSA, 178 Rexdale Boulevard, Toronto, Ontario, Canada, M9W 1R3.

⁽²⁾ With permission of the American Petroleum Institute, portions of this standard have been reproduced from API RP 5L7, "Recommended Practices for Unprimed Internal Fusion Bonded Epoxy Coating of Line Pipe," Second Edition, June 30, 1988, American Petroleum Institute Publications and Distribution Section, 1220 L Street, NW, Washington, DC 20005.

NACE International Standard Recommended Practice

Application, Performance, and Quality Control of Plant- Applied, Fusion-Bonded Epoxy External Pipe Coating

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Section 1: General

1.1 This standard presents guidelines for establishing minimum requirements to ensure proper application and performance of plant-applied, fusion-bonded epoxy (FBE) coatings to the external surfaces of pipe.

1.2 The function of such coatings is to prevent corrosion when used in conjunction with cathodic protection.

1.3 This standard suggests or describes methods for qualifying and controlling the quality of FBE pipe coatings, provides guidelines for their proper application, and identifies inspection and repair techniques to obtain the best applied FBE coating system.

Section 2: Definitions

Applicator: The organization responsible to the purchaser for the coating application.

Batch: The quantity of coating material produced during a continuous production run of not more than eight hours.

Coating: A liquid, liquefiable, or mastic composition that, after application to a surface, is converted into a solid protective, decorative, or functional adherent film.

Coating material: Epoxy powder.

Cutback: The length of pipe left uncoated at each end for joining purposes (e.g., welding).

Holiday: A discontinuity in a protective coating that exposes unprotected surface to the environment.

Inspector: The authorized agent of the purchaser.

MSDS: Material safety data sheet.

PD: Pipe diameter.

Purchaser: The owner company or the authorized agency that purchases the coated pipe.

Supplier: The manufacturer or distributor of the coating material and its authorized technician.

Section 3: Coating Material

3.1 Coating Supplier Information

3.1.1 The coating material supplier shall furnish to both the purchaser and the applicator the following information in a written form upon request:

3.1.1.1 Directions for handling and storage of the coating material,

3.1.1.2 Specification of the basic physical properties and laboratory performance test results,

3.1.1.3 Certification of the determined physical properties of each batch of material, and

3.1.1.4 Material safety data sheets.

recommendations and in such a manner that contamination or adverse effects on application are avoided.

3.2.2 Shelf Life

All batches on receipt and any batch of coating material that has exceeded the supplier's recommended shelf life shall be subject to coating material verification tests by the manufacturer (see Paragraph 7.3.2) prior to use.

3.2.3 Copies of all records of testing by the applicator or manufacturer shall be supplied to the purchaser or purchaser's representative within 24 hours of the test or as agreed to in the preproduction meeting(s).

3.3 Coating Material Properties

3.3.1 It is the supplier's responsibility to perform the tests cited by reference in this section. The purchaser or applicator may also perform any or all of the cited tests as part of a quality assurance program.

3.3.2 The coating material shall meet the value limits for the properties listed in Table 1.

3.2 Handling of Coating Materials

3.2.1 Coating material batches shall be identified by a batch coding system devised by the supplier. The batch code shall include a reference to the date of manufacture. Coating materials shall be shipped and stored under cover according to the supplier's recom-

TABLE 1: Epoxy Powder Properties

Property	Value Limits	Test Method
Density ± 3.5%	According to supplier's specification	See Appendix A
Particle Size	2% max. retained on 150 µm (100 mesh) sieve; 0.1% max. retained on 250 µm (60 mesh) sieve	
Shelf Life	According to supplier's specification; according to supplier's recommended storage conditions	See Appendix B
Gel Time	According to supplier's specification ± 20%	See Appendix C ^(A)
Cure Cycle	Capable of cure at temperatures below 275°C (527°F) (limitation imposed by regulations on heating of cold-expanded pipe); time: according to supplier's specification	According to supplier's specification
Glass Transition Temperatures	According to supplier's specification	See Appendix D ^(A)
H (Heat of Reaction)	According to supplier's specification	See Appendix D ^(A)
Moisture Content ^(B)	0.5% max.	See Appendix E

^(A) API RP 5L7^(B) Either moisture or total volatile content may be determined at the supplier's discretion.

3.3.3 All batches of FBE material shall be tested upon receipt by the applicator, at its cost, according to Paragraph 7.3.2 to verify that the FBE material meets

or exceeds the requirements of Table 2. This ensures the FBE material has been properly stored during handling and shipping.

TABLE 2: In-Plant Verification of Epoxy Powder Quality

Test	Acceptance Criteria	No. of Test Specimens	Test Method
Cross-Section Porosity	Rating of 1 to 3, inclusive	1	See Appendix G ^(A)
Interface Porosity	Rating of 1 to 3, inclusive	1	See Appendix G ^(A)
Flexibility (2°/PD Permanent Strain)	No cracks, tears, delamination, or disbondment	3	See Appendix H
Gel Time	According to supplier's specification ± 20%	1	See Appendix C ^(B)
Hot-Water Soak	Rating of 1 to 3, inclusive	1	See Appendix J

^(A) CAN/CSA Z245.20-M98^(B) API RP 5L7

3.3.4 Any batch of FBE material that has exceeded the supplier's recommended shelf life shall be tested according to Paragraph 7.3.2 to verify the FBE material

meets or exceeds the requirements of Table 2. These requalification tests shall be performed by the coating manufacturer, at its cost.

Section 4: Coating Performance

4.1 Typical desired characteristics of applied coatings are outlined in NACE Standard RP0169.¹

4.2 The coating shall not deteriorate (i.e., burn, blister, or char) more than 50 mm (2 in.) from the extreme edge of a weld or cut area when pipe is welded or torch cut. If deterioration of the coating occurs beyond 50 mm (2 in.) from the weld or cut area, the purchaser's representative must be notified to resolve the issue.

4.3 Performance Testing

4.3.1 Qualification

The coating system shall be qualified for production by testing laboratory-coated test specimens for each applicable test and by meeting the acceptance criteria (see Table 3). It is the responsibility of the purchaser or coating applicator to qualify the coating material prior to coating application. Once qualification is established further qualification testing is not required unless the coating material, formulation, or location of manufacture changes.

TABLE 3: Qualification Requirements

Test	Acceptance Criteria	No. of Test Specimens	Test Method
Cathodic Disbondment (24 h)	Avg. radius: 6.0 mm (0.25 in.)	3	See Appendix F
Cathodic Disbondment (28 d)	Avg. radius: 8 mm (0.3 in.)	3	See Appendix F
Cross-Section Porosity	Rating of 1 to 4	3	See Appendix G ^(B)
Interface Porosity	Rating of 1 to 4	3	See Appendix G ^(B)
Flexibility (3°/PD at 0°C [32°F] or -30°C [-22°F]) ^(A)	No cracks, tears, or delamination	5	See Appendix H
Impact Resistance	1.5 J (13 in.-lb) min.	3	See Appendix I
Hot-Water Soak	A rating of 1 to 3, inclusive	3	See Appendix J

^(A) Use the 0°C (32°F) temperature test for situations in which the pipe will be field bent at or above these temperatures. Use the -30°C (-22°F) temperature test for situations in which the pipe will be field bent at or above these temperatures.

^(B) CAN/CSA Z245.20-M98

4.3.2 Performance Testing Steel Panels

Test panels shall be hot-rolled carbon steel (AISI⁽³⁾ 1020 or approved equivalent) and have dimensions in accordance with the cited test method. The surface shall be blast cleaned using steel grit that shall be used during production to provide a surface profile of 38 to 100 µm (1.5 to 4.0 mils), measured from peak to valley using the following standards:

4.3.2.1 NACE No. 1/SSPC⁽⁴⁾-SP 5.²

4.3.2.2 NACE Standard RP0287.³

4.3.3 Coating of Test Panels

4.3.3.1 Coating application and curing shall be in accordance with the supplier's recommendations. Application and curing temperatures shall not exceed 275°C (527°F).

4.3.3.2 Coating thickness on the test panel shall be 360 ±50 µm (14 ±2 mils). Magnetic pull-off coating thickness gauges must be calibrated against a NIST⁽⁵⁾ thickness standard (NIST-SRM 1363⁴) that is within 20% of the specified coating thickness. Magnetic flux or fixed-probe gauges must be calibrated to SSPC-PA 2.⁵

⁽³⁾ American Iron and Steel Institute (AISI), 1101 17th St. NW Suite 1300, Washington, DC 20036.

⁽⁴⁾ Society for Protective Coatings (SSPC), 40 24th St, 6th Floor, Pittsburgh, PA 15222-4656.

⁽⁵⁾ National Institute of Standards Technology (NIST), formerly the National Bureau of Standards, Gaithersburg, MD 20899.

4.3.4 Performance of Laboratory-Coated Steel Panels

4.3.4.1 Testing

A coating shall be considered qualified when the results of a duplicate set of tests meet the acceptance criterion for each test shown in Table 3.

Section 5: Surface Preparation of Pipe

5.1 This section emphasizes the importance of proper surface preparation of the pipe because the condition of this interface directly affects the coating's performance.

5.1.1 Bare pipe shall be supplied to the applicator free of salts, mill lacquer, oil, grease, or other deleterious deposits. If any such deposits are present, the applicator shall attempt to remove any remaining deleterious deposits from the surface to be coated using the appropriate NACE/SSPC surface preparation standard. If the applicator cannot sufficiently remove these deposits these pipes may be rejected, or the applicator and purchaser may agree on an appropriate solution. If a decision is made to reject the contaminated pipes, the rejection may be for individual pipes or lots of pipe according to the severity of the problem.

NOTE: Mill lacquer, other protective coatings, or soluble salt left on the pipe surface adversely affects coating performance.

5.1.1.1 After blast cleaning, the pipe surface shall be tested for the presence of soluble salts. If the concentration is more than $2 \mu\text{g}/\text{cm}^2$ (0.0002 gr/in.²), the pipe surface shall be cleaned in accordance with Paragraph 5.1.9 or another suitable method. The cleaned pipe shall be retested to confirm the removal of soluble salts. The frequency and type of testing shall be determined by the purchaser's agent and applicator according to the type and severity of the contamination.

5.1.2 All pipe shall be uniformly preheated prior to blast cleaning to remove moisture from the surface, assist in raising slivers, and provide the proper heated surface for the phosphoric acid wash. The preheat shall be sufficient to ensure that the pipe temperature is at least 3°C (5°F) above the dew point temperature during blast cleaning and inspection. The preheat temperature shall keep the pipe surface heated in the proper range (as recommended by the phosphoric acid manufacturer) for phosphoric acid wash application, if used.

5.1.3 The surface of the pipe shall be blast cleaned to NACE No. 2/SSPC-SP 10⁶ or to ISO⁽⁶⁾ 8501-1.⁷

5.1.4 Surface profile shall be at least $50 \mu\text{m}$ (2 mils) from peak to valley (see NACE Standard RP0287). Surface profile shall not exceed $100 \mu\text{m}$ (4 mils).

5.1.5 Bevels, lands, and internal coatings shall be protected from shot/grit blasting and damage by impact or gouging.

5.1.6 Residual products from blasting shall be suitably removed from the interior and exterior surfaces of the pipe.

5.1.7 Prior to coating, the cleaned pipe shall be visually inspected and imperfections that may cause holidays in the coating shall be removed by grinding in such a manner as to give a surface finish suitable for subsequent application of coating, or by reblasting ground areas. The maximum grinding area is 0.09 m^2 (0.1 ft^2) for each location, and the maximum total grind area is the smaller of 0.2 m^2 (2 ft^2) for each joint or 2% of the total pipe surface. The disposition of any joint of pipe that exceeds these limits shall be subject to agreement between the applicator and purchaser.

5.1.8 Disposition of pipe with imperfections that cannot be removed without encroaching on minimum wall thickness or causing interference with the normal production cycle shall be subject to agreement between applicator and purchaser.

5.1.9 Phosphoric acid wash and rinse may be used for further surface cleaning, etching, and removal of soluble salts. Phosphoric acid shall be mixed with deionized or reverse osmosis water according to the manufacturer's recommendations. Deionized or reverse osmosis water shall be used for the mixture and for rinsing the pipe after the wash. The deionized or reverse osmosis water shall have no more than 20 ppm of total dissolved solids or $35 \mu\text{S}$ conductivity.⁸ The phosphoric acid wash shall be applied after the blast and before the heating process.

5.1.9.1 Application of the phosphoric acid mixture shall be at the rate and percent recommended by the phosphoric acid supplier, unless otherwise approved by the purchaser. The mixing container

⁽⁶⁾ International Organization for Standardization (ISO), 1 rue de Varembe, Case Postale 56, CH-1121 Geneva 20, Switzerland.

shall be continually agitated during the application process. The concentration of the mixture shall be checked by the applicator at least once every eight hours by sampling the mix at the spray head or application point.

5.1.9.2 The mixture shall stay on the pipe for at least 20 seconds. The mixture shall have a pH of one or less on the pipe surface 20 seconds after the mixture is applied. This pH shall be checked by the applicator a minimum of every two hours during production.

5.1.9.3 The mixture shall be rinsed from the pipe surface with a high-pressure rinse system using deionized or reverse osmosis water meeting requirements of Paragraph 5.1.9. The high-pressure rinse shall have a minimum tip pressure of 220 kPa (1,500 psi).

5.1.9.4 The pH of the wet pipe surface after the rinse shall be no less than 6 and no greater than 7.5 and shall be checked by the applicator a minimum of every two hours during production.

5.1.10 Prior to heating the pipe, a chromate chemical treatment may be used to provide additional surface pretreatment. This treatment is used to provide a conversion coating with the steel surface and create additional surface energy to help attract and hold the FBE

powder. A chromate material specifically produced for these types of applications shall be used. If a phosphoric acid wash is used, the chromate solution shall be applied after the phosphoric acid wash and rinse.

5.1.10.1 The chromate material shall be mixed with deionized or reverse osmosis water (as in Paragraph 5.1.9). The mix ratio shall be approved by the chromate manufacturer.

5.1.10.2 The chromate should be applied by dripping or brushing on the pipe as it rotates down the conveyor. Brushes, noncontaminating wipes, or squeegees shall be used to remove excess chromate mixture.

5.1.10.3 The mixture shall be thinly applied, leaving a light golden color on the pipe surface.

5.1.11 When approved or specified by the purchaser, additional surface treatments may be used prior to application of coating.

5.1.12 If used, these surface treatments can cause the pipe surface to discolor after heating to the proper coating application temperature and these surfaces will no longer meet the color requirements of Paragraph 5.1.3. During preproduction, the applicator and purchaser's representative shall agree to the acceptable color at this stage of production.

Section 6: Coating Application

6.1 This section provides information on application techniques for obtaining optimum performance of FBE pipe coatings.

6.1.1 When changing from one coating manufacturer or product to another, care should be taken to minimize cross-contamination of coating materials.

6.1.2 Application and curing temperatures of the external pipe surface shall be selected by the applicator, shall not exceed 275°C (527°F), and shall be in accordance with the coating supplier's recommendations.

6.1.2.1 The use of recycled FBE powder shall be permitted if the recycle system automatically and continuously blends recycled powder with a minimum of 80% virgin powder in the delivery system.

6.1.3 Cure schedule shall be selected by the applicator to ensure adequate cure of the coating, should be in accordance with the coating manufacturer's recommendations, and shall be subject to approval by the purchaser.

6.1.4 The minimum coating thickness shall be specified by the purchaser. Maximum coating thickness may

also be specified by the purchaser, if there is concern about field bending or application problems.

6.1.5 To meet the acceptance criteria in Table 4, the specified minimum thickness should not be less than 300 µm (12 mils) for any thickness reading.

6.1.5.1 When FBE coating is used in systems in which the service temperature of the coated surfaces exceeds 65°C (150°F), thicker FBE minimums should be used. Suggested minimums are:

Service Temperature	Minimum FBE Thickness
65°C (150°F) to 82°C (180°F)	500 µm (20 mils)
82°C (180°F) to 95°C (203°F)	760 µm (30 mils)
Above 95°C (203°F)	Consult FBE supplier/applicator.

CAUTION: If the pipe bends are to be made in temperatures below -10°C (14°F), greater thicknesses may cause the coating to crack or stretch, causing repair problems during construction.

6.1.5.2 Other situations that may require a higher FBE minimum thickness are:

- When the pipe is to be concrete coated;
- Placed through a drilled crossing;
- Rocky or high-impact backfill; and
- Mechanical damage during construction.

6.1.6 The cutback limits shall be specified by the purchaser.

TABLE 4: Production Test Ring Requirements

Test	Test Type ^(A)	Acceptance Criteria	No. of Test Specimens	Test Method ^(B)
Cathodic Disbondment (24 h)	A	Max. radius: 8 mm (0.3 in.)	1	See Appendix F
Flexibility (1.5°/PD Permanent Strain)	A	No cracks, tears, or delamination (unaided visual)	3	See Appendix H
Hot-Water Soak	A	Rating of 1 to 3, inclusive	1	See Appendix J
Interface Contamination	B	Max.: 30%	1	See Appendix K ^(C)
Cross-Section Porosity	B	Rating of 1 to 3, inclusive	1	See Appendix G ^(C)
Thermal Characteristics	C	ΔT_g of 5°C (9°F), max. or 95% conversion H minimum	1	See Appendix D
Impact Resistance	C	1.5 J (13 in.-lb) minimum	1	See Appendix I

^(A) Failure to meet the acceptance criteria for Type A tests shall be grounds for rejection of all pipe coated after the previous acceptable test result and prior to the next acceptable test result. Additional Type A testing of the affected day's production may be conducted in an attempt to reduce the amount of rejected pipe. Failure to meet the acceptance criteria for Type B or C tests shall be grounds for requiring changes to the application process parameters. Type C tests are required only when specified by purchaser. NOTE: The purchaser may require that the applicator limit the application process until the cause of the failure has been remedied.

^(B) Purchaser may specify more stringent requirements for specific applications. These requirements must be clearly documented and agreed to by purchaser and applicator before preproduction.

^(C) CAN/CSA Z245.20-M98

Section 7: Production Inspection and Testing

7.1 Plant Access

The inspector representing the purchaser shall have free access to all parts of the applicator's plant concerned with the storage, application, testing, and handling of the FBE powder and coating of the purchaser's pipe, while work on the contract of the purchaser is being performed. The inspection should be performed by a person qualified by experience and training in coating inspection methods. The applicator shall afford the inspector, without charge, inspection facilities to satisfy the inspector that the coating is being applied in accordance with the requirements of this standard. All inspections shall be made at the place of application prior to shipment of the coated pipe, unless otherwise specified by the purchaser, and shall be conducted so as not to interfere unnecessarily with the operation of the plant.

7.1.1 Inspection Records

Copies of all records from quality control, inspection, and testing by the applicator shall be supplied to the

purchaser or purchaser's representative within 24 hours of the inspection or test.

7.2 Inspection Notice

If the inspector representing the purchaser desires to inspect the coated pipe or witness the tests, the applicator shall give reasonable notice of the time at which the application or tests are to be made.

7.3 Production Tests

7.3.1 The applicator is responsible for and shall have suitable equipment and trained personnel at the plant to perform Type A and B tests as required by Table 4.

7.3.2 Verification of FBE Powder Quality

7.3.2.1 The minimum testing frequency shall be one sample from each batch of FBE powder received. Tests conducted and the acceptance requirements shall be in accordance with Paragraphs 7.3.2.2 and 7.3.2.3. For stock-stored FBE

powder, gel time shall be retested prior to each use, in accordance with Appendix C.

7.3.2.2 Laboratory-coated test specimens shall be prepared at the proposed plant application temperature in accordance with the requirements of Paragraphs 4.3.2 and 4.3.3.

7.3.2.3 The tests to be conducted and the acceptance criteria are shown in Table 2.

7.3.3 In-Line Inspection and Measurement

7.3.3.1 General

The inspection and measurements required by Paragraphs 7.3.3.1 through 7.3.3.8 shall be made and recorded by the applicator under the supervision of a person qualified by experience and training in coating inspection methods.⁽⁷⁾

7.3.3.1.1 Air for blasting, cleaning, drying, or powder application shall be checked and information recorded at least every four hours to ensure no water, oil, or other contaminants are present.

7.3.3.1.2 All temperature, dew point, humidity, and other such measurements as required by the coating manufacturer or applicator shall be taken and recorded at the start of each shift and at least once every two hours.

7.3.3.2 Surface Finish

Surface finish shall be monitored hourly to determine compliance with Paragraph 5.1.3.

7.3.3.3 Surface Profile

At least once every four hours of production the surface profile shall be measured using a replicating film or approved equivalent. The profile shall be within the limits specified in Paragraph 5.1.4.

7.3.3.4 Surface Inspection

Each cleaned pipe shall be visually inspected for surface defects and surface imperfections that may cause holidays in the coating. Surface imperfections shall be removed by grinding or other suitable means in accordance with Paragraphs 5.1.7 and 5.1.8. Pipe containing surface defects shall be rejected or repaired at the purchaser's option.

7.3.3.5 Application Temperature

The surface temperature of the pipe immediately prior to FBE powder application shall be monitored and controlled within the limits agreed on by the applicator, the purchaser, and the coating supplier.

7.3.3.5.1 Optical pyrometers, graduated heat-indicating sticks, or other purchaser-approved methods shall be used to monitor and control the temperature.

7.3.3.5.2 Pyrometers and other such temperature-monitoring devices shall be calibrated and information recorded daily.

7.3.3.5.3 Once the coating temperature is established, the temperature of every fifth pipe shall be taken and recorded.

7.3.3.6 Curing

The curing temperature and the time interval between application and quenching shall be controlled and monitored in accordance with Paragraphs 6.1.2 and 6.1.3.

7.3.3.7 Coating Thickness

7.3.3.7.1 The coating thickness shall be measured at five locations along the length of each coated pipe using a coating thickness gauge calibrated at least once every four hours during production, in accordance with the requirements of Paragraph 4.3.3.2. Each reading shall be at least 2 m (6 ft) from any other reading. All five of these thickness measurements shall be recorded.

7.3.3.7.2 If any individual measured thickness value is less than the specified minimum value of Paragraph 6.1.4, two coating thickness measurements shall be measured within 150 mm (6.0 in.) of the original measurement. The average of these measurements shall exceed the specified minimum value, and no individual value shall be more than 50 µm (2.0 mils) below the specified minimum value. All these thickness measurements shall be recorded.

7.3.3.7.3 Pipe failing to meet the requirements of Paragraph 7.3.3.7.2 shall, at the purchaser's option, be accepted, repaired, or stripped and recoated.

⁽⁷⁾ NACE International offers coating inspection certification and training programs. Contact the NACE International Membership Services Department for information.

7.3.3.7.4 If the purchaser's maximum thickness is exceeded, the pipe shall be placed on hold for further inspection, special marking, or stripping and recoating, as agreed on by the purchaser's representative and the applicator.

7.3.3.8 Further Inspection

7.3.3.8.1 General

7.3.3.8.1.1 The entire coated surface of each length of pipe shall be inspected with a holiday detector in accordance with NACE Standard RP0490.⁹

7.3.3.8.1.2 Inspection is best performed when the temperature of the coating is lower than 90°C (194°F).

7.3.3.8.1.3 The coated surface shall be 100% visually inspected to ensure it is free of blisters, bubbles, sags, voids, and other irregularities.

7.3.3.8.2 Acceptance Criteria

7.3.3.8.2.1 Pipe containing holidays shall be repaired or recoated in accordance with the requirements of Section 8.

7.3.3.8.2.2 The maximum number of repairs is on average one for each 2 m²

(22 ft²) of coated pipe surface, for pipes of all diameters.

7.3.3.8.2.3 The allowable number and type of coating surface defects shall be specified by the purchaser.

7.3.4 Production Test Rings

7.3.4.1 Test rings shall be a minimum of 460 mm (18 in.) long.

7.3.4.2 For each pipe size (distinct combination of diameter and wall thickness), the minimum frequency of obtaining test rings should be one sample for each of the following lots or fraction thereof:

7.3.4.2.1 One during each shift (maximum shift—12 hours), unless the pipe size is changed. At least one test should be made on each pipe size or wall thickness.

7.3.4.3 The tests to be conducted by the applicator and the acceptance criteria for test rings are shown in Table 4.

7.3.4.4 If the test results do not meet the criteria of Table 4, additional test rings can be taken and retested. If these tests pass, all pipes between this test and the last successful test can be accepted. If the second set of tests fail, additional bracket tests can be performed to isolate problem pipes.

Section 8: Repair

8.1 All coating defects should be repaired using materials that are compatible with, have the same or better performance at the expected service temperature, adhere well to the FBE coating, and are approved by the purchaser.

8.2 Repair materials normally consist of:

8.2.1 Heat melting sticks, and

8.2.2 Two-part epoxy or equivalent.

8.3 Repaired areas should overlap the parent coating a minimum of 13 mm (0.50 in.). The surface to be repaired should be suitably prepared to ensure adhesion of the repair material. Minimum thickness of the repaired coating shall be in accordance with the repair coating manufacturer's recommendations.

8.3.1 Areas 6.4 mm (0.25 in.) in diameter and smaller may be repaired with the supplier's recommended hot-melt stick, two-part epoxy, or equivalent.

8.3.2 Areas greater than 6.4 mm (0.25 in.) in diameter and less than 130 cm² (20 in.²) shall be repaired with the purchaser's or powder supplier's recommended two-part epoxy or equivalent.

8.3.3 The total maximum repaired areas for each pipe shall not exceed 520 cm² (80 in.²).

8.4 For stripping, pipe shall be heated to a temperature not exceeding 275°C (527°F) in order to soften the coating to permit removal by scraping, followed by abrasive blasting. All coating shall be removed prior to recoating. The identity of each stripped and recoated pipe shall be recorded.

Section 9: Handling, Storage, and Shipping

9.1 After being externally coated and cured, the pipe should be sufficiently cooled to permit handling.

9.2 Coated pipe shall be handled in such a way that damage to the pipe and coating is avoided. Equipment used in the handling and storage of coated pipe shall be appropriately padded.

9.3 Coating that is damaged during handling, storage, or shipping shall be repaired in accordance with the requirements of Section 8 of this standard. The applicator is responsible for repairing damage that occurs during the handling, storage, and shipping activities under its control. Repair to damage that occurs after the applicator no longer controls the pipe activity is the responsibility of the pur-

chaser. While under the control of the applicator, coating damage that exceeds the limits of Paragraph 7.3.3.8 shall be stripped and recoated, unless accepted by the purchaser. Coating damage that occurs after the pipe leaves control of the applicator and exceeds the limits of Paragraph 7.3.3.8 shall be the responsibility of the purchaser.

9.4 When loading or storing pipe, each pipe should be protected using full-encirclement separators. The separators shall be located within 0.9 m (3 ft) of the pipe ends and at one or more approximately equidistant intermediate location(s) less than 5.5 m (18 ft) apart. Separators near the pipe ends shall not interfere with the readability of identification markings.

Section 10: Marking

10.1 As specified, the following identification markings shall be placed on the coating:

10.1.1 Applicator's name or mark (work order number),

10.1.2 Markings required by the applicable pipe specification or standard (grade, weight, manufacturer, etc.),

10.1.3 Date of coating application,

10.1.4 Coating material identification, and

10.1.5 Additional markings as desired by the applicator or requested by the purchaser (e.g., purchase order number).

References

1. NACE Standard RP0169 (latest revision), "Control of External Corrosion on Underground or Submerged Metallic Piping Systems" (Houston, TX: NACE International).
2. NACE No. 1/SSPC-SP 5 (latest revision), "White Metal Blast Cleaning" (Houston, TX: NACE International, and Pittsburgh, PA: SSPC).
3. NACE RP0287 (latest revision), "Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape" (Houston, TX: NACE).
4. NIST SRM 1363, "Non-Magnetic Coating on Steel," Certified Coating Thickness Calibration Standards (Gaithersburg, MD: NIST).
5. SSPC-PA 2, "Measurement of Dry Coating Thickness with Magnetic Gages" (Pittsburgh, PA: SSPC).
6. NACE No. 2/SSPC-SP 10 (latest revision), "Near-White Metal Blast Cleaning" (Houston, TX: NACE International, and Pittsburgh, PA: SSPC).
7. ISO 8501-1 (latest revision), "Preparation of Steel Substrates Before Application of Paints and Related Products—Visual Assessment of Surface Cleanliness" (Geneva, Switzerland: ISO).
8. ASTM⁽⁸⁾ D 1125 (latest revision), "Standard Test Method for Electrical Conductivity and Resistivity of Water" (West Conshohocken, PA: ASTM).
9. NACE Standard RP0490 (latest revision), "Holiday Detection of Fusion-Bonded Epoxy External Pipeline Coatings of 10 to 30 mils (0.25 to 0.76 mm)" (Houston, TX: NACE International).

⁽⁸⁾ ASTM International (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA 19428.

10. ASTM G 95 (latest revision), "Standard Test Method for Cathodic Disbondment Test of Pipeline Coatings (Attached Cell Method)" (West Conshohocken, PA: ASTM).

11. ASTM G 14 (latest revision), "Standard Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test)" (West Conshohocken, PA: ASTM).

Appendix A—Specific Gravity Determination

Section A1: Scope

A1.1 To determine the specific gravity of a coating material.

A1.2 Two procedures are specified: the liquid displacement method and the pycnometer method. The procedure used must be designated on the supplier's data sheet. Whether the test is run on powder or cured coating must also be specified.

Section A2: Equipment

A2.1 Volumetric flask, 100 mL

A2.2 Balance accurate to 0.1 g

A2.3 Mineral spirits (aliphatic Hydrocarbon BP) having density of D_L

A3.1.2 All apparatus, samples, water, and mineral spirits must be conditioned to room temperature for a minimum of two hours prior to testing.

A3.1.3 Accurately weigh the flask and record the weight, which is designated W_F .

A3.1.4 Add approximately 20 g of coating material to the flask and weigh the flask with coating material. This weight is designated W_{FP} .

A3.1.5 Add sufficient mineral spirits to cover and wet the coating material. Place the stopper on the flask and agitate it for several minutes in order to ensure that there are no air pockets or lumps of dry coating material. Wash the stopper and walls of the flask with mineral spirits until they are free of any coating materials and fill the flask to the 100-mL level. Weigh the flask, coating material, and liquid together to obtain W_{FPL} .

A3.1.6 Calculate the density of the coating according to Equation (A1):

A3.1 Procedure A—Liquid Displacement Method

A3.1.1 This method is used to determine the density of coating material by the liquid displacement method.

$$\text{density} = \frac{W_{FP} - W_F}{100 - \frac{(W_{FPL} - W_{FP})}{D_L}} \quad (\text{A1})$$

A3.1.7 Clean and dry the flask, fill the flask with distilled water to the 100-mL level, and weigh. This weight is designated W_{FW} .

A3.1.8 Clean and dry the flask, fill with mineral spirits to the 100-mL level, and weigh it to determine the weight (W_{FL}) of the mineral spirits used.

A3.1.9 Calculate the specific gravity of the coating material according to Equation (A2):

$$\text{Specific gravity} = \frac{(W_{FP} - W_F)(W_{FL} - W_F)}{[(W_{FL} - W_F) - (W_{FPL} - W_{FP})](W_{FW} - W_F)} \quad (\text{A2})$$

A3.2 Procedure B—Pycnometer Method

A3.2.1 This procedure determines the density of the powder that can be expressed in units of g/cm^3 . Specific gravity is dimensionless; however, the numbers are the same.

A3.2.2 Determine the density of the coating material using an air-comparison pycnometer or equivalent, in accordance with the instrument manufacturer's instructions.

NOTE: Both specific gravity and density vary with temperature. The differences that may be observed within normal room temperature ranges are within the accuracy of the method.

Section A4: Report

A4.1 The following information shall be reported:

A4.1.1 Manufacturer, product code, batch number, and date tested; and

A4.1.2 Specific gravity or density.

Appendix B—Shelf Life Determination

Section B1: Scope

B1.1 To estimate the shelf life of coating materials

Section B2: Equipment

B2.1 0.5-L (pint) glass jars and lids

B2.2 Oven

B2.3 Gel time apparatus

Section B3: Procedure

B3.1 Record the initial gel time (see Appendix C) of the coating material. Place a sample of the coating material into each of two jars and screw on the lids. Store one sample at 24°C (75°F) and the other sample in an oven at 43°C

(109°F). Evaluate the 24°C (75°F) sample monthly and the 43°C (109°F) sample weekly. To evaluate the samples, look for evidence of hard caking of the coating material in the jar. Remove a portion of sample and measure the gel time (see Appendix C).

B3.2 A 30% reduction in gel time indicates the shelf life has been exceeded.

Section B4: Report

B4.1 The following information shall be reported:

B4.1.1 Manufacturer, product code, batch number, and date tested; and

B4.1.2 Shelf life in days for each test temperature.

Appendix C—Gel Time Determination

Section C1: Scope

C1.1 To determine the gel time of a coating material.

C1.2 Two procedures are allowed for gel time determination; the procedure used must be reported on the supplier's data sheet. Tests shall be made in triplicate and averaged.

Section C2: Equipment

C2.1 Hot plate

C2.2 Stop watch or electric timer (0.1-second interval)

C2.3 Spatula

C2.4 Draw-down bar with gap depth of approximately 600 μm (0.024 in.)

C2.5 Stiff wire

C2.6 Calibrated thermometer or contact pyrometer (capable of measuring temperature of hot plate surface)

Section C3: Procedure

C3.1 Procedure A

C3.1.1 Determine gel time by placing approximately 1 g of coating material on a hot plate stabilized at 204 $\pm 3^\circ\text{C}$ (400 $\pm 5^\circ\text{F}$). Take the temperature by placing the thermometer or contact pyrometer on the top center of the heated surface. Use a spatula to coat out at least 650 mm^2 (1.0 in.²) to a uniform thickness of 300 to 350 μm (0.012 to 0.014 in.). Start the timer as soon as the coating material is applied to the hot plate surface. Stir the coating with a stiff wire or spatula, and stop the watch when the coating becomes an unstirrable gelatinous product. The elapsed time is the gel time.

C3.2 Procedure B

C3.2.1 Adjust and stabilize the hot plate to 204 $\pm 3^\circ\text{C}$ (400 $\pm 5^\circ\text{F}$). Take the temperature by placing the thermometer or contact pyrometer on the top center of the heated surface. Place enough powder on the draw-down tool to create a tongue of epoxy powder approximately 25 mm (1.0 in.) wide and 50 mm (2.0 in.) long. In a smooth motion, deposit and draw the epoxy pow-

der across the metal plate while holding the tool at an angle of approximately 45° to the hot plate surface. Start the timing device and deposition of the powder on the hot plate surface simultaneously. Applying only light pressure on the spatula, draw it through the melted powder at short intervals.

C3.2.2 The gel time is the length of time from when the film is applied until the spatula rides up on the gelled surface.

Section C4: Report

C4.1 The following information shall be reported:

C4.1.1 Manufacturer, product code, batch number, and date tested; and

C4.1.2 Gel time in seconds and procedure used.

Appendix D—Glass Transition and Heat of Reaction Determination

Section D1: Scope

D1.1 To determine the glass transition temperature (T_g) and the amount of exothermic heat of reaction (ΔH) of epoxy powder or FBE pipe coating.

D1.2 Round-robin comparisons between laboratories have resulted in significant variation in all parameters measured. Achieving comparable results between laboratories requires strict compliance with this test procedure followed by laboratory comparison testing.

Section D2: Equipment

D2.1 Differential scanning calorimeter (DSC) and accessories

D2.2 Analytical balance accurate to 0.1 mg

D2.3 Knife or file

D2.4 Aluminum pan with cover

D2.5 An inert gas, such as nitrogen

Section D3: Procedure

D3.1 Obtain a 10 ± 1 -mg sample of FBE powder or coating as applicable.

D3.2 Place the sample in a preweighed aluminum pan and put cover in place. Crimp the cover into place with the encapsulating press and obtain the sample weight by subtracting pan and cover weight from the total weight. Place a small vent hole in the lid without damaging the pan.

D3.3 Place sample and reference (as suggested by the instrument supplier) in the DSC cell.

D3.4 Use an inert gas, such as dry nitrogen, to purge the cell.

D3.5 Heat the sample to just beyond the glass transition temperature (T_{g0} for coating powder; T_{g1} for coating chip) using a heating rate of 20°C (36°F)/min. Do not record this scan.

D3.6 Immediately after heating, cool the DSC to 20°C (68°F) or below.

D3.7 Using a programmed rate of 20°C (36°F)/min, heat the sample from 25°C (77°F) to a point about 25°C (45°F) beyond the end of the expected exothermic reaction region as determined from a coating material (powder) scan. Record this scan. Name the glass transition measured in this scan T_{g1} if the sample is a coating chip, or T_{g0} if the sample is coating material (powder).

D3.8 As in Paragraph D3.6, cool the DSC cell to 20°C (68°F) or below and proceed to the next run immediately.

D3.9 Heat the sample at 20°C (36°F)/min, recording the second scan from 25°C (77°F) to a point about 25°C (45°F) past the glass transition. Name the glass transition measured in this scan T_{g2} if the sample is a coating chip or T_{gF} if the sample is the coating material (powder).

Section D4: Calculations

D4.1 The T_g is taken as the point of intersection of the extrapolated baseline at the low-temperature end and the tangent to the curve at the inflection point.

D4.2 Calculate the residual exothermic heat of reaction (ΔH_1) following the instructions provided by the manufacturer of the DSC equipment.

D4.3 For coating chips, determine the change in the T_g value (ΔT_g) by using Equation (D1).

$$\Delta T_g = T_{g2} - T_{g1} \quad (D1)$$

D4.4 Calculate the percent conversion using Equation (D2).

$$\frac{(\Delta H - \Delta H_1)}{\Delta H} \times 100 \quad (D2)$$

Where

ΔH = amount of exothermic heat of reaction

ΔH_1 = residual exothermic heat of reaction

Section D5: Report

D5.1 The following information shall be reported:

D5.1.1 Manufacturer, product code, batch number, and date tested;

D5.1.2 Pipe sample identification, if applicable;

D5.1.3 T_{g0} , T_{gF} , and ΔH for coating material (powder), and T_{g1} , T_{g2} , ΔT_g , and ΔH_1 for coating, including units;

D5.1.4 Type of apparatus used; and

D5.1.5 Percent conversion.

Appendix E—Moisture Analysis Determination**Section E1: Scope**

E1.1 To determine moisture content of FBE powder by direct titration with Karl Fischer reagent to an electrometric endpoint.

Section E2: Equipment and Reagents**E2.1 Equipment**

E2.1.1 Aquameter apparatus

E2.1.2 Lab mill

E2.1.3 Analytical balance

E2.1.4 15-mL serum bottle and cap

E2.1.5 Spatula

E2.1.6 Metal pipette holder—1 mL

E2.1.7 1-mL syringe

E2.1.8 100-mm (4-in.) hypodermic needle

E2.1.9 Plastic syringe (10 mL)

E2.1.10 Automatic buret (50 mL)

E2.2 Reagents

E2.2.1 Chloroform (trichloromethane)

E2.2.2 Generator solution

E2.2.3 Vessel solution (Parts A and B)

E2.2.4 Neutralizing solution

E2.3 Safety Precautions

E2.3.1 Karl Fischer reagent is toxic. During handling of the solutions, avoid breathing of the vapors, and perform all operations in a well-ventilated area.

E2.3.2 Follow the MSDS instructions for personal protection requirements.

Section E3: Procedure

E3.1 Run duplicate samples following the instrument manufacturer's instructions.

Section E4: Report

E4.1 The following information shall be reported:

E4.1.1 Manufacturer, product code, batch number, and date tested; and

E4.1.2 Percent moisture content for each sample and the average moisture content.

Appendix F—Cathodic Disbondment Test**Section F1: Scope**

F1.1 This test provides an assessment of the resistance of the coating to disbondment when subjected to cathodic protection. This test is similar to ASTM G 95.¹⁰ This procedure covers both the 28-day qualification test and the 24-hour qualification and production test.

Section F2: Equipment

F2.1 DC power supply unit

F2.2 Platinum or platinum-coated anode wire

F2.3 Electrolyte solution consisting of 3 wt% sodium chloride (NaCl) in distilled water

F2.4 Plastic cylinder 89 mm (3.5 in.) diameter, 100 mm (4 in.) long

F2.5 High-impedance voltmeter

F2.6 Hot plate or oven capable of maintaining $66 \pm 3^\circ\text{C}$ ($150 \pm 5^\circ\text{F}$)

F2.7 Calomel reference electrode

F2.8 Utility knife

Section F3: Test Specimen

F3.1 Laboratory-Coated Specimen

F3.1.1 The minimum dimensions of the specimen shall be 100 mm (4 in.) square x 6 mm (0.25 in.) thick. The specimen shall be prepared and coated in accordance with Paragraphs 4.3.2 and 4.3.3.

F3.2 Test-Ring Specimen

F3.2.1 The test specimen shall be a 100-mm (4-in.) square segment cut from the test ring.

F3.3 A 3.3-mm (0.13-in.)-diameter holiday shall be drilled in the coating at the center of the specimen.

F3.4 A plastic cylinder shall be attached to the test specimen with the holiday at the center of the cylinder. This cylinder shall have an inside diameter not to exceed 100 mm (4 in.), but not less than 75 mm (3.0 in.).

Section F4: Procedure

F4.1 Pour approximately 350 mL of electrolyte, heated to the proper test temperature, into the plastic cylinder.

F4.2 When testing specimens cut from pipe, use a heat-transfer medium (e.g., steel shot or grit) to provide uniform heating of the test specimen. Use of a metal pan partially filled with the heat-transfer medium into which the specimen is implanted is preferred. Place on a hot plate or in an oven to maintain the electrolyte temperature at $66 \pm 3^\circ\text{C}$ ($150 \pm 5^\circ\text{F}$) for the 24-hour test. Immerse the thermometer and rest it on the test specimen. Run the 28-day test at $20 \pm 3^\circ\text{C}$ ($68 \pm 5^\circ\text{F}$).

F4.3 Connect the negative lead from the power supply to the test specimen and the positive lead to the anode after the test temperature is reached.

F4.4 Turn on the power supply and apply voltage to the test specimen: negative 3.5 V with respect to the calomel

reference electrode for the 24-hour test and negative 1.5 V for the 28-day test.

F4.5 Monitor the voltage, temperature, and electrolyte level at the start, and at every 24-hour interval thereafter. For the 28-day test, the electrolyte level need not be monitored on weekends or other non-working days if a cover plate is loosely fitted over the test cell. Add distilled water as required to maintain the electrolyte level. The electrolyte level shall be maintained at $\pm 25\%$ of the original level and cylinders shall be marked to indicate such.

F4.6 Evaluation Procedure

F4.6.1 After 24 hours, remove the 24-hour test cell from the hot plate or oven, immediately drain the electrolyte from the cell, rinse with tap water, dismantle the test cell, and air cool the sample to room temperature. The evaluation shall be performed within one hour of removal from the hot plate. After 28 days, remove the 28-day test cell using the same procedure.

F4.6.2 Using a utility knife, make 8 radial cuts from the edge of the holiday outward through the coating to the substrate. The radial cuts shall be at least 20 mm (0.8 in.) in length.

F4.6.3 If possible insert the blade of a utility knife under the coating at the holiday edge. Using a levering action, chip off the coating. Continue until the coating demonstrates a definite resistance to the levering action.

F4.6.4 Measure the radius of the disbonded area from the holiday edge along each radial cut and average the measured results.

Note: The cathodic disbondment is relatively equal radius from the holiday edge and does not extend down the radial cut. The coating should not be removed by "forcing" the coating off at the radial cuts. The coating disbondment area is normally easily removed.

Section F5: Report

F5.1 The following information shall be reported:

F5.1.1 Manufacturer, product code, batch number, and date tested;

F5.1.2 Pipe identification, if applicable; and

F5.1.3 Average disbonded radius and length of longest disbonded area.

Appendix G—Test for Porosity of the Coating

Section G1: Scope

G1.1 To determine the degree of porosity or voids in the applied coating

accordance with Paragraphs 4.3.2 and 4.3.3. Specimens from test rings shall be approximately 200 mm (8 in.) long x 25 mm (1.0 in.) wide x pipe wall thickness, with the 200-mm (8-in.) dimension parallel to the axis of the pipe.

Section G2: Equipment

G2.1 Microscope

G2.2 Bench vise or guided-bend jig

G2.3 Dry ice or freezer

G2.4 Utility knife

Section G4: Procedure

G4.1 Cool the test specimen to a temperature low enough to allow removal of the coating when bent over a sharp radius.

G4.2 Pry off a piece of coating from the bent test specimen and examine the coating for porosity at 30X to 40X magnification.

G4.3 Rate the cross-section porosity in the coating by comparing it to the photographs shown in Figure G1.

G4.4 Rate the interface porosity by comparison with Figure G2.

Rating 1



Rating 2



Rating 3



Rating 4



Rating 5



Figure G1:
Examples of Cross-Section Porosity

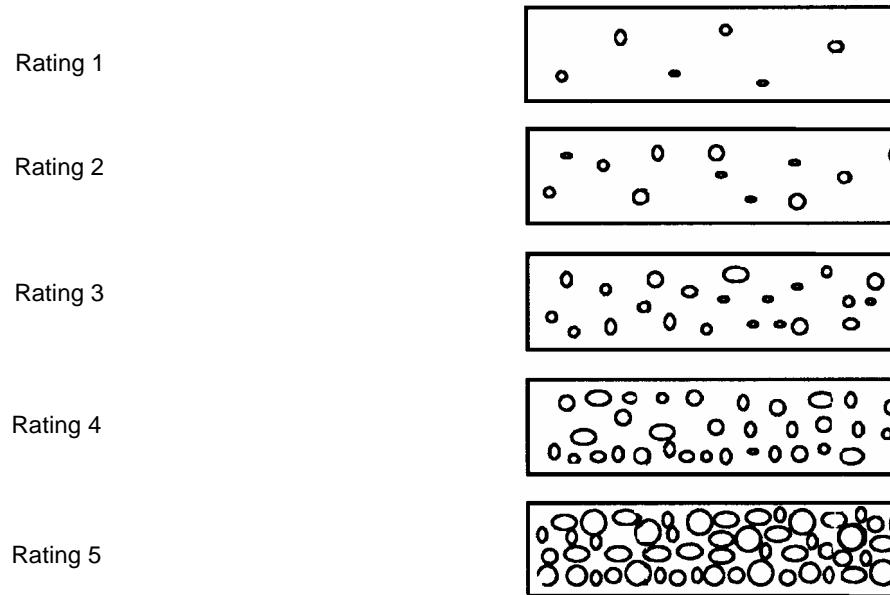


Figure G2:
Examples of Interface Porosity

Appendix H—Flexibility Test

Section H1: Scope

H1.1 To evaluate flexibility of the coating for field bending

Section H2: Equipment

H2.1 Press

H2.2 Bending mandrels of fixed radii (Procedure A) or four-point bending apparatus (Procedure B)

H2.3 Freezer

H2.4 Microscope

Section H3: Test Specimen

H3.1 Laboratory-Coated Specimen

Each specimen shall be approximately 200 mm (8 in.) long x 25 mm (1.0 in.) wide x 6 mm (0.25 in.) thick. The test specimen shall be prepared and coated in accordance with Paragraphs 4.3.2 and 4.3.3.

H3.2 Test-Ring Specimen

Each specimen shall be approximately 200 mm (8 in.) long x 25 mm (1.0 in.) wide x pipe wall thickness, with the 200-mm (8-in.) dimension parallel to the axis of the pipe.

Section H4: Procedure

H4.1 Ensure the test specimen edges have all stress raisers removed and that substrate is exposed along the edges. Place the test specimens in the freezer, cool them to -18°C (0°F) if the bend is to be performed at 0°C (32°F), and hold for at least one hour. If the bend is to be performed at -30°C (22°F) or some other purchaser-specified temperature, then cool the specimens to -10°C (14°F) below the specified bend temperature and hold for at least one hour.

H4.2 Procedure A—The Mandrel Bend

H4.2.1 Calculate the required mandrel radius (R) using Equation (H1):

$$R = \frac{(57.3)(t)}{s} - \frac{t}{2} \quad (H1)$$

where: R = mandrel radius, t = effective strap thickness, and s = strain (deflection) in degrees per pipe diameter (°/PD).

Determine the effective strap thickness (t), which includes the test specimen thickness and any curvature, by placing the test specimen on a flat surface and measuring the thickness as shown in Figure H1.

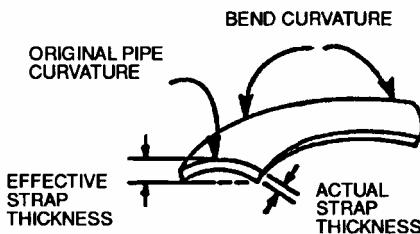


Figure H1:
Determination of Effective Strap Thickness

H4.2.2 If a mandrel of the calculated radius is not available, use the mandrel of the next smaller radius.

NOTE: Because the mandrel flexibility test is to determine the total coating strain before "spring back," do not use a smaller radius to achieve a "residual" (after spring-back-bend radius). Using a smaller radius mandrel can cause the coated test specimen to be bent past the required strain.

H4.2.3 Bend the test specimens over the radius so that the uncoated side is in contact with the mandrel, completing the bend within 30 seconds of removal from the freezer or at the point the specimen reaches the proper bend temperature. The bend test shall take a minimum of 10 seconds for completion.

H4.2.4 Visually inspect the specimens for cracks, tears in the coating, and disbonding of the coating, after the test specimens have warmed to room temperature. The presence of any such defect within 2.5 mm (0.10 in.) of the strap edge does not constitute failure. The presence of strain marks alone does not constitute a failure.

H4.3 Procedure B—The Four-Point Bend

H4.3.1 Estimate the required bend using Equation (H1).

H4.3.2 Bend the test specimens using the four-point apparatus so that the uncoated side is in contact with the support pins. Complete the bend within 30 seconds. The bend test shall take a minimum of 10 seconds for completion.

H4.3.3 Measure the residual bend radius by matching the outer curve of the test specimen to the nearest arc from Figures H2, H3, H4, or H5.

H4.3.4 Visually inspect the test specimens for cracks, tears in the coating, and disbonding of the coating after the specimens have warmed to room temperature. The presence of any such defect within 2.5 mm (0.1 in.) of the strap edge or within 12 mm (0.50 in.) of the support pins does not constitute a failure. The presence of strain marks alone does not constitute a failure.

H4.4 Calculate the permanent (residual) strain using Equation (H2):

$$^{\circ} / PD = \frac{(57.3)(t)}{R - t / 2} \quad (H2)$$

where t = "effective thickness" of coated strap, as defined in Paragraph H4.2.1; R = bend radius of outer curve of test panel.

Section H5: Report

H5.1 The following information shall be reported:

H5.1.1 Manufacturer, product code, batch number, and date tested;

H5.1.2 Pipe identification, if applicable; and

H5.1.3 Specimen effective thickness, angle of deflection in degrees for each pipe diameter for passing bend, and test procedure used. Record permanent (residual) strain radius only for the four-point bend test method.

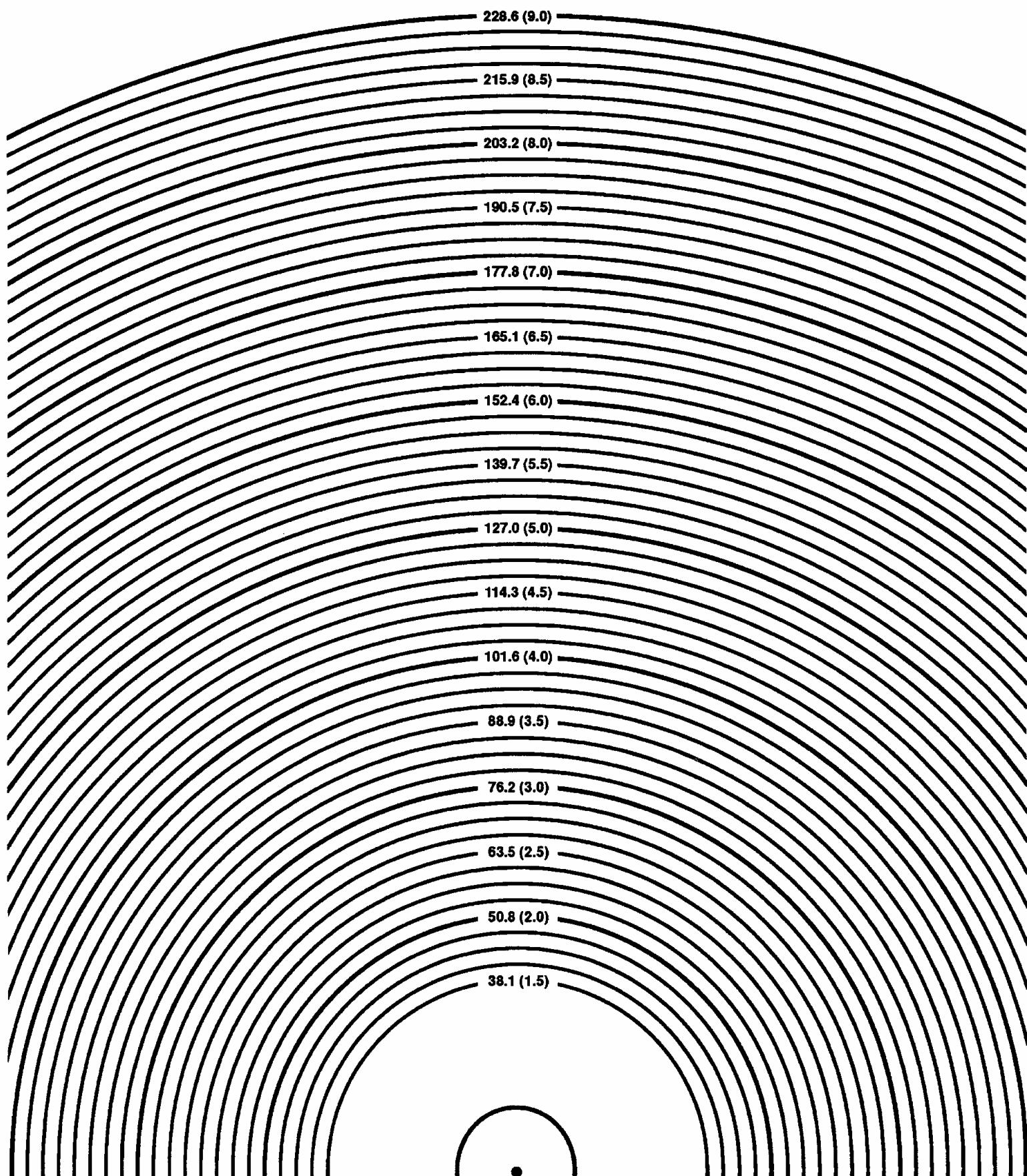


Figure H2:
Radii 3.18-mm (0.125-in.) Increments

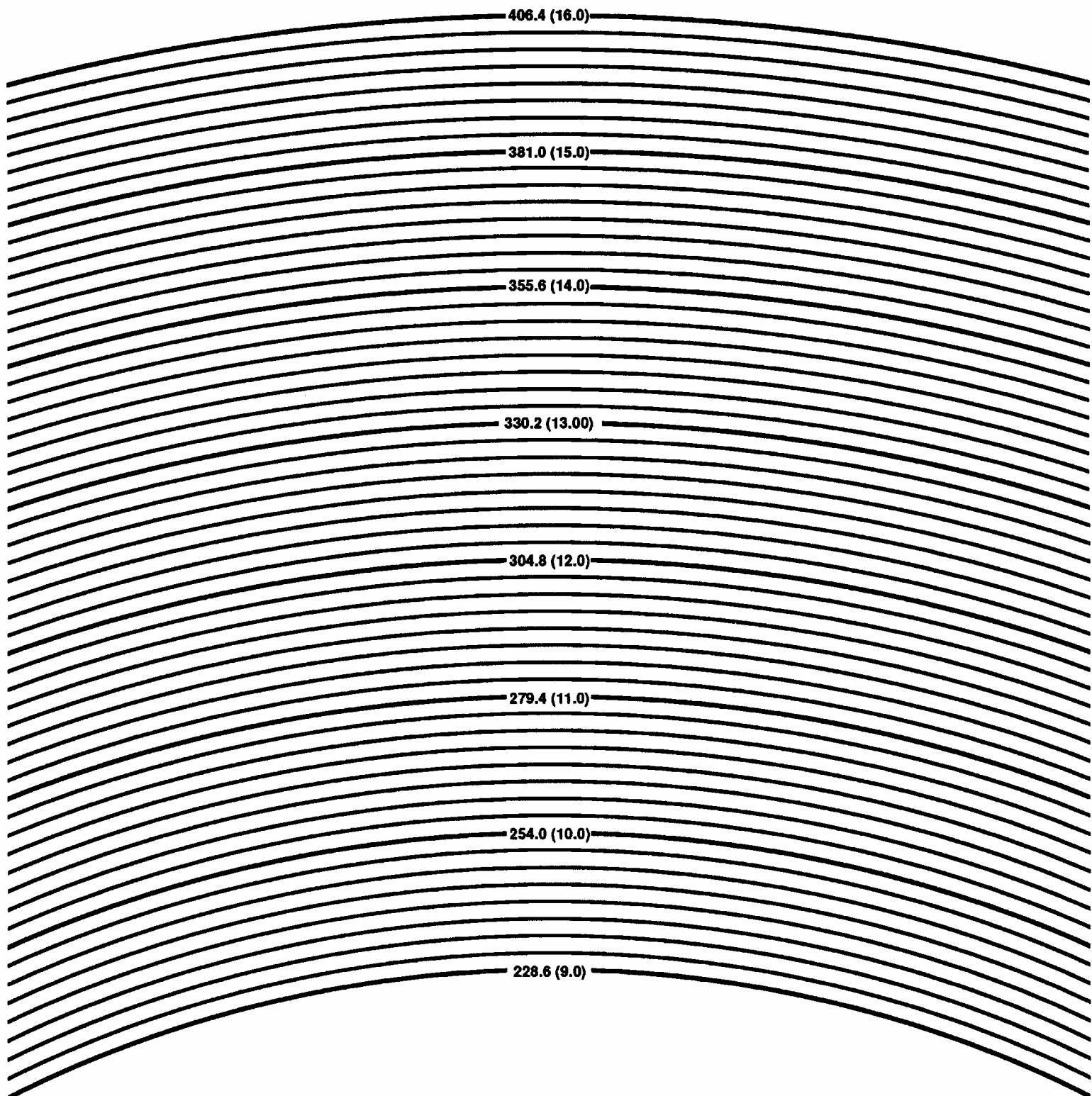


Figure H3:
Radii in 3.18-mm (0.125-in.) Increments

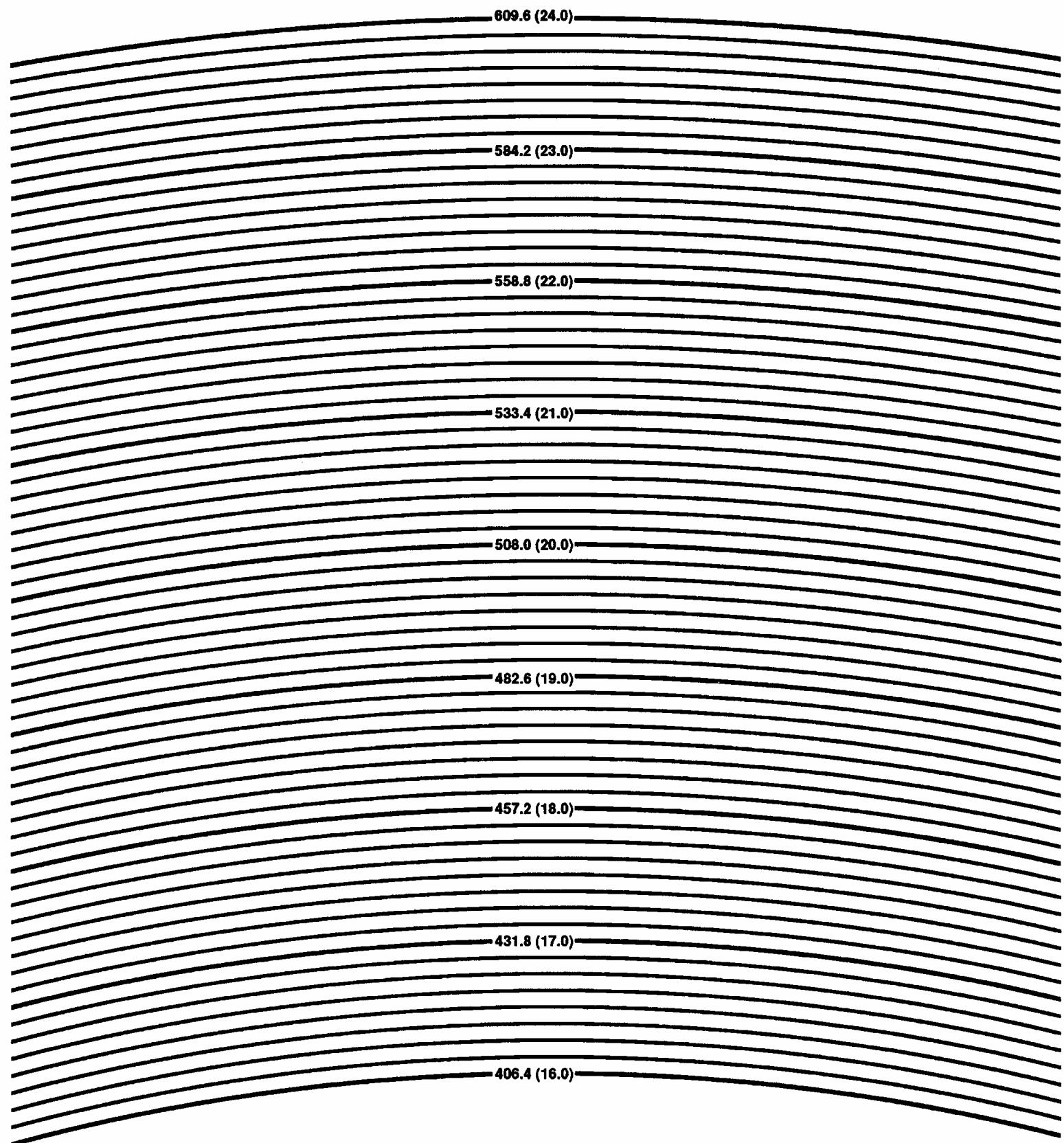


Figure H4:
Radii in 3.18-mm (0.125-in.) Increments

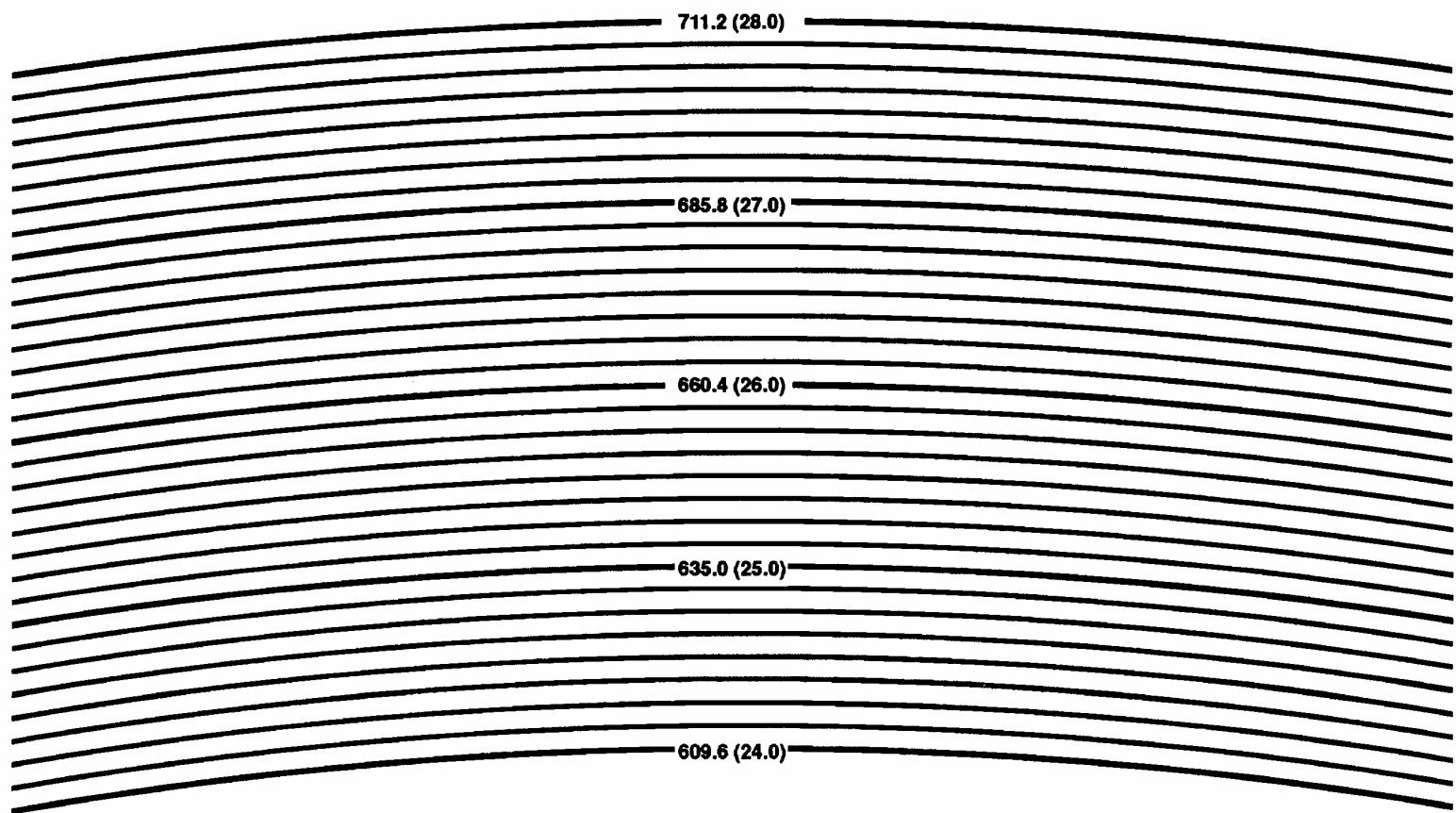


Figure H5:
Radii in 3.18-mm (0.125-in.) Increments

Appendix I—Impact Test

Section I1: Scope

I1.1 To provide a method for assessing the coating's resistance to damage by impact.

Section I2: Equipment

- I2.1 ASTM G 1411 Impact Tester, or equivalent
- I2.2 DC holiday detector
- I2.3 41-mm (1.6-in.)-radius mandrel hardened to 55 \pm 5 HRC

Section I3: Test Specimen

I3.1 Laboratory-coated test specimens shall be approximately 100 mm (4 in.) square x 6.0 mm (0.25 in.) thick. Specimens shall be prepared and coated in accordance with Paragraphs 4.3.2 and 4.3.3.

I3.2 Test-ring specimens shall be approximately 200 mm (8 in.) long x 25 mm (1.0 in.) wide x wall thickness. The 200-mm (8-in.) dimension shall be parallel to the axis of the pipe.

Section I4: Procedure

I4.1 ASTM G 14 Impact Tester shall be modified as follows: A tup (heavy metal object) that can accommodate a 15.9-mm (0.625-in.)-diameter ball bearing shall be used. The tup shall have a hardness of 50 to 55 HRC.

I4.2 The modified impact tester shall be screwed to a block of laminated wood. The wood block should measure

approximately 610 mm (24 in.) on each side and have a top facing of hardwood.

I4.3 The impact test shall be carried out with 1.0-kg (2.2-lb) weight in a 1.0-m (39-in.) graduated slotted tube. The ball bearing shall be rotated every 10 impacts to a new location and replaced after 200 impacts.

I4.4 Using a flat anvil for laboratory-coated test specimens and the 41-mm (1.6-in.)-radius mandrel for test-ring specimens, the weight shall be allowed to fall onto the tup such that the metal substrate is not deformed.

I4.5 Test temperature shall be 23 \pm 3°C (73 \pm 5°F).

I4.6 Each impact indentation on the test specimen shall be checked for substrate exposure with a holiday detector set at approximately 1,600 V or with a wet-sponge, low-voltage holiday detector.

Section I5: Report

I5.1 The following information shall be reported:

- I5.1.1 Manufacturer, product code, batch number, and date tested;
- I5.1.2 Pipe identification, if applicable;
- I5.1.3 The maximum amount of energy (J or in.-lb) that the coating absorbed without substrate exposure; and
- I5.1.4 Holiday detection voltage.

Appendix J—Hot-Water Soak

Section J1: Scope

J1.1 To provide an accelerated assessment of the coating's adhesion to the substrate in a hot, wet environment.

Section J2: Equipment

- J2.1 Hot plate or oven capable of maintaining the test temperature within \pm 3°C (\pm 5°F) of specified value
- J2.2 Plastic cylinder (such as in Appendix F)
- J2.3 Utility knife
- J2.4 Deionized or reverse osmosis water.

J2.5 For full immersion test, a pot and hot plate or heated water container capable of maintaining test temperatures within \pm 3°C (\pm 5°F).

Section J3: Test Specimen

J3.1 Laboratory-coated test specimens shall be approximately 100 mm (4 in.) square x 6.0 mm (0.25 in.) thick. Test-ring specimens shall be approximately 100 mm (4 in.) square x pipe wall thickness. For pipe smaller than 100-mm (4-in.) diameter, the length shall be approximately 100 mm (4 in.).

J3.2 Laboratory-coated specimens shall be prepared and coated in accordance with Paragraphs 4.3.2 and 4.3.3.

Section J4: Procedure

J4.1 For Cylinder Test

J4.1.1 Glue the plastic cylinder approximately centered onto test specimen.

J4.1.2 Pour approximately 350 mL of deionized or reverse osmosis water into the plastic cylinder.

J4.1.3 When testing specimens cut from pipe, use a heat-transfer medium (e.g., steel shot or grit) to provide uniform heating of the specimen. Use of a metal pan partially filled with the heat-transfer medium into which the test specimen is implanted is preferred. Place on a hot plate or in an oven to maintain the metal temperature at $66 \pm 3^\circ\text{C}$ ($150 \pm 5^\circ\text{F}$) for the 24-hour test.

J4.2 For Full Immersion Test

J4.2.1 Heat deionized or reverse osmosis water in the container to $66 \pm 3^\circ\text{C}$ ($150 \pm 5^\circ\text{F}$).

J4.2.2 Place test specimen in the container. Be sure there is enough water in the container to keep the test specimen completely immersed for the duration of the test. Add hot deionized or reverse osmosis water as needed.

J4.3 Water should be changed after each test and the container cleaned.

J4.4 Evaluation Procedure

J4.4.1 After 24 hours, remove the test cell from the hot plate or oven and immediately drain the water and dismantle the test cell. While the sample is hot, use a utility knife to scribe a rectangle approximately 25 x 12 mm (1 x 0.5 in.) through the coating to the substrate. Air cool the sample to room temperature. The evaluation shall be performed within one hour of removal from the hot plate.

J4.4.2 The utility knife blade shall have a blade thickness no greater than 7.6 mm (0.30 in.). If possible, insert the utility knife 3.20 mm (0.125 in.) under the coating at a corner of the scribed rectangle. Using a levering action, attempt to remove the coating. After three attempts, if the coating cannot be easily removed in pieces the size of or larger than the inserted portion of the blade, rotate to the next corner. If the coating can be removed in pieces of coating the size of or larger than the inserted blade, continue inserting the knife

and levering under the coating until either all of the coating in the rectangle is removed or the coating demonstrates a definite resistance to the levering action. Coating removed by following the scribed lines, gouging, cutting, knife-point scrapes, or by forcing the knife blade through the coating shall not be considered adhesion failure. Only coating removed by the levering action are considered to be adhesion loss.

J4.4.3 Rate the adhesion of the coating within the rectangle as follows:

J4.4.3.1 Rating 1—After three attempts at each corner, the coating pieces removed are the same size as, or smaller than, the size of the inserted knife point;

J4.4.3.2 Rating 2—Coating can be removed in chips that are slightly larger than the inserted knife point. Coating remains on 50% or more of the scribed area. In areas where coating has been removed by chipping, partial coating fragments may remain firmly attached to the steel surface and shall be counted as part of the 50% or more with coating;

J4.4.3.3 Rating 3—Coating can be removed in chips larger than the inserted knife point. Coating remains on 20% or more of the scribed area. In areas where coating has been removed by chipping, partial coating fragments may remain firmly attached to the steel surface and shall be counted as part of the 20% or more of coating;

J4.4.3.4 Rating 4—The coating can be easily removed in strips or large chips considerably larger than the inserted knife point and coating remains on less than 20% of the rectangle, and;

J4.4.3.5 Rating 5—The coating in the rectangle can be completely removed as a single piece or in a few large chips with little effort.

Section J5: Report

J5.1 The following information shall be reported:

J5.1.1 Manufacturer, product code, batch number, and date tested;

J5.1.2 Pipe identification, if applicable; and

J5.1.3 The rating obtained.

Appendix K—Test for Interface Contamination of the Coating

Section K1: Scope

K1.1 To determine degree of visual contamination on pipe surface.

NOTE: This procedure does not detect the presence of hydrocarbons, salts, or other nonvisual contaminants.

Section K2: Equipment

K2.1 Microscope

K2.2 Utility knife with sharp point

Section K3: Test Specimen

K3.1 Test specimens shall be approximately 200 mm (8 in.) long x 25 mm (1.0 in.) wide x pipe wall thickness, with the 200-mm (8-in.) dimension parallel to the axis of the pipe.

Section K4: Procedure

K4.1 Use the utility knife to remove an approximately 3 x 19 mm (0.125 x 0.75 in.) piece of coating from the test

specimen subsequent to bending in accordance with Appendix G.

K4.2 Examine the metal interface side of the coating with the microscope at 30X to 40X magnification, and rate the percentage of interface contamination. The preferred method for determining area percentage is point counting, using an optical microscope of at least 30X to 40X magnification and a lens reticle with a point-count grid containing at least 25 points.

Section K5: Report

K5.1 The following information shall be reported:

K5.1.1 Manufacturer, product code, batch number, and date tested;

K5.1.2 Pipe identification; and

K5.1.3 Percentage of interface contamination.

Standard Recommended Practice

Field-Applied Fusion-Bonded Epoxy (FBE) Pipe Coating Systems for Girth Weld Joints: Application, Performance, and Quality Control

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Foreword

This NACE standard recommended practice provides the most current technology and industry practices for the use of field-applied, fusion-bonded epoxy (FBE) external pipe coating systems for girth weld joints. This standard is intended for use by corrosion control personnel, design engineers, project managers, purchasing personnel, and construction engineers and managers. It is applicable to underground steel pipelines in the oil and gas gathering, distribution, and transmission industries.

This standard was prepared by NACE Task Group 249 on Fusion-Bond Epoxy Coatings for Weld Joints on Pipelines. This Task Group is administered by Specific Technology Group (STG) 03 on Coatings and Linings—Immersion/Buried. It is also sponsored by STG 04 on Protective Coatings and Linings—Surface Preparation, and STG 35 on Pipelines, Tanks, and Well Casings. This standard is issued by NACE International under the auspices of STG 03.

In NACE standards, the terms *shall*, *must*, *should*, and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. The term *should* is used to state something considered good and is recommended but is not mandatory. The term *may* is used to state something considered optional.

**NACE International
Standard
Recommended Practice**

**Field-Applied Fusion-Bonded Epoxy (FBE) Pipe Coating
Systems for Girth Weld Joints: Application, Performance, and
Quality Control**

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Section 1: General

1.1 This standard presents guidelines for establishing minimum requirements to ensure proper application and performance of a field-applied fusion-bonded epoxy (FBE) coating system to the external surfaces of pipe at girth weld joints. Included are methods for qualifying and controlling the quality of FBE, guidelines for its proper application, and inspection and repair techniques to ensure its long-term performance.

1.2 This standard is applicable to FBE coating systems used to prevent corrosion in conjunction with cathodic protection.

1.3 All applicable safety and environmental codes, rules, and regulations must be followed when using this standard.

Section 2: Definitions

Applicator: The organization responsible to the purchaser for the coating application.

Approved FBE Powder: A fusion-bonded epoxy powder that meets the criteria in NACE Standard RP0394.¹

Coating Materials: Fusion-bonded epoxy powder (FBE).

Cutback Area: Area of each section of line pipe that was left uncoated at the coating mill/plant to facilitate welding of adjacent pipe joints.

Field Joint Area: The area of pipe over which the coating is applied in the field after welding of adjacent pipes.

Holiday: A discontinuity in a protective coating that exposes unprotected surface to the environment.

Inspector: The authorized agent of the purchaser.

Purchaser: The owner company or the authorized agency that has the authority over the pipe to which the coating is to be applied.

Repair Area: Area of original coating system that has been damaged and is being repaired using the coating materials.

Shelf Life: The maximum-allowable storage time for a coating material prior to its use.

Supplier: The manufacturer and/or distributor of the coating material and its authorized technician.

Section 3: Coating Systems

3.1 The standard FBE required for normal conditions contains the following components:

(a) FBE powder in accordance with NACE Standard RP0394.

Section 4: Coating Material

4.1 Coating Material Supplier Information

4.1.1 Upon request, the coating material supplier shall furnish the following information in writing to the purchaser and/or applicator:

- (a) Instructions for handling and storing the coating material;
- (b) Laboratory performance test results of the basic physical properties of the coating materials;
- (c) Batch certificates;
- (d) Material safety data sheets (MSDS); and

(e) Any other technical information regarding the FBE powder that is normal and customary.

4.2 Handling of Coating Materials

4.2.1 Coating material batches shall be identified by a batch coding system devised by the supplier. The batch code shall include a reference to the date of manufacture. Coating materials shall be shipped and stored according to recommendations from the supplier, and so that contamination or adverse effects on the coating are avoided.

4.2.2 Shelf Life: Any batch of coating material that has exceeded the recommended shelf life may be rejected by the purchaser.

4.2.2.1 At the discretion of the purchaser, any batch of coating material that has exceeded the recommended shelf life may be tested to verify that it meets or exceeds the requirements as set forth herein or by other industry standards as

agreed on by the purchaser and the applicator. The expense of such tests shall not be the responsibility of the purchaser. The purchaser shall not be under any obligation to accept material that has exceeded its shelf life.

4.2.2.2 Any rejected coating material shall be immediately removed from the job site.

Section 5: Coating and Applicator Performance

5.1 Recommended characteristics, properties and performance of an applied coating system are outlined in NACE Standards RP0394 and RP0169.²

5.2 The need for performance testing shall be determined according to performance history. Three categories shall be used:

5.2.1 Established FBE coating system to be used in the established service or environment.

5.2.2 Established FBE coating system to be used in a new service or environment.

5.2.3 New FBE coating system with no service history.

5.3 An FBE coating system that meets one or more of the following criteria for a period of at least five years, without formulation change, shall be considered an established FBE coating system:

5.3.1 No significant increase in the cathodic protection current density, attributable to deterioration of the coating, required to maintain the pipe-to-soil potential in accordance with NACE Standard RP0169.

5.3.2 No significant decrease in the coating's effectiveness as a result of moisture transmission.

5.4 An established FBE coating system to be used in the established service or environment shall not require additional performance testing.

5.5 An established FBE coating system to be used in a new service or environment may be required to have additional performance testing.

5.6 A new FBE coating system with no service history shall be required to have additional performance testing and it

shall be tested for the following properties as required by NACE Standard RP0394:

5.6.1 Electrical resistance;

5.6.2 Dielectric strength;

5.6.3 Coating adhesion (hot water soak);

5.6.4 Water vapor permeability (perms);

5.6.5 Maximum cathodic disbondment;

5.6.6 Adhesion;

5.6.7 Impact resistance; and

5.6.8 Glass transition temperature.

5.7 Applicator Performance

5.7.1 Test rings are required to qualify the applicator. Coating shall be applied to a test pipe according to Sections 6 and 7 of this standard. Ring samples cut from test pipe should be approximately 30 cm (12 in.) long. After samples are cut from the ring, the applicator shall mark the date of coating application on the unused portion of the ring sample. Testing of the samples shall commence on the same day as the coating application. Required tests are listed in Paragraphs 5.6.1 to 5.6.8. Cutting and rebeveling shall be at the applicator's expense. Pipe used shall be provided at the purchaser's expense. When additional test pipes are sampled to reduce the size of the failed lot, all costs except for the cost of the pipe sample shall be borne by the applicator. The purchaser may require additional test rings. The cost of pipe, coating, and cut-off for these test rings shall be borne by the purchaser.

Section 6: Surface Preparation of Pipe

6.1 The area to be coated (steel and mill coating) shall be cleaned of all grease, dirt, dust, or any other foreign material according to SSPC⁽¹⁾-SP 1.³ This area should be at least 30 cm (1 ft) on each side of the weld area. Visible oil and grease spots shall be removed by wiping the contaminated area with an approved emulsifying detergent or nonresidual solvent.

6.2 Prior to abrasive blasting, all weld spatter shall be removed using a file or other acceptable method. NACE Standard RP0178⁴ provides a good representation of a proper weld area. Any blast profile with an altered (destroyed) area greater than 3 cm² (0.5 in.²) shall be reblasted prior to induction heating.

6.3 All sharp edges of the weld bead or any raised portion of the weld crown shall be rounded by hand filing or a purchaser-approved method.

6.4 Prior to abrasive blasting, preheating may be necessary to bring the steel temperature above the dewpoint.

6.5 On each side of the weld joint, the bare metal cutback and a strip of mill-applied coating shall be prepared by abrasive blasting. The mill-applied coating shall not be removed during abrasive blasting, but cleaned and roughened (slightly etched, feathered, or sugared) by brush blasting for a minimum of 5 cm (2 in.) with a taper toward the weld bead. The mill-applied coating may be hand abraded using abrasive paper, pads, or wheels in lieu of abrasive blasting, according to the purchaser's specification.

6.6 The bare metal in the girth weld area shall be abrasive blasted to a minimum NACE No. 2/SSPC-SP 10⁵ near-white metal finish. A photographic or visual standard, such as SSPC-VIS 1,⁶ shall be used to verify that a near-white finish has been achieved. The blast abrasive chosen should be selected to achieve a blast profile of 64 to 100 µm (2.5 to 4.0 mils). This profile shall be verified in accordance with NACE Standard RP0287.⁷ The purchaser may make standards available for comparison with the anchor pattern.

6.7 Water/oil traps and filters shall be used on all blast-cleaning apparatus. The water/oil traps and filters must be checked and drained or replaced periodically as necessary. Any blast-cleaned surface contaminated with water or oil shall be cleaned and reblasted until the appropriate standard of cleanliness has been achieved.

6.8 The abrasive blast operation should be at least three welds ahead of the coating application operation to prohibit contamination of the powder application, but in no case shall the abrasive blasted weld joints be allowed to visibly

rust prior to coating. If flash rusting does occur, the area shall be reblasted.

6.9 If jagged or rough areas remain along the edge of the mill-applied coating after blast cleaning, or if any of the coating has disbanded, these areas shall be removed until a sound coating has been obtained. The areas shall then be recleaned.

6.10 File or abrasive sanders shall remove raised slivers, scabs, laminations, or bristles of steel remaining on the newly cleaned surface. This cleaning operation shall not burnish or completely destroy the anchor pattern.

6.11 During periods of inclement weather, cleaning and coating operations shall be discontinued unless tents, shelters, wind shields, etc., can be erected. The shelters must fully exclude the weather conditions to provide an acceptable environment for the coating operation.

6.12 Just prior to heating, the area to be coated shall be blown clean of all dust, sand, etc., using clean, dry, high-pressure air. It is recommended that this area also be brush-cleaned with a clean, dry bristle-type paintbrush.

6.13 The pipeline on either side of the weld joint area shall be blown free of all standing dust, sand, etc. with clean, dry, high-pressure air.

6.14 Preheating

6.14.1 The area to be coated shall be heated by high-frequency induction-heating coils to a temperature within a range defined in accordance with the supplier's written recommendations.

6.14.2 The heating equipment shall be approved by the purchaser and shall be sized to ensure that the entire area to be coated reaches the required temperature. The induction coil shall have been tested for heat profile and should have a difference across the weld joint not exceeding 10°C (18°F). The heating time to reach the required temperature shall be established.

6.14.3 The temperature of the steel shall be checked using temperature-indicating crayons or by an approved heat-measuring device.

6.14.4 At no time during the entire coating process shall the pipe be heated to a temperature in excess of 260°C (500°F). If the pipe temperature exceeds 260°C (500°F), the purchaser must be informed immediately.

⁽¹⁾ SSPC: The Society for Protective Coatings (SSPC), 40 24th St, 6th Floor, Pittsburgh, PA 15222-4656.

Section 7: Coating Application

7.1 Prior to coating the pipe, the surface must be in compliance with Section 6 of this standard.

7.2 Machine Application of Powder

7.2.1 The powder application machine shall be placed around the heated weld joint immediately after the heater is removed.

7.2.2 The coating machine shall travel at a uniform speed and apply a correct width of coating, centered on the girth weld.

7.2.3 To prevent differential curing of the resin powder, the total thickness of coating required shall be applied by the coating machine in the least number of passes possible. At least two passes are required.

7.3 Manual Application of Powder

7.3.1 The powder shall be applied to the heated weld area from the delivery hose on the flocking unit.

7.3.2 Holding the delivery hose by hand and using the spraying technique, the powder flow can be directed onto the area to be coated. As the spraying operation is continued around the circumference of the weld area, the thickness of the coating can be controlled by the speed at which the delivery hose is fanned over the hot surface. The FBE powder shall be applied to the girth weld area to a minimum thickness of 640 μm (25 mils), measured dry on the apex of the weld. Maximum thickness shall be as specified by the purchaser, but not exceeding the manufacturer's recommendations. The coating shall overlap the mill-applied coating a minimum of 5 cm (2 in.) on each side of the weld area. Maximum thickness at the overlap should be 1 mm (40 mils).

7.4 Application of Powder with Dual FBE Coating Systems

7.4.1 The powder shall be applied to the heated weld area by either the mechanical method or the manual method as detailed in Paragraphs 7.2 and 7.3.

7.5 General Procedures

7.5.1 The coating operation shall immediately follow the heating operation. The coating material shall be an approved FBE powder, preferably the same category as used on the initial coating of the line pipe, but may be of contrasting color.

7.5.2 The FBE powder shall be fluidized, then flock-applied to the girth weld area to a minimum thickness of 640 μm (25 mils), measured dry on the apex of the weld. Maximum thickness shall be as specified by the

purchaser, but not exceeding the manufacturer's recommendations. The coating shall overlap the mill-applied coating a minimum of 5 cm (2 in.) on each side of the weld area. Maximum thickness at the overlap should be 1 mm (40 mils).

7.5.3 Care shall be taken to prevent the spray head, braces, hoses, etc., from dragging on the ground during application operations.

7.5.6 Dirt, dust, or deleterious material must not be allowed to contaminate the powder-coated area during the application and curing stages.

7.5.7 The powder container, hoses, etc., on the application unit shall be cleaned after each workday.

7.5.8 The FBE powder shall be stored at a stock warehouse location in such a manner that its temperature is in accordance with the manufacturer's written recommendations and it is protected from any moisture contamination.

7.5.9 The FBE powder shall be transported and stored along the right-of-way in such a manner that its temperature is never below freezing and is in accordance with the manufacturer's written recommendations. The powder containers should never be in direct sunlight or near hot equipment. The powder shall be taken from the warehouse to the right-of-way only in quantities to be used for one day. The powder shall always be protected from any moisture contamination. The inspector shall advise the purchaser when improper conditions are being encountered. Open containers of powder shall either be disposed of daily or, if the purchaser allows, resealed and reused within 24 hours.

7.5.10 If the ambient air temperature falls, it may be necessary to increase the heating temperature, subject to limits of Paragraph 6.14, to provide adequate curing energy.

7.6 Curing

7.6.1 To prevent coating damage, the pipe shall not be handled until the field joint coating is sufficiently cured. During the pre-job meeting the purchaser and applicator shall agree on the definition of "sufficiently cured."

7.6.2 Adhesion of the cured coating to the surface of the pipe shall be checked periodically by pushing a sharp knife blade through the fully cured coating to the surface of the pipe in a whittling motion. Attempts shall be made to remove the coating from the surface. The

coating shall fully adhere and shall not easily strip, chip, or peel from the steel.

7.6.3 All areas tested for adhesion shall be repaired in accordance with Section 8 of this standard.

Section 8: Inspection and Repair

8.1 Coating System Inspection and Tests

8.1.1 The entire coated surface of each length of pipe shall be inspected with a holiday detector in accordance with NACE Standard RP0274.⁸

8.1.1.1 Inspection is best performed when the temperature of the coating is less than 90°C (194°F). Higher temperatures may be acceptable as long as the holiday detector does not create excessive holidays. There shall be no gaps in the electrode or separations between the electrode and the surface of the coating. The detector operation shall readily and audibly indicate all holidays. All holidays and other coating defects shall be marked with a marker in a manner that shall not adversely affect the patching operation.

8.1.2 The purchaser reserves the right to supply a nonpulsating holiday detector set at 2,000 volts DC, and to recheck the coating. If holidays are found, they shall be repaired by the applicator.

8.1.3. If there is any evidence or indication that the mill coating is being damaged during heating or coating of the weld joint, it must be brought to the attention of the purchaser's inspector immediately.

8.1.4 The thickness of the finished cured coating system shall be checked and verified using a dry-film thickness gauge that has been properly calibrated using certified coating thickness calibration standard chips.

The FBE coating shall have a minimum dry thickness of 640 µm (25 mils) and a maximum thickness as specified by the purchaser, measured on the apex of the girth weld, when used with dual FBE powders.

8.1.5 At various times during the coating operation the purchaser may request complete cure tests of the coating. Third-party laboratory tests shall be conducted with the complete cooperation of the applicator. The purchaser shall specify the testing vendor.

8.1.6 Cured coating shall be of uniform color, gloss, and thickness, and shall be free of blisters, pinholes, fisheyes, sags, or other irregularities.

8.2 Coating System Repairs

8.2.1. All coating defects should be repaired using materials that are compatible with and shall adhere well to the FBE powder coating and are approved by the purchaser. All holidays shall be repaired utilizing a purchaser-approved technique. Patched areas should overlap the parent coating a minimum of 13 mm (0.50 in.). The surface to be repaired should be suitably prepared to ensure adhesion of the patch material. Minimum thickness of the repaired coating shall be in accordance with Section 7 of this standard.

8.2.2 Holidays along the pipe joint shall be inspected and repaired to the satisfaction of purchaser's authorized representative.

References

1. NACE Standard RP0394 (latest revision), "Application, Performance, and Quality Control of Plant-Applied, Fusion-Bonded Epoxy External Pipe Coating" (Houston, TX: NACE).
2. NACE Standard RP0169 (latest revision), "Control of External Corrosion on Underground or Submerged Metallic Piping Systems" (Houston, TX: NACE).
3. SSPC-SP 1 (latest revision), "Solvent Cleaning" (Pittsburgh, PA: SSPC).
4. NACE Standard RP0178 (latest revision), "Fabrication Details, Surface Finish Requirements, and Proper Design Considerations for Tanks and Vessels to Be Lined for Immersion Service" (Houston, TX: NACE).
5. NACE No. 2/SSPC-SP 10 (latest revision), "Near-White Blast Cleaning" (Houston, TX: NACE and Pittsburgh, PA: SSPC).
6. SSPC-VIS 1 (latest revision), "Visual Standard for Abrasive Blast Cleaned Steel" (Pittsburgh, PA: SSPC).
7. NACE Standard RP0287 (latest revision), "Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape" (Houston, TX: NACE).
8. NACE Standard RP0274 (latest revision), "High-Voltage Electrical Inspection of Pipeline Coatings Prior to Installation" (Houston, TX: NACE).

Standard Recommended Practice

Field Measurement of Surface Profile of Abrasive Blast-Cleaned Steel Surfaces Using a Replica Tape

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Foreword

Prior to the application of protective coatings to steel surfaces, the surfaces are frequently cleaned by abrasive impact. Such abrasive cleaning roughens the steel surface, providing a surface profile. The resulting degree of surface roughness is affected by many variables, including the type, size, and shape of the abrasive used, velocity of impact, etc.

Many techniques and instruments are currently used to measure the surface texture or surface profile; however, those that provide a high degree of precision are suitable only for laboratory use. Because a surface profile range is frequently specified and the recommended surface profile is different for various types of coatings, a means of surface profile measurement at the work site is desirable.

The purpose of this standard recommended practice is to provide a procedure to measure the surface profile of abrasive blast cleaned steel. The measurement technique utilizes a tape that replicates the surface profile. The thickness of the tape (with the profile replicate) is then measured with a dial micrometer to determine the surface profile. Other common methods of measuring surface profile are not discussed. The procedure described in this standard is limited to the measurement of surface profile with a profile defined as being between 38 and 114 μm (1.5 and 4.5 mils) prepared to a white metal,¹ near-white metal,² or commercial³ blast-cleaned surface finish.

The determination of surface profile depends on its definition. This procedure determines surface profile only as it is defined in this standard (see Paragraph 1.2.1). If surface profile is defined differently, the procedures outlined in this standard may not provide accurate results. Individual measurements of the surface profile of an abrasive blast-cleaned metal surface vary significantly from area to area over a given surface.

Appendix A presents the results of a round-robin series of measurements by several individuals, and illustrates the degree of accuracy of the procedure described in this standard. Appendix B statistically summarizes the data shown graphically in Appendix A. Panels used in the tests shown in Appendix A were hot-rolled and nonrusted. The extraneous profile of severely rusted surfaces reduces the accuracy of the procedure. Measurements are taken on relatively flat areas where the surface appears to be continuous and uniform.

This standard is intended for use by persons, usually in an inspection capacity, who have a requirement to measure the surface profile of abrasive blast-cleaned steel prior to the application of a protective coating.

This standard was originally prepared in 1987 by NACE International Task Group T-6G-19, a component of Unit Committee T-6G on Surface Preparation for Protective Coatings. The standard was reaffirmed in 1991 and 1995 by Unit Committee T-6G, and in 2002 by Specific Technology Group (STG) 04 on Protective Coatings and Linings—Surface Preparation. This standard is issued by NACE International under the auspices of STG 04.

In NACE standards, the terms *shall*, *must*, *should*, and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. The term *should* is used to state something considered good and is recommended but is not mandatory. The term *may* is used to state something considered optional.

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Field Measurement of Surface Profile of Abrasive Blast-Cleaned Steel Surfaces Using a Replica Tape

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Section 1: General

1.1 This standard describes a procedure for on-site measurement of the surface profile of abrasive blast-cleaned steel surfaces that have a surface profile, as defined in Section 2, between 38 and 114 μm (1.5 and 4.5 mils). The procedure has been demonstrated to correlate well with the

measurements obtained by the defined laboratory procedure on nonrusted panels prepared to NACE No. 1/SSPC⁽¹⁾-SP 5,¹ NACE No. 2/SSPC-SP 10,² or NACE No. 3/SSPC-SP 6.³ Suggestions are given regarding the implementation and use of this procedure.

Section 2: Definitions

Surface Profile: For the purposes of this standard, surface profile is defined as that value obtained when the profile of a surface is measured using an optical microscope as described in NACE Publication 6G176.⁴ The laboratory procedure described in 6G176 entails averaging a stat-

istically significant number of readings (20 to 30) using an optical microscope, magnification of 250 to 280X, with a field of 0.41 to 0.46 mm (0.016 to 0.018 in.) diameter, and recording the distance measured from the top of the highest peak to the bottom of the lowest valley in the field of view.

Section 3: Equipment

3.1 Replica Tape

3.1.1 The replica tape consists of a compressible foam containing microscopic bubbles attached to a polyester film 50 μm (2 mils) thick. The film has a

circular cut-out 9.5 mm (0.38 in.) in diameter that exposes the underlying foam.

3.2 Calibrated spring-loaded dial micrometer, precise to within 3 μm (0.1 mils). The anvil feet should be flat and approximately 6.6 mm (0.25 in.) in diameter.

Section 4: Procedure

4.1 A clean representative surface site shall be identified. Surface dirt and dust shall have been removed from the surface, because contaminants distort the results. The tape shall not be used on surfaces with a temperature higher than 54°C (130°F).

4.2 The micrometer shall be adjusted to zero with the anvils closed.

4.3 The wax paper backing shall be removed from the replica tape. The specimen of replica tape shall be inspected; the tape should not be used if it is visually damaged or distorted. The unexposed compressible foam in the circular cut-out shall be measured with the spring micrometer, because its thickness may vary. The thickness of the compressible foam is the micrometer reading minus 50 μm (2 mils) for the polyester film. The premeasured thickness of the compressible foam is the maximum profile height for which the replica tape may be used.

4.4 The replica tape film shall be placed on the blast-cleaned surface, dull side down. The tape shall be held firmly to avoid movement. A burnishing tool (a hard plastic rod with a spherical end could be used) shall be rubbed over the circular cut-out portion of the replica tape. The tape shall be rubbed repeatedly until the entire circular area has uniformly darkened. Excessively hard rubbing should be avoided because the polyester film could become distorted.

4.5 The replica shall be removed and placed between the anvils of the micrometer. The profile measurement is the gauge reading minus 50 μm (2 mils) to compensate for the polyester film. If most of the profile measurements closely approach the premeasured thickness of the compressible foam, alternative procedures should be considered because the accuracy of the procedure may be affected.

4.6 If desired, and if the dial micrometer can be so adjusted, the micrometer may be set at -50 μm (-2 mils) with the anvils closed, and subsequent readings of the compressible foam may be made directly.

⁽¹⁾ SSPC: The Society for Protective Coatings, 40 24th St., Pittsburgh, PA 15222.

4.7 If a reading exceeds the thickness of the compressible foam found in Paragraph 4.3, it shall be disregarded. Such a reading indicates that contaminant (dirt, abrasive, etc.) is attached to the compressible foam.

4.8 Three individual readings should be taken on any given local area and averaged to determine the surface profile measurement. The number of such measurements to be

taken on a given area should be as agreed or specified by contracting parties.

4.9 This procedure should be routinely verified using a surface with a known surface profile, such as a visual comparator. While a comparator cannot be used for exact calibration because of design differences, verification should ensure consistent, reproducible results.

References

1. NACE No. 1/SSPC-SP 5 (latest revision), "White Metal Blast Cleaning" (Houston, TX: NACE and Pittsburgh, PA: SSPC).
2. NACE No. 2/SSPC-SP 10 (latest revision), "Near-White Metal Blast Cleaning" (Houston, TX: NACE and Pittsburgh, PA: SSPC).
3. NACE No. 3/SSPC-SP 6 (latest revision), "Commercial Blast Cleaning" (Houston, TX: NACE and Pittsburgh, PA: SSPC).
4. NACE Publication 6G176 (withdrawn), "Cleanliness and Anchor Patterns Available Through Centrifugal Blast Cleaning of New Steel" (Houston, TX: NACE International). (Available from NACE International as an historical document only.)

Appendix A: Results of NACE Task Group T-6G-19 Round-Robin Tests

Figures A1 through A14 depict the results of the NACE Task Group T-6G-19 round-robin tests. The solid line

represents the profile as determined by NACE Technical Committee Report 6G176.

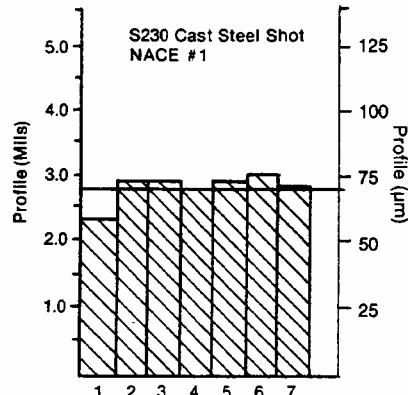


Figure A1

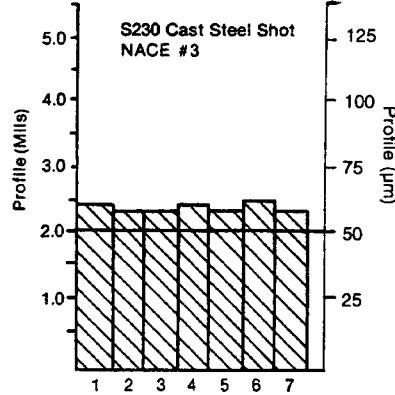


Figure A2

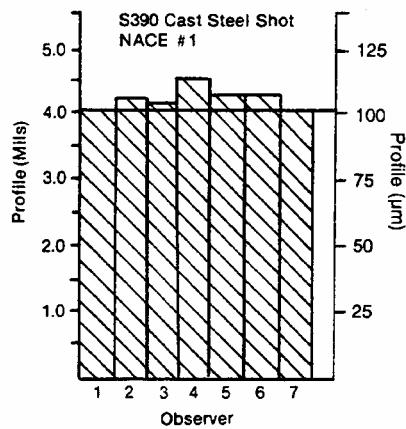


Figure A3

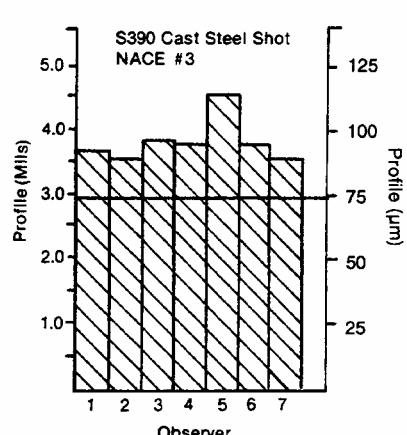


Figure A4

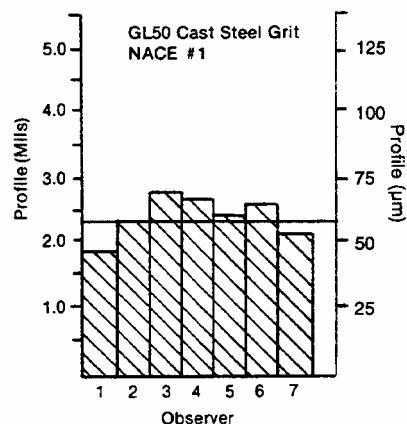


Figure A5

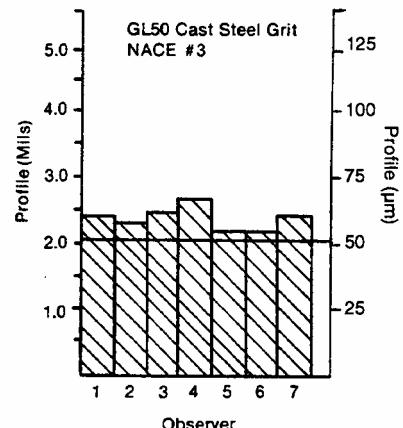


Figure A6

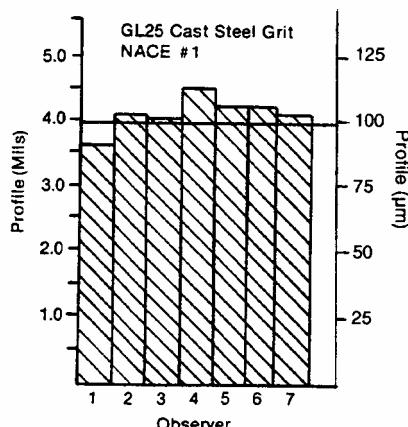


Figure A7

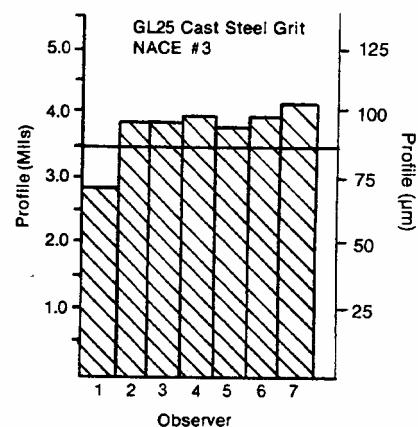


Figure A8

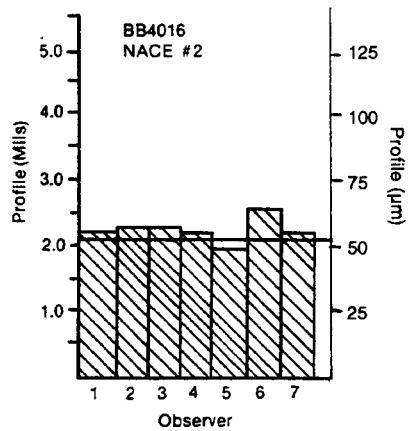


Figure A9

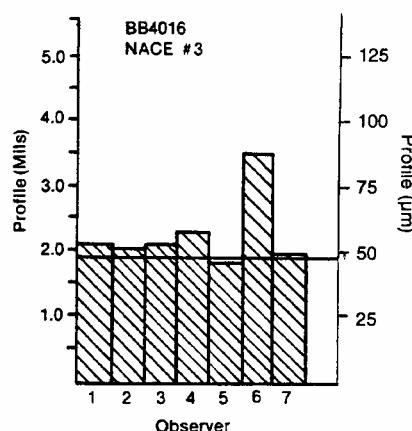


Figure A10

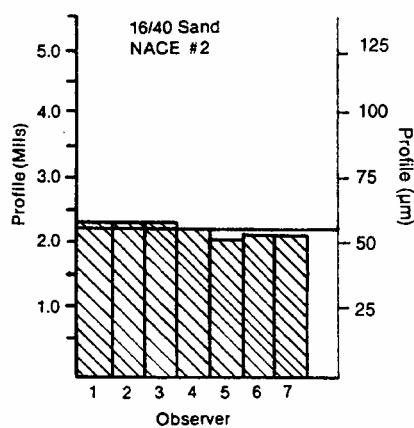


Figure A11

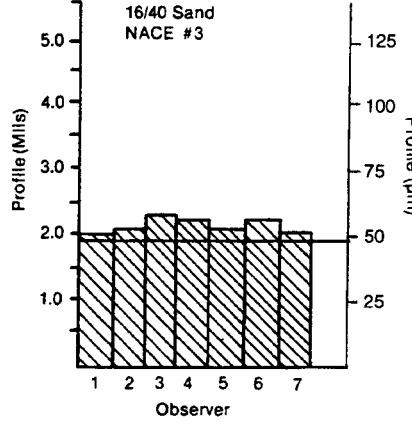


Figure A12

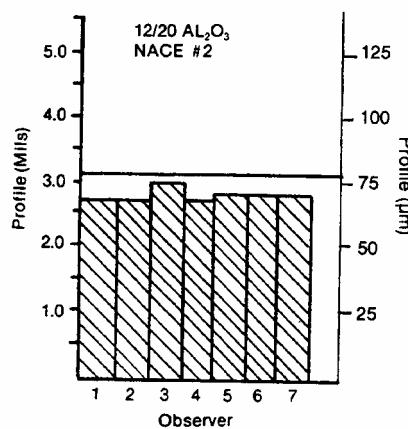


Figure A13

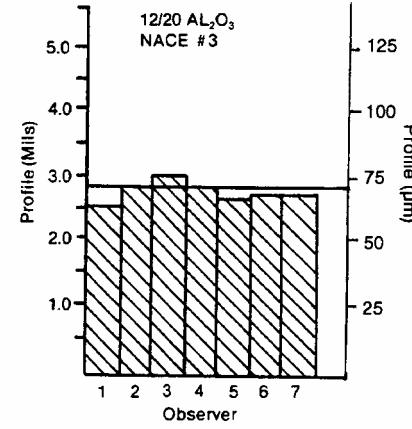


Figure A14

Appendix B: Statistical Summary

Table B1 gives a statistical summary of the results of the T-6G-19 round-robin tests. Figure B1 compares the surface

profile measurements obtained using a microscope with those obtained using replica tape.

TABLE B1
Statistical Summary^(A)

Number		Avg.	Microscope Readings		Replica Tape Readings			
			95% Confidence Limits ^(B)	95% Confidence Limits ^(B)	Avg.	95% Confidence Limits ^(B)		
1.	S230	NACE No. 1/SSPC-SP 5	2.72	2.41	3.03	2.79	2.57	3.00
2.	S230	NACE No. 3/SSPC-SP 6	2.02	1.54	2.49	2.36	2.28	2.43
3.	S390	NACE No. 1/SSPC-SP 5	4.05	3.47	4.63	4.17	4.01	4.33
4.	S390	NACE No. 3/SSPC-SP 6	2.85	2.38	3.33	3.76	3.44	40.8
5.	GL-50	NACE No. 1/SSPC-SP 5	2.31	2.15	2.48	2.39	2.06	2.71
6.	GL-50	NACE No. 3/SSPC-SP 6	2.00	1.81	2.19	2.39	2.22	2.55
7.	GL-25	NACE No. 1/SSPC-SP 5	3.94	3.41	4.47	4.10	3.85	4.35
8.	GL-25	NACE No. 3/SSPC-SP 6	3.46	2.88	4.04	3.71	3.32	4.10
9.	BB4016	NACE No. 2/SSPC-SP 10	2.14	1.93	2.35	2.24	1.71	2.78
10.	BB4016	NACE No. 3/SSPC-SP 6	1.87	1.74	1.99	2.24	2.05	2.43
11.	16/40 Sand	NACE No. 2/SSPC-SP 10	2.22	2.04	2.41	1.93	1.74	2.18
12.	16/40 Sand	NACE No. 3/SSPC-SP 6	1.89	1.72	2.05	1.90	1.72	2.08
13.	12/20 Al ₂ O ₃	NACE No. 2/SSPC-SP 10	3.18	2.93	3.44	2.79	2.69	2.88
14.	12/30 Al ₂ O ₃	NACE No. 3/SSPC-SP 6	2.85	2.59	3.11	2.73	2.58	2.88

(A) This statistical summary was conducted using standard U.S. units of measure. To convert to metric units, use 1 mil = 25.4 μm .

(B) 95% confidence limits. Example: Panel 1 microscope data, average = 2.72; 95% lower limit = 2.41; 95% upper limit = 3.03. This indicates 95% confidence that the average of an infinite number of microscope readings on Panel 1 would be between 2.41 and 3.03 mils.

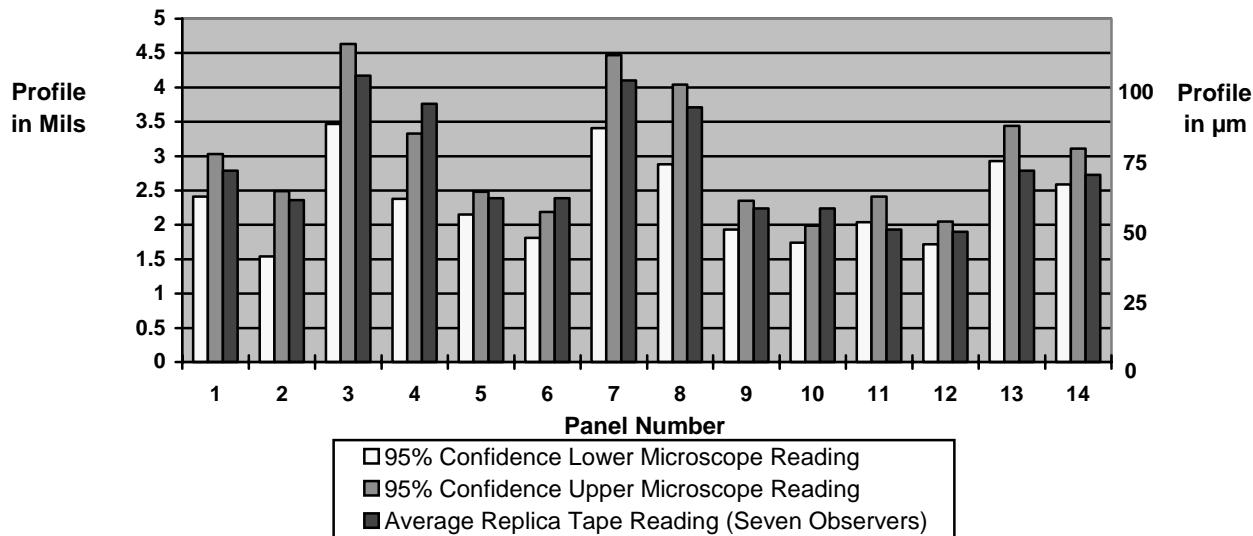


Figure B1
Microscope vs. Replica Tape Measurements

Standard Recommended Practice

Inspection of Linings on Steel and Concrete

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Foreword

Inspection is an integral part of the coating process. The purpose of inspection is to verify compliance to the specifications and work procedures, not to question the integrity of the applicator. Many applicators perform their own inspection or hire an independent inspection agency. The NACE International Coating Inspector Training and Certification Program provides exposure to knowledge and skills pertaining to coating inspection.⁽¹⁾

The intent of this NACE standard recommended practice is to provide appropriate inspection requirements to verify compliance to the specification. It is not intended to address the selection of a coating or to specify surface preparation and application requirements. This standard is intended for use by facilities' owners and their representatives, coating contractors, coating suppliers, and coating inspectors involved with the inspection of linings on steel and concrete.

For further information on coatings for concrete users of this standard should refer to NACE No. 6/SSPC⁽²⁾-SP 13¹ and NACE Publication 02203/ICRI⁽³⁾ Technical Guideline 03741/SSPC-TR 5.² For further information about selecting and specifying surface preparation methods for concrete before application of linings, users of this standard should refer to ICRI Technical Guideline 03732.³ For further information on the design, installation, and inspection of linings users of this standard should refer to NACE No. 10/SSPC-PA 6⁴ and NACE No. 11/SSPC-PA 8.⁵

For the purpose of this standard, the terms *linings* and *coatings* are synonymous.

This standard was originally prepared in 1988 by NACE International Task Group T-6-2 on Inspection of Linings on Steel and Concrete. It was revised in 1994 by Task Group T-6-4 on Review of NACE Standard RP0288-88. In 2004 it was reaffirmed by Specific Technology Group (STG) 03 on Protective Coatings and Linings—Immersion/Buried. This standard is issued by NACE International under the auspices of STG 03.

In NACE standards, the terms *shall*, *must*, *should*, and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. The term *should* is used to state something considered good and is recommended but is not mandatory. The term *may* is used to state something considered optional.

⁽¹⁾ Contact the NACE International Membership Services Department for more information.

⁽²⁾ SSPC: The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, PA 15222-4656.

⁽³⁾ International Concrete Repair Institute (ICRI), 3166 S. River Road, Suite 132, Des Plaines, IL 60018.

**NACE International
Standard
Recommended Practice**

Inspection of Linings on Steel and Concrete

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Section 1: General

1.1 Successful coating application is usually the result of a well-prepared coating specification, properly selected high-quality coating materials, a competent, experienced, knowledgeable coating applicator, and an inspector. Adherence to a well-prepared coating specification that clearly details industry-accepted requirements and procedures for quality coating application usually results in a satisfactory application. The coating inspector relies on a well-prepared coating specification, which should include methods, standards, and acceptance criteria.

1.2 Specifications should be written with the purpose of designating materials and methods that result in high-quality products appropriate for the user. Attention to relevant details in a specification is essential. The specification should refer to industry standards whenever possible to minimize confusion or disputes over methodology and to reflect the latest technology that satisfies engineering and

design principles for a particular application and environment.

1.3 Inspectors shall have previously performed the functions outlined in this standard and be proficient in the use of inspection equipment. When required, inspectors shall provide necessary documentation of evidence demonstrating suitable qualifications.

1.4 The coating inspector shall maintain a detailed report that outlines observations and/or measurements of surface preparation, ambient conditions, mixing techniques, application procedures, curing, final inspection, and other information requested at the prejob conference.

1.5 When agreed to by the owner, an inspector shall have the authority to suspend coating work if the work being performed is not in accordance with the specification.

Section 2: Prejob Conference

2.1 A prejob conference shall be arranged by the owner and shall be attended by representatives of the owner, coating contractor, coating supplier, and coating inspector.

2.2 The parties shall review the specification, procedures, manufacturer's latest data sheets, and inspection standards, and shall define details of the coating application, review safety practices, and resolve any ambiguities or conflicts.

2.3 All actions that are taken and agreed upon at the prejob conference shall be documented.

2.4 The following items shall be reviewed at every prejob conference:

2.4.1 Acceptable levels and methods or procedures for determining moisture content, alkalinity, and cure time required for concrete surfaces for the coating being applied;

2.4.2 Acceptable methods for repairing concrete defects such as bug holes, rock pockets, fins, structural cracks, etc., and acceptable methods for treating construction and expansion joints;

2.4.3 Acceptable methods for the removal of curing membranes and release agents;

2.4.4 Degree of surface preparation required for welds, attachments, and surface imperfections, including those illustrated in NACE Standard RP0178⁶ (see Section 4);

2.4.5 Degree of surface cleanliness and depth of profile specified, and the agreed-upon standard(s) to be employed for the verification thereof;

2.4.6 Acceptable methods of removing dust and abrasive and the test procedure for verifying degree of cleanliness;

2.4.7 Number of coats to be applied and method of application;

2.4.8 Method of inspection for discontinuities and, if other than a holiday-free coating application is required, the number of allowable holidays or discontinuities and acceptable marking materials for highlighting discontinuities;

2.4.9 Acceptable coating repair procedures as supplied by the coating manufacturer;

2.4.10 The nominal, minimum, and maximum dry-film thickness (DFT) to be obtained for each coat, the final cured coating film thickness, and the agreed-upon instrument to be used to measure the DFT;

2.4.11 Number and frequency of DFT readings to be taken;

2.4.12 Procedure for verifying the degree of cure of the coating;

2.4.13 Requirements for proper ventilation of solvent fumes and drying time between coats;

- 2.4.14 Work sequence and scheduling, including estimated interim and final completion dates;
 - 2.4.15 Inspection points in the project beyond which work shall not progress until inspection has been completed and the work has been accepted;
 - 2.4.16 Responsible contact personnel of all parties to the contract;
 - 2.4.17 The extent of documentation, job control records, and number and distribution of copies required of the coating inspector;
 - 2.4.18 Inspection instrument calibration procedures; and
 - 2.4.19 The use of destructive inspection instruments.
-

Section 3: Inspection Equipment

- 3.1 The following is a list of inspection equipment commonly used by the coating inspector for inspecting coatings and linings:
 - 3.1.1 Psychrometer (sling or automatic fan type);
 - 3.1.2 National Weather Service⁽⁴⁾ relative humidity-psychrometric tables;
 - 3.1.3 Surface thermometer;
 - 3.1.4 Hypodermic needle abrasive blasting air pressure gauge;
 - 3.1.5 Surface cleanliness standards: written specifications, visual comparators, or panels;
 - 3.1.6 Weld preparation standard and replica;
 - 3.1.7 Surface profile replica tape or comparator;
 - 3.1.8 pH paper;
 - 3.1.9 Wet-film gauge;
 - 3.1.10 Paint thermometer;
 - 3.1.11 DFT gauge (nondestructive) and calibration standards;
 - 3.1.12 DFT gauge (destructive), (i.e., Tooke gauge);
 - 3.1.13 Holiday detector (low- or high-voltage);
 - 3.1.14 Magnifying glass (10x); and
 - 3.1.15 Moisture meter.
- 3.2 Inspection equipment shall be calibrated before, during, and after use when applicable.
- 3.3 Inspection equipment that is destructive or detrimental to the integrity of an applied coating shall not be used for routine inspection. *If a destructive test is necessary to verify degree of preparation, number of coats applied, adhesion, or total DFT achieved, the damaged area resulting from the test shall then be repaired following procedures agreed upon during the prejob conference.*

Section 4: Inspection Requirements

- 4.1 Surface Preparation
 - 4.1.1 The abrasive shall be examined periodically for cleanliness and proper grade size.
 - 4.1.2 The cleanliness of blasting air at the nozzle shall be determined in accordance with ASTM⁽⁵⁾ D 4285⁷ or other applicable standards.
 - 4.1.3. The pressure achieved at the nozzle shall be measured.
 - 4.1.4 Verification shall be made that the surface temperature of the substrate to be blasted and coated is a minimum of 3°C (5°F) above the dew point or at the temperature determined in the prejob conference in accordance with ASTM E 337.⁸
 - 4.1.5 All steel surfaces to be coated shall be inspected immediately prior to the application of the first coat to verify compliance with the specified degree of cleanliness and profile in accordance with NACE No. 1/SSPC-SP 5,⁹ NACE No. 2/SSPC-SP 10,¹⁰ NACE No. 3/SSPC-SP 6,¹¹ NACE No. 4/SSPC-SP 7,¹² NACE Standard RP0287,¹³ SSPC-VIS 1,¹⁴ or other applicable standards.
 - 4.1.6 Surface preparation and condition of welds shall be verified as required by the governing specification and by NACE Standard RP0178 or other applicable standards.

⁽⁴⁾ National Oceanic and Atmospheric Administration, National Weather Service, 1325 East West Highway, Silver Spring, MD 20910.

⁽⁵⁾ ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

4.1.7 The moisture content of concrete substrates to be coated shall be determined with a moisture meter or by the plastic sheet method (ASTM D 4263¹⁵). Verification shall be made that incompatible compounds, curing membranes, or form-release compounds have been removed and that laitance, bug holes, rock pockets, fins, and structural cracks have been removed or repaired to the degree defined at the prejob conference.

4.2 Coating Material

4.2.1 Verification shall be made that the coating material used is that which has been specified.

4.2.2 Coating material storage procedures and conditions shall be verified.

4.2.3 Batch numbers of all components of a coating system shall be recorded.

4.2.4 The age and shelf life of the coating shall be verified.

4.2.5 Verification shall be made that mixing of the coating is in accordance with the coating manufacturer's written instructions and that the amount and type of thinner used for reduction is as specified.

4.3 Application of Coating Material

4.3.1 Verification shall be made that the substrate, ambient, and material temperatures are within the range agreed to at the prejob conference or specified by the coating manufacturer. The humidity and dew point shall be measured.

4.3.2 Verification shall be made that the method of application, time interval between coats, and number of coats applied meet the criteria provided in the specification.

4.3.3 Verification shall be made that the coated surface is free of abrasives, contaminants, runs, sags, and other defects determined at the prejob conference prior to the application of successive coats.

4.3.4 On steel surfaces the DFT of each coat shall be measured in accordance with ASTM D 1186¹⁶ or SSPC-PA 2,¹⁷ or as determined at the prejob conference.

4.3.5 Estimating DFT by calculating solids of wet film applied may be required on concrete substrates.

4.3.6 When required, a discontinuity (holiday) test employing the instrument specified shall be conducted after the coating has been allowed to cure sufficiently, as recommended by the coating manufacturer. This test shall be performed in accordance with NACE Standard RP0188¹⁸ or ASTM D 4787.¹⁹

4.3.7 Discontinuities shall be identified with an approved marker.

4.3.8 Determining DFT with a destructive instrument, if required, shall be done following procedures agreed to at the prejob conference.

4.4 Curing of Coating

4.4.1 The degree of cure shall be determined and documented using specified procedures agreed upon at the prejob conference.

References

1. NACE No. 6/SSPC-SP 13 (latest revision), "Surface Preparation of Concrete" (Houston, TX: NACE and Pittsburgh, PA: SSPC).
2. NACE Publication 02203/ICRI Technical Guideline 03741/SSPC-TR 5 (latest revision), "Design, Installation, and Maintenance of Protective Polymer Flooring Systems for Concrete" (Houston, TX: NACE, Des Plaines, IL: ICRI, and Pittsburgh, PA: SSPC).
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4. NACE No. 10/SSPC-PA 6 (latest revision), "Fiberglass-Reinforced Plastic (FRP) Linings Applied to Bottoms of Carbon Steel Aboveground Storage Tanks" (Houston, TX: NACE and Pittsburgh, PA: SSPC).
5. NACE No. 11/SSPC-PA 8 (latest revision), "Thin-Film Organic Linings Applied in New Carbon Steel Process Vessels" (Houston, TX: NACE and Pittsburgh, PA: SSPC).
6. NACE Standard RP0178 (latest revision), "Fabrication Details, Surface Finish Requirements, and Proper Design Considerations for Tanks and Vessels to Be Lined for Immersion Service" (Houston, TX: NACE).
7. ASTM D 4285 (latest revision), "Standard Test Method for Indicating Oil or Water in Compressed Air" (West Conshohocken, PA: ASTM).
8. ASTM E 337 (latest revision), "Standard Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)" (West Conshohocken, PA: ASTM).

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14. SSPC-VIS 1 (latest revision), "Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning" (Pittsburgh, PA: SSPC).
15. ASTM D 4263 (latest revision), "Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method" (West Conshohocken, PA: ASTM).
16. ASTM D 1186 (latest revision), "Standard Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base" (West Conshohocken, PA: ASTM).
17. SSPC-PA 2 (latest revision), "Measurement of Dry Paint Thickness with Magnetic Gages" (Pittsburgh, PA: SSPC).
18. NACE Standard RP0188 (latest revision), "Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates" (Houston, TX: NACE).
19. ASTM D 4787 (latest revision), "Standard Practice for Continuity Verification of Liquid or Sheet Linings Applied to Concrete Substrates" (West Conshohocken, PA: ASTM).

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ASTM D 5161 (latest revision). "Standard Guide for Specifying Inspection Requirements for Coating and Lining Work (Metal Substrates)." West Conshohocken, PA: ASTM.

SSPC-SP COM (latest revision). "Surface Preparation Commentary for Steel and Concrete Substrates." Pittsburgh, PA: SSPC.

U.S. Code of Federal Regulations (CFR) Title 29. "Permit-Required Confined Spaces." Part 1910. Subpart J. Washington, DC: Office of the Federal Register, ⁽⁶⁾ 1998.

⁽⁶⁾ Office of the Federal Register, National Archives and Records Administration, 700 Pennsylvania Ave. NW, Washington, DC 20408-0001.



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NACE 6A192 (2000 Revision)
Item No. 24083

Joint Technical Committee Report

Dehumidification and Temperature Control During Surface Preparation, Application, and Curing for Coatings/Linings of Steel Tanks, Vessels, and Other Enclosed Spaces

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Approved December 2000

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Foreword

The use of dehumidification and temperature control has become more common during coating/lining operations and much has been learned about ways to optimize its use to achieve maximum benefits at minimum cost. This technical committee report presents current information about why and how dehumidification and temperature control are being used to achieve higher-quality coating/lining projects. It is intended to be a resource for engineers and coating consultants who write specifications for coating projects involving tanks or enclosed spaces.

This report was originally prepared by NACE Task Group T-6A-60 on The Need for Dehumidification Equipment in the Application of Linings. This revision was prepared by NACE Task Group 003 on Dehumidification. This Task Group is administered by NACE Specific Technology Group (STG) 80 on Intersociety Joint Coatings Activities, and is sponsored by STG 03 on Protective Coatings and Linings – Immersion/Buried. The Task Group also has representation from SSPC Group Committee C.2 on Surface Preparation. This report is published by NACE International under the auspices of STG 80, and by SSPC.

Introduction

The use of dehumidification and temperature control during surface preparation and coating/lining application can be beneficial in a variety of ambient conditions. When used properly, dehumidification (DH) provides air dew points well below the surface temperature and reduces the relative humidity (RH) at the surface. Reducing the RH at the surface can retard rust bloom.

The health and safety of personnel is also a factor in the design of a dehumidification system. Dehumidification equipment that is properly sized for a given space provides air flow for safe working conditions. The lower

explosive limits (LELs), toxicity levels, and oxygen levels are all evaluated at each stage of the project.

The volume of coating to be sprayed per hour and the percentage of solvent and solids to be added is calculated using manufacturers' data sheets. The formulas for these calculations can be found in NFPA⁽¹⁾ 33.¹ The appropriate air-flow rate of the dehumidified and of the exhausted air through the enclosure and the proper instrumentation to be used for monitoring during both stages of the project are also determined.

Glossary of Terms

Terms used in this report are widely used in several engineering disciplines. Precise definitions are contained in other references, notably the ASHRAE⁽²⁾ *Handbook of Fundamentals*.² The explanatory definitions contained here are sufficient for this report but are not as precise and detailed as the ASHRAE definitions.

Absorbent: A desiccant material that holds water vapor through a hydration reaction that is reversible when the material is heated. Sodium chloride (table salt) and lithium chloride are examples of absorbent desiccants.

Adsorbent: A desiccant material that holds water vapor on its surface without a change in the chemical or physical structure of the material. Silica gel and the naturally occurring zeolites used for pet-waste granules are examples of adsorbent desiccants.

Dehumidification: The removal of moisture from the air.

Desiccant: A material commonly used to absorb moisture from the air; a solid or liquid material that has

the ability to collect moisture from the air and later release the water vapor when the material is heated. A desiccant used for dehumidification has a vapor pressure below that of the air to be dehumidified is in its active, dehydrated state.

Dew Point: The temperature of the air at which the moisture it contains condenses on nearby surfaces or suspended dust particles. At constant pressure, each dew point temperature represents a single value of air moisture content. As a result, air dew point is often used to describe air moisture content in absolute terms rather than relative humidity, which does not define the absolute amount of moisture in the air unless the air temperature is also known.

Flash Rusting: (1) Rusting that occurs on metal within minutes to a few hours after cleaning is complete. The speed with which flash rusting occurs may be indicative of salt contamination on the surface, high humidity, or both; (2) Appearance of rust spots on the surface of newly applied water-borne film during the drying phase.

⁽¹⁾ National Fire Protection Association (NFPA), P.O. Box 9101, Quincy, MA 02269-9101.

⁽²⁾ American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle NE, Atlanta, GA 30329-2305.

Humidity Ratio: The amount of moisture in the air, expressed as the weight of the water vapor compared to the weight of the air if it were perfectly dry. This results in a small decimal fraction. For example, air at 70°F (21°C) with 50% relative humidity has a humidity ratio of 0.0079. In the SI measurement system, this ratio is expressed as g water vapor/kg dry air. In the U.S. customary system of measurement, the weight of water vapor is converted to a whole number by multiplying the humidity ratio by 7,000 (the number of grains of water vapor in 1 lb). Therefore, air at 70°F (21°C) with 50% relative humidity has a humidity ratio of 55 grains/lb (7.9 g/kg) of dry air.

Process Air: Dry air produced with a dehumidifier.

Reactivation Air: Air used to remove moisture from a desiccant material.

Relative Humidity (RH): The ratio, expressed as a percentage, of the amount of water vapor present in a given volume of air at a given temperature to the amount required to saturate the air at that temperature.

Rust Bloom: Discoloration of steel surface indicating the beginning of rusting.

Methods of Dehumidification

Dehumidification can be accomplished by compression, refrigeration, desiccation (liquid sorption, solid sorption), or a combination of these systems. While compression and liquid sorption are common methods of dehumidification, their use is not generally applicable to field conditions. Therefore, only the refrigerant-based and desiccant solid-sorption techniques are discussed in detail in this report.

Refrigeration

The cooling of air to below its dew point is an economical method of dehumidification. This method is commonly used at ambient temperatures of approximately 85°F (29°C) and high humidity. Ambient air is circulated over a system of refrigeration coils. The surface temperature of the coils is set at temperatures considerably lower than the temperature of the incoming ambient air. As the air cools, it reaches saturation, and condensation forms. This condensation is collected and removed from the system. The air exits the cooling-coil section of the dehumidifier at a reduced temperature, dew point, and absolute humidity. This refrigeration-based dehumidification system is illustrated in Figure 1. The cooler air, which has a lower dew point, can then be reheated to lower the relative humidity.

Refrigeration is often used to pre-cool and dehumidify inbound air before it reaches a desiccant system in order

Temperature: A measure of hotness or coldness usually recorded with a thermometer on either the Fahrenheit or Celsius scale; the dry-bulb temperature of the air, which is the temperature of the air as measured by a thermometer with a dry-sensing bulb properly shielded from heat radiation sources such as sun or electric heaters.

Vapor Pressure: The pressure exerted by water molecules, either suspended in an air sample or at the surface of a solid material. A desiccant material attracts water vapor because the vapor pressure at its surface is lower than the vapor pressure exerted by molecules suspended in the air. In an effort to equalize this pressure differential, water molecules move from the air to the desiccant surface.

Wet-Bulb Temperature: The temperature of the air flowing across a thermometer with its sensing bulb surrounded by a wetted wick. The water evaporating from the wick cools the sensing bulb in proportion to the amount of evaporation. The evaporation effect (therefore a cooling effect) is greater when the air is drier. By measuring the wet- and dry-bulb temperatures and plotting the values on a psychometric chart, the amount of moisture in the air can be determined.

to obtain lower dew points after desiccation. The air can be re-cooled, if necessary, by refrigeration.

Desiccant

Solid-sorption dehumidification systems utilize either granular beds or fixed desiccant structures. These structures are contained within machines through which an air stream is passed. The desiccant used is in an active, dehydrated state and has a vapor pressure below that of the air to be dehumidified. The most commonly used desiccants are silica gel and lithium chloride. Air is passed through beds or layers of the desiccant, which absorb moisture from the air stream, producing a hydrated salt. Regeneration of the hydrated salt is accomplished with heated air, which drives off the water of hydration, returning the sorbent to its dehydrated state. The previously sorbed moisture is diverted to a separate air stream.

The exothermic hydration reaction typically raises the temperature of the exiting air stream by 10 to 15°F (6 to 8°C). Therefore, in hot climates, refrigeration-type dehumidifiers are frequently used in combination with desiccant equipment to cool the air entering the space. A typical desiccant dehumidification system is illustrated in Figure 2. Because this type of system absorbs moisture as vapor, it is commonly used at all temperatures and levels of humidity.

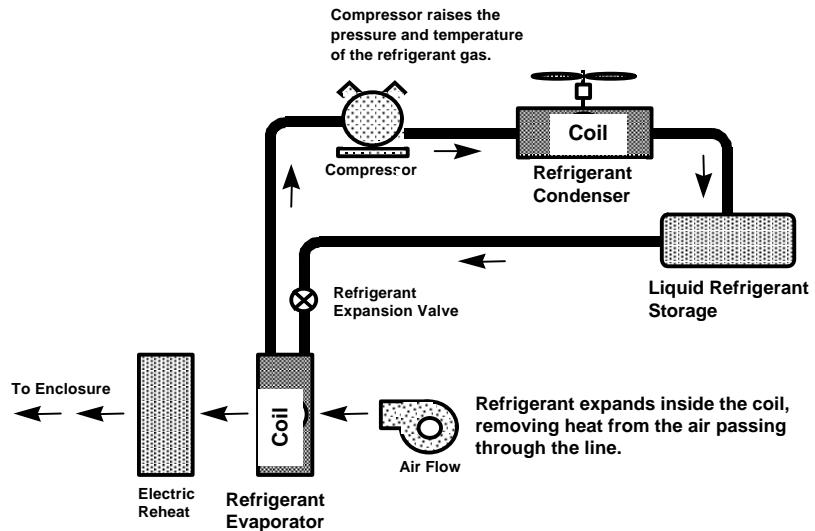


FIGURE 1: A Refrigeration-Type Dehumidifier

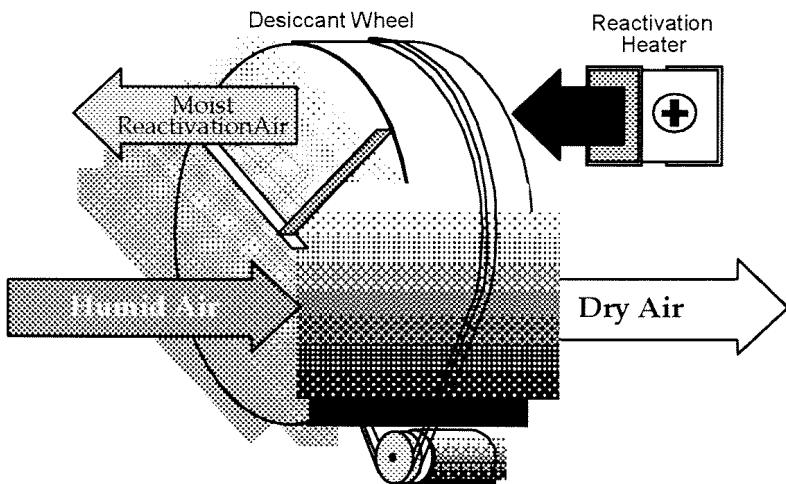


FIGURE 2: Desiccant Wheel

Sizing Equipment

The size of dehumidification equipment is typically determined by considering the balance between air extraction from the space and the dehumidification desired to accomplish the specified dew point depression from the surface temperature. If the capacity of the dehumidification equipment becomes marginal through unexpected weather changes, its efficiency can be improved by reducing the amount of air being extracted for dust control.

The appropriate air-change rate for maintaining a prepared surface during blasting and between shifts while maintaining a large differential between dew point and surface temperature for an extended period of time is dependent on air-space volume, equipment, geographical

location, climate, and season. The number of openings in the enclosure, the airtightness of the structure, the distance of equipment from the space, and the amount of air to be extracted or exhausted by means other than DH equipment also influence the DH capacity. Relatively airtight enclosures generally require less DH volume because little or no additional air or moisture is introduced into the space. Relatively large spaces usually require fewer air exchanges. Equipment contractors usually have guides that give volume data for their equipment.

The flow capacity of a dehumidifier for a given number of air changes per hour is calculated using the formula shown in Equation (1):

$$\frac{(V_i)(RAC)}{60} = X \quad (1)$$

Where:

- V_i is the internal volume of the space minus the volume of any obstructions in ft^3
- RAC is the required air changes per hour
- X is the air-flow capacity in ft^3/min that corresponds with the specified air change rate

Or, for DH equipment with a capacity expressed in m^3/h , the flow capacity is calculated using the formula shown in Equation (2):

$$(V_i)(RAC) = X \quad (2)$$

Where:

- V_i is the internal volume of the space minus the volume of any obstructions in m^3
- RAC is the required air changes per hour
- X is the air-flow capacity in m^3/h that corresponds with the specified air change rate

Example One: Find the capacity of dehumidification equipment that can dehumidify a 110-ft-diameter enclosed space with a 6.0-ft-high floating roof.

1. Find the internal volume (V_i):

$$V_i = d^2 \frac{\pi}{4} h$$

$$V_i = (110 \text{ ft})(110 \text{ ft})(0.7854)(6.0 \text{ ft})$$

$$V_i = 57,000 \text{ ft}^3$$

Impact of Contaminants and RH

Reducing RH at the surface inhibits corrosion and rust bloom. The appropriate RH to be maintained during blasting depends on the amount of surface contaminants present. The amount and type of surface contamination can greatly influence the rate of rust bloom. As a general rule, assuming surface RH is constant, the rate of deterioration (e.g., corrosion and rust bloom) increases with increased contamination.

The critical relative humidity of a material is defined as the humidity level above which the corrosion rate accelerates rapidly. For example, clean iron in pure, clean air does not corrode until the RH is approximately 90%. However, when a small amount (0.01%) of sulfur dioxide is present in the air, the critical relative humidity is lowered to 65%, and the steel begins to corrode at this much lower RH level. More severe corrosion, which can occur if the surface is exposed to a 3% sodium chloride solution, lowers the critical relative humidity to 55%. Appendix A provides more information about the relative humidities at which different contaminants can bring

Where:

d = diameter
 h = height

2. Set the required air changes (RAC) per hour: 2
3. Multiply the internal volume by the required air changes to determine the amount of air needed per hour: $(57,000 \text{ ft}^3)(2) = 114,000 \text{ ft}^3/\text{h}$
4. Convert ft^3/h into ft^3/min :
 $114,000 \text{ ft}^3/\text{h} \div 60 \text{ min/h} = 1,900 \text{ ft}^3/\text{min}$

Example Two: Find the capacity of dehumidification equipment that can dehumidify a 60-m-diameter, 12-m-high enclosed space.

1. Find the internal volume (V_i):

$$V_i = d^2 \frac{\pi}{4} h$$

$$V_i = (60 \text{ m})(60 \text{ m})(0.7854)(12 \text{ m})$$

$$V_i = 34,000 \text{ m}^3$$

2. Set the required air changes (RAC) per hour: 1

3. Multiply the internal volume by the required air changes to determine the amount of air needed per hour: $(34,000 \text{ m}^3/\text{h})(1) = 34,000 \text{ m}^3/\text{h}$

moisture to the surface. This absorbed moisture dissolves in the contaminant, forming an electrolyte that accelerates rust bloom. Properly cleaned steel corrodes at a much slower rate in high-humidity environments provided surface contaminants are not present.

It is generally recognized that a larger dew point differential is needed for equivalent rust bloom protection at conditions of greater surface and atmospheric contamination. Steel surfaces can be tested for the presence of soluble salts and other nonvisible contaminants so that these factors can be taken into consideration. Testing methods are utilized either in the initial stage of projects, when specified, or at any time during the project if detrimental levels of soluble surface contamination are suspected.

The traditional cycle of blasting, cleaning, and priming can mask contaminants by not allowing enough time for ambient humidity to react and begin to show rust bloom, and thus show evidence of the contaminants.

Example: A surface is blasted on a day when the dew point is marginally acceptable. The steel "turns" (i.e., rust bloom appears). Overnight, a weather front brings drier weather. The next day, the same area is reblasted and does not show evidence of rust bloom.

The reason that the area does not show rust bloom on the second day of blasting is that the dew point differential has decreased, and is not great enough for flash rusting to occur. However, this does not indicate that the surface is not contaminated. Contaminants can be masked by the lowered dew point differential.

Dehumidification, if not used correctly, can mask contaminants. Exposure to dehumidification for a short period of time might not allow the corrosion process to appear as rust bloom. If dehumidification is properly employed and the blast is held for an extended period of time, during which rust bloom occurs, the surface might be tested for contaminants. A brief list of surface RH values that initiate accelerated rust bloom for different contaminants is found in Appendix A. Table 1 illustrates surface RH according to surface temperature and dew point differential.

TABLE 1: Dew Point Differential and Surface RH

Difference Between Dew Point and Surface Temperature	5°F (3°C)	10°F (6°C)	15°F (8°C)	20°F (11°C)	25°F (14°C)	30°F (17°C)	35°F (20°C)
Approximate RH at Surface	82 to 86%	74 to 80%	54 to 62%	43 to 51%	34 to 42%	27 to 35%	19 to 26%

Through field experience in controlling conditions in enclosed spaces, it is known that lowering the dew point temperature well below the surface temperature is effective in slowing the corrosion rate. The typical minimum dew point differential specified for holding a blast over an extended period of time is 17 to 25°F (9 to 14°C) with a relative humidity not to exceed 40 to 55%. It has been found that rust bloom accelerates if the surface RH exceeds 40 to 55% RH (see Table 1).

Because it is often not practical to obtain a surface RH reading in the field by instrumentation alone, the following dew point differential method is often used:

To compute the surface RH, the dew point of the surrounding air is subtracted from the surface temperature. This can then be plotted on a psychrometric chart (Figure 3) or a dew point chart (Table 1). The intersection of the surface temperature value and the dew point value on the chart indicates the RH of the air at the surface. Because this thin layer of air at the surface assumes the temperature of the surface, this value can be assumed to be equivalent to the RH at the surface.

Figure 3 can be used to determine the surface relative humidity. The dry bulb temperature represents the actual surface temperature. The vertical line can be followed up to where it intersects the horizontal line representing the actual dew point. The surface relative humidity at that dew point can then be read. For example, a wet bulb temperature of 75°F with a dry bulb temperature of 100°F indicates an absolute RH of 30 to 40%.

The dew point differential method allows the specifier to monitor the inside surface RH conditions in an enclosed space by measuring the differential between the surface temperature and the air dew point. Table 1 shows the relative surface humidities that correspond to typical dew point-to-surface temperature differentials. For example, if a specifier determines that it is beneficial for a particular surface to not contact air with an RH greater than 40 to 55% RH, he/she can specify that a 17 to 25°F (10 to 14°C) dew point differential be maintained whenever the steel is not coated. This computation is approximately the same at all dry-bulb temperatures.

Uses of Dehumidification and Temperature-Control Equipment

Improved productivity and scheduling can be achieved by eliminating the daily blast/clean/prime cycle. Properly designed, installed, and operated DH equipment can reduce the risk of coating failure with the same, or improved, productivity.

When using dehumidification and temperature control, installation of multiple-coat linings can be divided into two distinct phases:

- Phase One: From surface preparation through complete application of the first coat of coating/lining material
- Phase Two: The application of additional coating/lining material in a multiple-coat system, including drying and curing

Each of these phases involves separate considerations that influence the selection and operation of climate-control equipment.

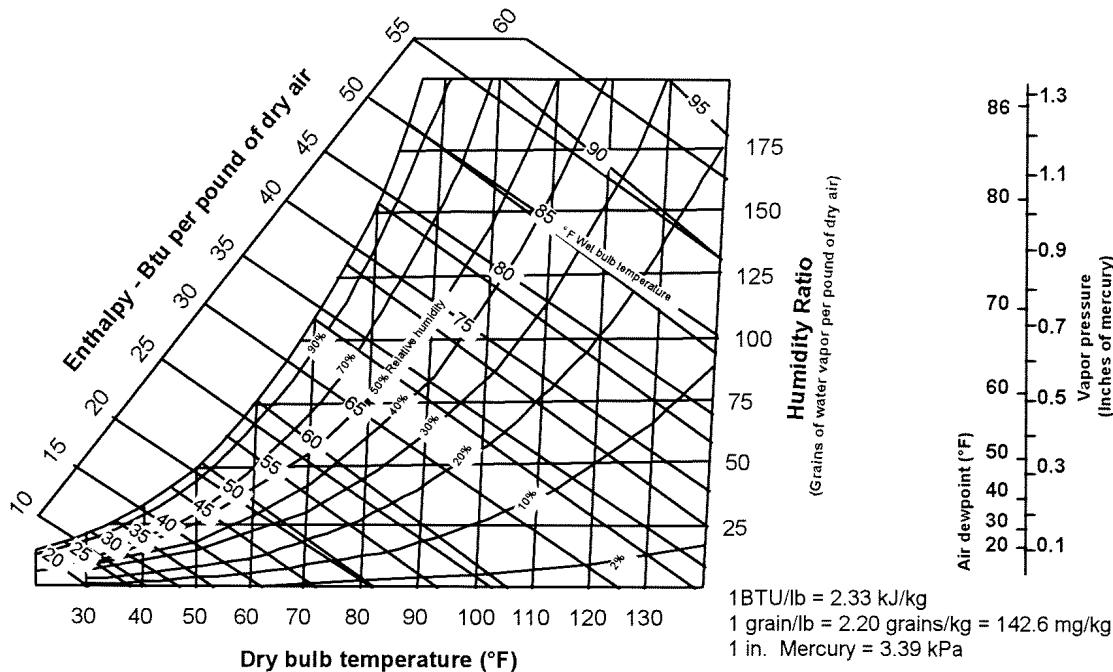


FIGURE 3: Psychrometric Chart

Phase One: From surface preparation through complete application of the first coat of coating/lining material

During abrasive blasting, large amounts of dust can accumulate in an enclosure. At the same time, the newly cleaned, unprotected steel is especially vulnerable to corrosion or rust bloom. In the past, it was common to blast the surface, clean the area, and prime the blasted surface in a single shift. This was done to prevent the rust bloom of freshly blasted steel between shifts. A disadvantage of the blast/clean/prime cycle is that it can cause overblast damage to freshly primed surfaces. Dehumidifiers have been used to protect the surface from this type of rust bloom for an extended period of time. This can allow for more time and attention to inspect and clean the surface prior to coating.

When blasting operations cease and the enclosure is left until the next shift, steel is exposed to weather changes at a time when personnel are not on site to protect the surface. Dehumidification equipment is used to maintain a dew point differential great enough to avoid rust bloom during unexpected weather changes. In circumstances other than those involving insulated tanks, it is generally considered more cost-effective to dehumidify the air than to heat the surface to maintain a given dew point differential. Dew point differentials greater than those specified on coating data sheets are often specified in order to provide a greater safety margin for weather changes when blast-cleaned steel is at risk.

Freshly blasted surfaces are typically allocated the greatest practical dew point differential (lowest possible surface RH). Also, large volumes of fresh air are often introduced into the enclosed space to replace the air exhausted to control dust. If dust collectors are being used, a percentage of the air can be recirculated. Because of the large airflow and dew point differential requirements, the dehumidification equipment used during this stage of the project is often of a larger volume than that used later. This is maintained until the first coat can be completely applied.

During blasting and holding periods, the temperature of the air inside the enclosure is not normally a concern, except as it affects worker comfort, productivity, and safety. During warm seasons, the contractor is careful to ensure that the air temperature inside the enclosure does not exceed the limits established by regulatory agencies for personnel safety. Changing the air temperature does not reduce the dew point or absolute humidity of the air. Therefore, heating the air does not prevent condensation or high RH at the surface unless the skin temperature is also appreciably raised. This is illustrated by plotting on the psychrometric chart (Figure 3).

Phase Two: The application of additional coating/lining material in a multiple-coat system, including drying and curing

Many specifiers elect to retain dehumidification, cooling, and heating equipment on site during Phase Two. Even though the steel is now fully protected from flash rusting,

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the curing cycles of most coatings are affected in some way by the humidity of the surrounding air. Although in the case of a few coatings (such as moisture-cure urethanes and solvent-based inorganic zinc) overdrying can retard the cure, DH is usually beneficial. The coating system supplier can advise the specifier on the optimal humidity for coating cure.

Just as air is exhausted during blasting operations for particulate control, air is also exhausted during coating operations to prevent the build-up of hazardous vapors. Consequently, the incoming fresh air is dehumidified by adequately sized DH equipment to remove the moisture from that air or to maintain the proper balance of DH and exhaust air.

Most coatings have specified application temperature ranges. These specifications usually refer to the temperature of the substrate rather than the temperature of the air. However, because the air temperature can affect the substrate, some specifications include a maximum and/or minimum air temperature. Surface temperature is most often a problem during colder weather. Hot air moves toward cold air. The greater the temperature differential, the faster the hot air moves toward the cold. In addition, steel loses heat depending on how fast the air is moving across it. Therefore, cold and windy weather can present difficulties.

In most cases, the primary concern during Phase Two dehumidification operations is maintaining the surface temperature high enough, although a maximum temperature is sometimes also specified. Surfaces are usually heated by supplying hot air to the enclosed space.

Inspection Instrumentation

Inspectors use a variety of instruments to measure environmental conditions and the performance of temperature- and humidity-control equipment. Each type of equipment has its proper use, and each project can benefit from different levels of accuracy from these instruments.

Humidity Readings

Most instruments used to measure humidity in the field are not designed for high levels of accuracy and repeatability. Accuracy greater than $\pm 2\%$ relative humidity (RH) is not generally available outside the laboratory. Further, instruments can drift from their specification accuracy because of sensor-surface contamination. These possible problems are often overlooked by those who specify humidity levels for a project, and dew point differentials are often not specified in light of the uncertainty of these measurements. For example, if a low-cost sensor has a tolerance of $\pm 5\%$ and the apparent reading it displays is 95°F (35°C), 50% RH, the true value can be as high as 55% or as low as 45%. That range allows a difference in

Because steel alone has nearly no resistance to heat loss, the air is supplied much hotter than the specified surface temperature to offset the heat loss through the wall of the enclosure. The inside "wall temperature" of a large steel tank is within 1°F (0.6°C) of the outside steel temperature. In very cold or very hot weather, exterior insulation or a temporary enclosure can be used to reduce the size and cost of the temperature-control equipment.

The surface temperature provides part of the energy needed to cure the coating. Too much heat from the surface can interfere with proper cure, and too little heat can cure the surface of the coating before the solvents evaporate, trapping those solvents and slowing overall curing time. Usually, surface temperatures of 50 to 100°F (10 to 38°C) are acceptable for coating cure, and faster curing rates occur at elevated temperatures. The specific coating used governs the surface temperature range for proper curing.

With the exception of coatings that require a "forced cure" (high-temperature cure), the minimum air temperatures used are generally modest (usually 50 to 70°F [10 to 21°C]). However, extremes of air temperature, like extremes of surface temperature, can be detrimental during cure. If the inside air is too cool, curing can take so long that the project is delayed or the coated surface is put back into service without complete coating cure. Air temperatures of 65 to 100°F (18 to 38°C) are generally considered adequate for coating cure.

moisture content of 114 grains/lb (16 g/kg) versus 86 grains/lb (12 g/kg) and a differential between dew points of 71°F (22°C) and of 63°F (17°C).

In critical situations, not only the instrument to be used, but also the frequency of its calibration can be specified. In less critical situations, the project manager can allow any instrument to be used, as long as the type and accuracy of the instrument is documented along with its readings.

A common problem with relative humidity readings is a failure to obtain a simultaneous temperature reading. Relative humidity by itself is not a useful value for monitoring coating projects. Unless both temperature (dry-bulb temperature) and relative humidity (wet-bulb temperature) are recorded, the dew point cannot be calculated.

Psychrometers or Wet- and Dry-Bulb Thermometers

The key to gaining accurate wet- and dry-bulb temperatures is to achieve rapid evaporation of water from the wet-bulb thermometer. If evaporation is impeded, the

wet-bulb instrument records a humidity reading that is higher than the true humidity. Only an absolutely clean wick provides accurate wet-bulb thermometer readings. Even the oil from a human fingerprint can prevent proper evaporation from the wick. Clean, distilled water is used to wet the wick in order to prevent contamination from dirt, oil, or other sources. Also, the reading can be falsely high if the air does not flow smoothly around the wet wick at a velocity of at least 500 ft (150 m) per minute.

For these reasons, readings from hand-held, wet- and dry-bulb devices like the sling psychrometer have a reputation of being accurate only within +5%. Aspirated (fan-powered) psychrometers are less subject to errors due to inadequate airflow, but they remain subject to errors due to inadequate wetting and wick contamination. Therefore, several wet-bulb readings are usually taken. When such instruments are used, any measurement error is generally above, rather than below, the true wet-bulb reading. The lowest of these is usually closest to the true value.

Electronic Hygrometers

The accuracy, repeatability, and response time of electronic instruments varies widely. Electronic measurements are not inherently more accurate than psychrometric measurements. Even readings taken with a very costly instrument can be less accurate than good wet- and dry-bulb temperature readings. A more costly device can initially be very accurate, but can drift over time in the rugged field environment of blasting and coating operations. A good technician is aware of the accuracy limitations of the device used, and records the RH accuracy of the instrument along with the readings taken.

The sensor element of an electronic hygrometer can change behavior if it becomes contaminated with dust or adsorbed vapors. Therefore, the sensor is typically protected with some form of air filter. However, such filters slow the response time of the sensor. On-site measurements are typically taken at a variety of temperature and humidity levels. Most technicians are aware that although an electronic instrument can display a value instantly, the sensor might not have yet reached equilibrium with the air being measured. For example, if a measurement is taken in the cold, saturated air leaving a cooling coil, the sensor can take five minutes to an hour to reach equilibrium for accurate measurements in a very dry environment. In general, moving from a dry environment to a more humid one provides faster response times than moving from a humid environment to a drier one.

Air Temperature Readings

Dry-bulb air temperature readings are much less subject to error than either humidity or surface temperature measurements. Accuracy of $\pm 1^{\circ}\text{F}$ ($\pm 0.6^{\circ}\text{C}$) is common even for a low-cost thermometer. However, one common source of error is the influence of radiational heat sources. A reading taken in the shade can be several degrees lower than a reading taken 1.0 in. (2.5 cm) away in full sunlight. The sensor bulb of the thermometer or electronic temperature sensor is protected from sunlight and other sources of radiational heat (such as the glowing elements of electric heaters) for accurate measurements.

Surface Temperature Readings

Obtaining accurate surface temperature measurements presents some challenges in the coating environment. The surfaces in question are likely to be rough, and they can be wet with uncured coatings. Each of the common surface thermometers commonly used in the field has advantages and limitations.

Bimetallic Magnetic Surface-Contact Thermometers

These devices are used widely in the industry, and are inexpensive. However, they are only used on a ferrous metal substrate with a smooth surface for reasonable accuracy. Also, they cannot be used to monitor the temperature of surfaces as they are being coated, because the thermometer must remain in contact with the substrate while the reading is being taken.

Electronic Surface-Contact Thermometers

Another low-cost alternative is the electronic surface-contact thermometer. These are generally accurate to $\pm 1^{\circ}\text{F}$ ($\pm 0.6^{\circ}\text{C}$), and have a faster response time than bimetallic thermometers. The sensor maintains full contact with the surface during a reading. Electronic devices intended for measurements in air do not provide useful results if used to read surface temperatures.

Infrared Surface Temperature Measurement Devices

Infrared devices have the advantage of not having to remain in contact with the surface while a temperature measurement is being taken. Also, these more costly devices can take highly accurate temperature readings at long distances away from the surface. In general, however, the sensor head is placed as close as possible to the surface.

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Appendix A: Corrosion Mechanisms

The thickness of the moisture film on a metal surface can be characterized by the following four stages as illustrated in Figure A1:

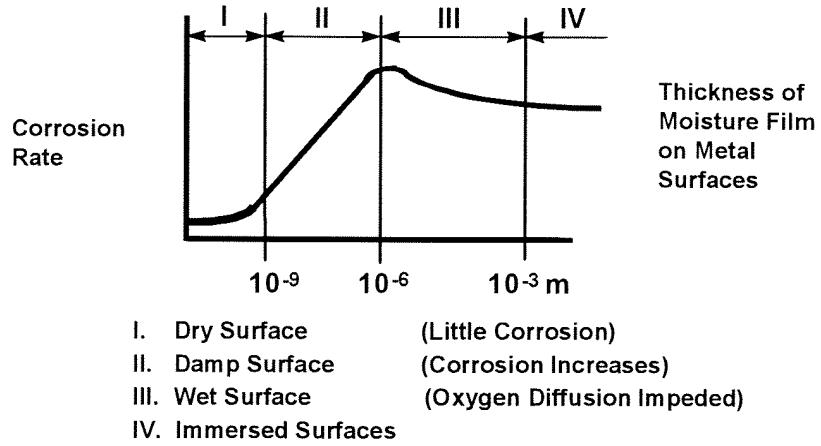


FIGURE A1: Corrosion Rate Versus Surface Moisture

Stage 1: Dry surface: Very little corrosion: water molecules do not behave as water.

Stage 2: Damp surface: Corrosion steadily increases: water molecules tend to act as electrolytes.

Stage 3: Wet surface: Thickness slightly impedes oxygen diffusion.

Stage 4: Immersed surface

Chemical reactions are very temperature-sensitive and are limited to creating a thin oxide coating, usually

invisible, on a freshly prepared metal surface at room temperatures. This oxide layer is formed almost immediately and the metal shows little sign of further degradation in a dry atmosphere. This is called a Stage 1 (dry) surface. At low RH, a molecular layer of water molecules adheres to the surface.

Wet Corrosion

As the relative humidity increases, the moisture film increases exponentially in thickness (Figure A2). The thicker moisture film behaves progressively more like an electrolyte and creates corrosion cells. These cells can

be created by a wide variety of factors such as differential aeration, presence of different atoms in the crystal lattice, pores in the protective oxide layer, or even the presence of grain boundaries. The corrosion rate increases as the

moisture film thickens. This is called a Stage 2 (damp) surface.

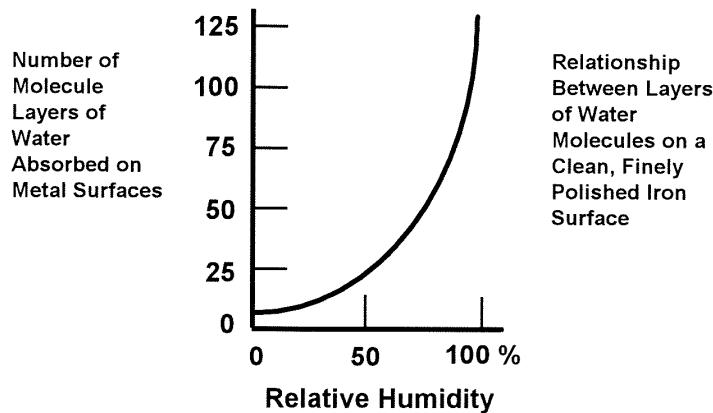


FIGURE A2: Relationship Between Adsorbed Layers of Water Molecules on a Clean, Finely Polished Iron Surface

Chemical Factors

If trace chemical contaminants are present in the air, these can form a fine film of surface salt that can be hygroscopic. The presence of any soluble salt enhances condensation because the vapor pressure above a salt solution is lower than that over pure water.

The hygroscopic characteristics of salts can be quantified in terms of the equilibrium relative humidity in a closed air space above the saturated solution. This relative humidity represents the condition in which the salts dissolve in moisture absorbed from the air. Lower relative humidity values are associated with the more hygroscopic salts. The relative humidity range over which condensation occurs on different salts is illustrated in Figure A3.

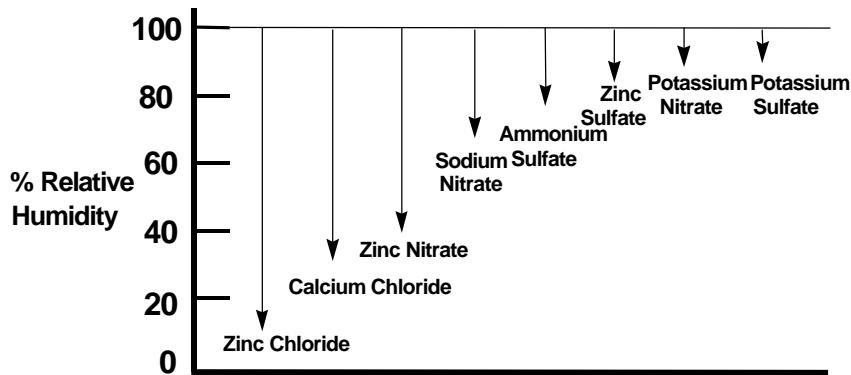


Figure A3: Relative Humidities at Which Salts Begin to Dissolve

Corrosion, Coatings, and Coating Inspection in Specific Industries

Introduction

This chapter consists of seven (7) sections each relating to a specific industry. Today's very brief discussion will touch on corrosion, coatings, and coating inspection for each industry listed. The industries to be highlighted include:

- Marine transportation (ships)
- Bridge and highway structures
- Electric power industry (oil, coal, nuclear generating plants)
- Chemical and petrochemical
- Water and wastewater
- Fertilizer
- Pulp and paper

Each of these *stand-alone* industries is unique in itself and each has its own range of operating concerns. However, there is one problem—**corrosion**—that is common to all of these industries.

Portions of steel structures in each industry--structural members, tanks, towers, equipment, etc., are exposed to moisture in varying degrees, either atmospheric, splash, spray, spillage and/or immersion. Electrochemical (galvanic) corrosion can occur on any of the uncoated or unprotected steel surfaces in contact with moisture.

The corrosion process can be accelerated by the presence of chemicals, such as acids, alkalis, oxidizing agents, and also soluble chemical salts, etc.

Each industry relies on the use of coatings to protect steel and concrete surfaces from corrosion. The selection of coatings will vary with the industry and may range from medium to high performance type materials.

The fundamentals of coating inspection, including tools, tests, methods, and techniques discussed in the three workshops of the Coating Inspector Program will apply regardless of the industry.

In the sections to follow, we will indicate some coating concerns of these industries and will try to provide a glimpse of some specific areas where coating inspection generally may be required.

Marine Transportation

Protective coating of the vessel and equipment used to transport bulk (wet or dry) materials can provide a rigorous test for the specific coating system used.

Corrosion resistant materials, such as stainless steel and Monel are widely used in marine service, however, mild steel is more commonly used.



*Figure 1
Interior Cargo Hold*

The exterior of the marine vessel (ship or barge) is coated to help prevent or control corrosion.

The interior of cargo tanks of marine vessel usually are coated to:

- Protect the substrate from any attack by the product contained
- Prevent the substrate from contaminating the product contained

In addition, the coating itself must not adversely affect the cargo transported.

Containers dedicated to use with a single product may be relatively easy to protect since coatings can be designed for just one specific purpose. When the container is scheduled for multi-purpose use, the coating selection becomes more critical, since it must provide adequate service with the many materials that may be transported.

Frequently, the coating inspector is called on to check the condition of the coating between cargoes.

Generally, more attention must be given to the interior surfaces of the container, than to the exterior. Interior welds may be required to be ground smooth or flush, sharp edges, may be rounded and all welds, corners, edges may be stripe coated, oftentimes between each application of coating material.

In some cases, corners are filled with a *putty-like* coating to afford a rounded corner rather than a sharp one. Coatings applied to a sharp corner can shrink back, creating stress within the coating and can cause some thinning of the coating film in the area of the corner.



Figure 2
Ship

A large part of the ship's hull, rudder, and propeller(s) are in constant contact with seawater, which is an excellent electrolyte. Well-bonded high performance coatings are required on the ship's hull and bottom to:

- Isolate the hull and bottom from the sea water or fresh river water
- Protect the ship from attack by chemical waste or refuse that may be in the water especially in or near coastal waterways
- Provide some measure of abrasion resistance against the ocean or river bottom, piers, docks and tugboats
- Provide resistance to fouling caused by vegetable and marine organisms



Figure 3
Ship in Dry Dock with Bottom and Hull Painted

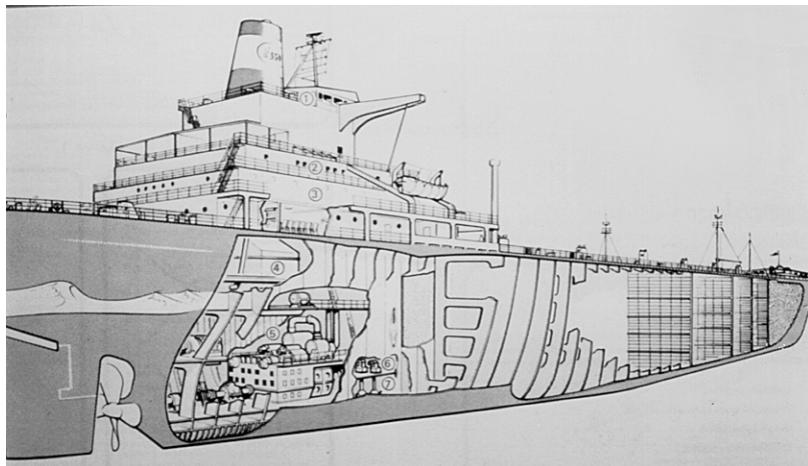


Figure 4
Schematic of Ship

The ship's sides (boot top) above the water line, the deck, equipment, hatch covers, and the superstructure have alternate exposure to the sun, cold waves, and salt spray. For these areas, properly selected high performance coatings may be desirable.

Skid-resistant coatings that have good weatherability may be used on topside decks, ladders, etc., where foot traffic may be prevalent.

Frequently, maintenance painting on deck areas and the superstructure is performed while the ship is underway.

High performance coatings are applied to the ship's hull below the water line and to the bottom areas and then are overcoated with some type of antifouling coating to minimize the accumulation of marine organisms on those surfaces.



Figure 5
Applying Coal Tar Spray to Bottom Before Applying AntiFouling Coating

The accumulation and growth of these organisms serve to slow the speed of the vessel. More fuel is required to generate the extra power necessary to maintain proper speed of the vessel. As a result, the cost of the extra fuel increases the cost of transporting goods.



*Figure 6
Typical Dry Dock*

Eventually, the ship must enter dry dock, where the marine and vegetable fouling must be removed, the hull repainted and equipped with a new coating of antifoulant material.



*Figure 7
Ship in Dry Dock*

Coating inspection issues may vary slightly between different types of ships; however, the chief responsibility of the marine coating inspector is to ensure that the specifications are adhered to—generally does not change.

Marine coating inspection offers many challenges to the coating inspector. To be effective, the marine inspector should:

- Be knowledgeable about the general construction of a ship. The inspector should be able to quickly detect hard to reach areas, problem areas, fabrication faults, etc. especially in enclosed spaces, such as tanks, cargo holds, etc.
- Be familiar with nautical terms that refer to the construction and operation of a ship, and should, where necessary, be able to use them correctly
- Be able to assess the extent of animal and vegetable fouling
- Understand and be able to prepare dry docking and inspection reports

The following reference material is included in this section.

- Schematic of a “typical” cargo ship
- General description of ship construction
- Listing of maritime classifications societies
- Glossary of nautical terms
- Explanation of ship’s registry and periodical surveys
- Typical dry docking reports
- Description of common fouling organisms

The following material will be discussed briefly:

- Classification Societies
- Ship’s registry and periodical surveys
- Dry docking reports.

Classification Societies

The principal maritime nations have the following Classification Societies:

- Great Britain—Lloyd's Register of Shipping
- USA—American Bureau of Shipping
- France—Bureau Veritas
- Germany—Germanischer Lloyd
- Norway—Det Norske Veritas
- Italy—Registro Italiano
- Russia—Register of Shipping
- Japan—Nippon Kaiji Kyokai
- Poland—Polish Register of Shipping

The classification societies operate throughout the world and publish rules and regulations directly related to the structural efficiency of the ship and the reliability of the propelling machinery.

In general, they have a long history dating back to the era of wooden ships. Classification is purely voluntary on the part of the shipowner, and the only penalty that can be imposed for noncompliance with the rules is suspension or cancellation of class.

Classification implies that a ship and the machinery conform to the standards published in the rules of the society.

With Lloyd's Register of Shipping, classification entails approval of:

The fundamental purpose of classification is to ensure maintenance of seaworthiness of all classed ships. So far as Lloyd's Register of Shipping is concerned, classification entails approval of:

- Plans of construction
- Testing of materials
- Construction under survey
- Recommendation for class from surveyors by report to the Committee

Following the acceptance of the report by the Lloyd's Committee, the certificate of class is issued and a record made in the Register Book.

Lloyd's Register of Shipping

This society was:

- Founded in 1760
- Reconstituted in 1834
- United with the Underwriter's Registry for Iron Ships in 1885
- Amalgamated with the British Corporation

The head office is located at 71 Fenchurch Street, London EC3, England

Steel ships built in accordance with the Society's Rules and Regulations or with alternative arrangements equivalent thereto, will be assigned a class in the Register Book.

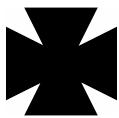
They will continue to be classed so long as they are found, upon examination at the prescribed annual and other periodical surveys, to be maintained in a fit condition and in accordance with the Rules.

Classification will be conditioned upon compliance with the Society's requirements in respect of both hull and machinery.

100A1 classification is assigned to seagoing ships built in accordance with the Society's Rules and Regulations for the draught required. The class 100A1 is also assigned to ships designed for the specific purposes such as 100A1 oil tanker, 100A1 tug, etc.

Four classes of ice strengthening are detailed in the Rules. Ice class 1 strengthening is for ships intended to navigate in extreme ice conditions.

The Figure 1 in the character of classification assigned to a ship indicates that her equipment of anchors, chain cables, and hawsers is in good and efficient condition and in accordance with the Rules.



This symbol indicates that the ship was built under the Society's Special Survey and will be classed as 100A1.

Machinery constructed and installed on board in accordance with the rules and on satisfactory completion of trials is assigned the class notation LMC (Lloyd's Machinery Certificate).

New machinery for ships intended for classification is to be constructed under the Society's Special Survey and on completion will have the mark inserted before the machinery class notation Thus: *LMC*

Periodical Surveys

Annual Surveys

All steel ships should be surveyed at approximately one-year intervals in accordance with the Rules, and where practicable, should be held concurrently with statutory annual or other line surveys.

Docking Surveys

A ship should be examined in dry dock at intervals of about 12 months; the maximum interval is two years.

Special Surveys



Figure 8
Ship in Dry Dock

All-steel vessels classed with Lloyd's are to be subjected to Special Surveys in accordance with the Rules. These surveys become due at five yearly intervals, the first five years from the build date or date of Special Survey for Classification, and thereafter five years from the date of the previous Special Survey.

Dry Docking Inspection Reports

Dry docking reports are designed to provide the full record of performance of the coating systems on a marine vessel. Frequently the dry docking report is the only record of coating performance for a particular vessel, consequently extreme accuracy is vital when compiling this report.

Generally, for this report, the hull is divided into 19 areas, and 10 separate assessments are made for each area. This provides 190 distinct items for information. Sample dry docking report forms are located at the end of this section.

The dry docking reports provide a history of previous surface treatment and surface preparation, application information, coating inspection reports, and coating performance in different areas with different service conditions.

It is vital to be able to estimate some time before the vessel is due to dry dock, the amount of remedial work that may be required while the ship is in dry dock. This estimate can only

be made by comparing previous dry docking reports and previous reports on work actually performed.

The estimate can only be as good as the previous dry docking reports and it should again be emphasized that the report must be very accurate.

In addition to accurate reporting on the condition of the ship's hull, it is essential also to obtain full details of all voyages since the previous dry-docking.

Usually, this information can be obtained from the Chief Officer of the vessel; again, it is stressed that this information should be accurate.

The coating inspector frequently is assigned the task of preparing the dry docking report and he should be aware of the individual sections normally found on these inspection report such as:

- Animal fouling
- Vegetable fouling
- Coating condition(paint blistering, stripping, rust staining, etc.)
- Extent and location of corrosion
- General appearance

Animal Fouling

This type of fouling is called SHELL and should be identified by name in the report i.e., barnacle, mussel, etc. Some common types are:

- Tube worms
- Barnacles
- Goose necks

Vegetable Fouling

This type of fouling is called WEED and should be properly identified in the report. Some common types illustrated here include:

- Enteromorpha ulva (dark green)
- Enteromorpha (light green)
- Ectocarpus (brown)

This section includes all plants, which should be noted by name.

For example: Port 1 Grass Starboard Ectocarpus

The estimation of the amount of weed growth, in particular grass, is not easy and it is suggested that a preliminary estimate is made by walking around the dry dock while the water level is being reduced and observing the amount of growth from a distance

This should be done before any cleaning down, such as *brooming* is done. Then, when it is possible to enter the dock bottom, the inspector should make a full estimate of the weed as soon as possible.

It is important that the inspector make this determination quickly, because if the hull is allowed to dry out for some time, the weed, especially near the boot top, will have turned a brown color making it difficult to distinguish from oil residues on the hull.

Coating Condition

Deterioration of the coating may be due to abrasion damage from jetties, or by scraping the bottom (grounding) as shown here, by scraping of chains, welding/burning etc. Coating that has been stripped to bare metal due to this abrasion, should be specifically reported.



Figure 9
Abrasion Damage due to Grounding

Care should also be taken in reporting areas of rust staining, since it may be found that an area below the paint breakdown and corrosion may be rust stained by the corrosion products, but the underlying coating may be sound.

Coating deterioration may also take the form of:

- Blistering
- Checking/Cracking
- Blisters



Figure 10
Blistering

Blisters, if any, in the paint film may be evaluated according to ASTM D 714 Standard Test Method for Evaluating Degree of Blistering of Paints

- Checking/Cracking



Figure 11
Checking

The coating may be evaluated to determine if the coating shows any sign of checking or cracking, and these areas marked and noted on the dry docking report.

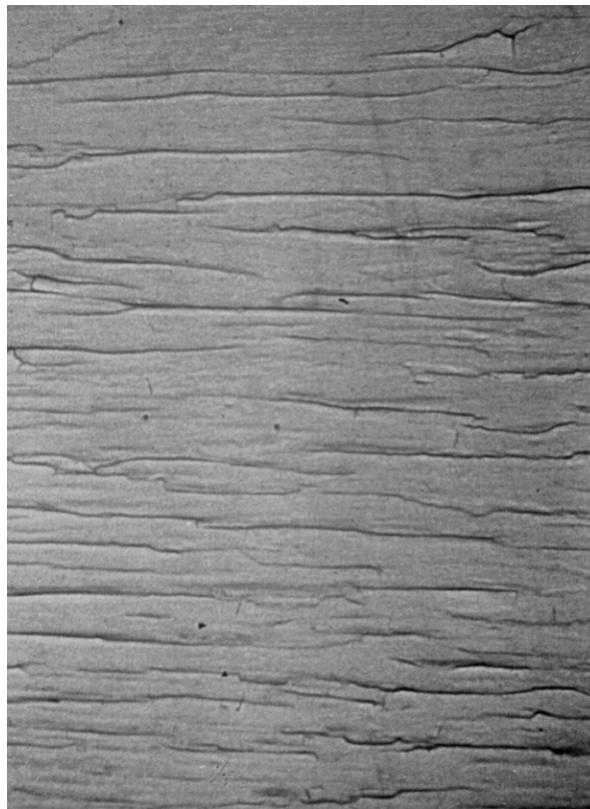


Figure 12
Checking Leading to Cracking

Extent and Location of Corrosion

If corrosion has begun, it should be noted according to the degree and location on the ship. For example,

- Pitting
 - Area of pitting—This may be expressed as the number of pits and the average size
 - Depth of pitting—This should be the deepest point of the pit, and it is helpful in the report to indicate if the pits are polished or not.

General Appearance

In some areas of the hull, it may not be possible to get near the surface (i.e., the boot top) to make a close inspection, and a purely distant visual estimate will have to be made. This should be indicated in the report.

The general appearance and any comments the inspector feel may be relevant should be noted in the “remarks” section of the report form. Photographs of the hull before, during, and after cleaning/coating operations will be a valuable element of the dry docking report.

Report Forms

Included here are some typical dry docking report forms. Sheet #1 shows the port side and the keel divided into 11 separate areas for inspection. Assessment of each area may be made according to the items listed as follows.

- Shell
- Weed
- Blistering
- Stripping intercoat
- Stripping to bare metal
- Rust staining
- Pitting (area)
- Pitting (depth)
- Rust (bare areas)

- Roughness

Sheet #2 shows the starboard side divided into eight areas for inspection and the same items for assessment as shown on Sheet. #1. It should be noted that area # 8 is for the rudder, which is shown as a separate area for both port and starboard sides.

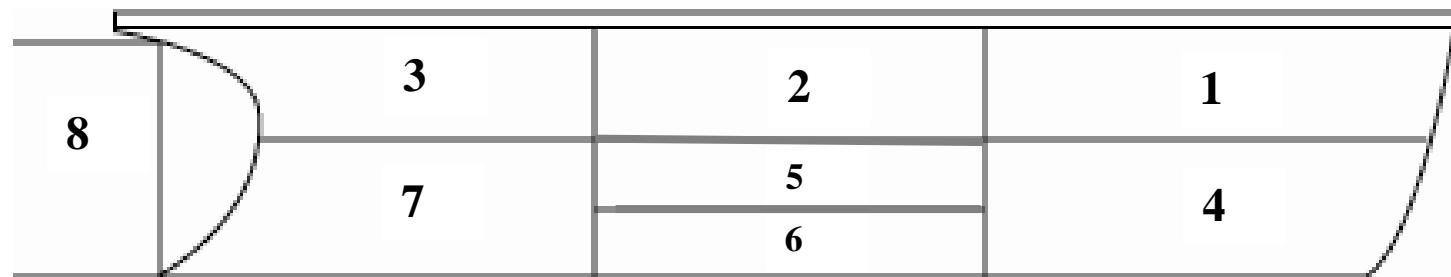
Sheet #3 provides space for vessel identification and for information on previous voyages.

Sheet #4 is entitled “Numerical Assessment of Hull Condition Grading Code”. This form allows the inspector to assess:

- Fouling
 - Paint blistering
 - Degree of corrosion on steelwork
 - Roughness
- according to a specific grading code.

The inspector should be diligent in assessing each area of the ship, and should include in the report any appropriate remarks that would assist the next inspector involved in a future dry docking inspection and report.

SHEET 1



SHEET 2

Rudder (8)	Boot topping (3)	Underwater (7)	Underwater		Boot topping (1)		
			Above b/k (5)	Below b/k (6)			Shell
							Weed
							Blistering
							Stripping undercoat
							Stripping to bare metal
							Rust staining
							Pitting (area)
							Pitting (depth)
							Rust bare (areas)
							Roughness
							Remarks
Cathodic Protection System:					Weather Conditions During Assessment		
Sacrificial Anodes (Percent Wasted)							

SHEET 3

SHEET 4: NUMERICAL ASSESSMENT OF HULL CONDITION GRADING CODE

Assessment	Item Detail	Definition	Grading				
			0	1	2	3	4
Fouling	Weed	All types of weeds and hydroids	0	0-2 %	2-10%	11-30%	30% or greater
	Shell	All types of shell organisms					
Paint Blistering	Blistering	The area enclosing the unbroken blisters	0	0-2 %	2-10 %	11-30 %	30 % or greater
	Stripping (intercoat)	Area showing stripping since last painting					
	Stripping to Bare Metal	Area of bare metal due to mechanical or paint failure					
	Rust Staining	Area of paintwork either containing rust nibs or discolored due to rust under the paint					
Degree of Corrosion on Steelwork	Area of Pitting	Area showing pits	0	0-2 %	2-10%	11-30%	30% or greater
	Depth of Pitting	Depth of pits					
	Rust	This applies to the amount of rust on bare areas	0		light rust		Heavy Rust
Roughness	Surface Roughness	Estimated amplitude of roughness on surface	150 mm		500 mm		1000 mm

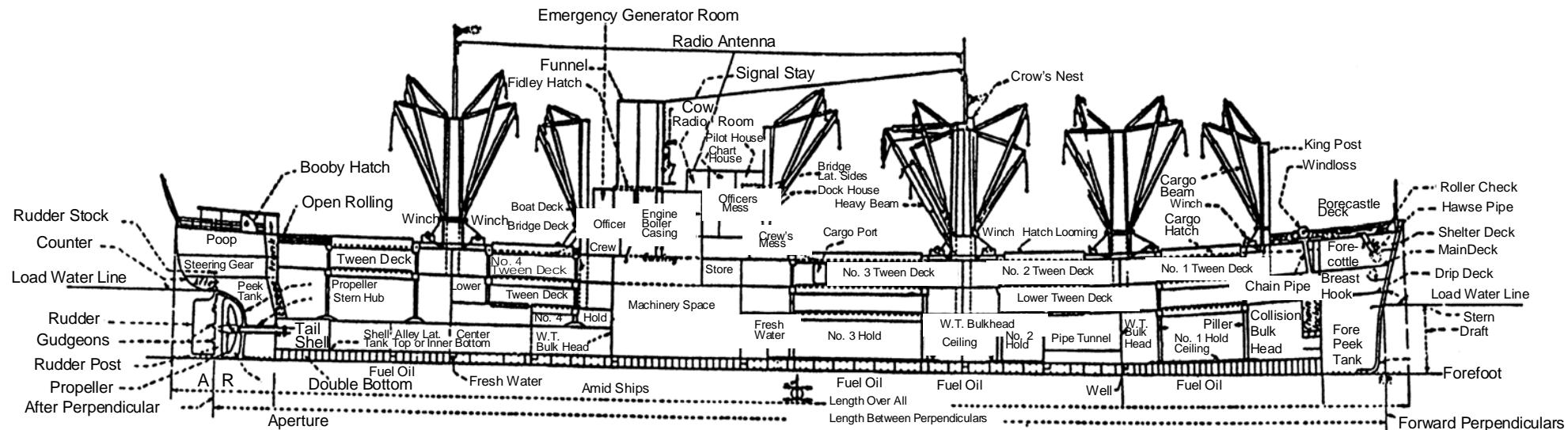


Figure 13
Schematic of Ship

SHIP CONSTRUCTION

The structure of a ship may conveniently be regarded as comprising a framework of girders, which is almost completely enveloped in a steel skin, which is riveted or welded to the framework. The steel covering is made up of plates, which collectively form the *SHELL* and *DECK PLATING*.

The members of the framework of the ship's structure may be classified as either *LONGITUDINAL* or *TRANSVERSE*. Longitudinal members extend length-wise or fore and aft, and transverse members extend breadthwise or transversely.

The main function of the framework is to stiffen the shell plating and prevent it from caving inwards. The members of the framework at the ship's sides and bottom are arranged so that they form a rectangular network of girders.

Transverse stiffness is provided principally by partitions known as *BULKHEADS*, which are constructed of steel plates fitted across the ship between the two sides of the shell plating. These bulkheads, if watertight, divide the ship longitudinally into a series of watertight compartments. Those in which cargo is carried are known as *HOLDS*. These are generally arranged symmetrically with respect to the machinery space that is usually in the middle part of the ship. The end compartments are normally reserved for the carriage of water ballast, oil fuel, or fresh water for boiler or domestic purposes.

Most vessels are fitted with water-ballast or oil-fuel tanks which extend throughout the greater part of the ship's length along the bottom. The top boundary of these tanks forms an inner bottom, so that for the greater part of the most ship's lengths there is a double skin between which are the so-called *DOUBLE-BOTTOM TANKS*.

The framework of a ship may be designed on either the transverse or longitudinal system. The traditional system of framing is the transverse system, in which the ship may be regarded as comprising a large number of regularly and closely spaced *TRANSVERSE SECTIONS*. In its simplest form, each transverse section consists of a pair of girders, usually bulb angle sections known as *FRAMES*, one fitted to each side; a girder known as a *BEAM* which connects the top ends of the corresponding frames by means of *BEAM KNEES*, and which collectively support the deck which is riveted or welded to the

beams; and a deep girder known as a *FLOOR* which extends across the bottom of the ship, and connects the bottom ends of corresponding frames. To the bottom edges of the floors, the bottom shell plating is secured by means of riveted or welded joints. The top edges of the floors support the inner bottom.

The transverse sections are strapped together through the agency of the longitudinal members of the ship's structure, principally by shell and deck plating assisted by the longitudinal members of the framework itself.

The rectangular pattern of the ship's framework requires that certain members are interrupted by members which lie at right angles to them and which are *CONTINUOUS*. The interrupted members are referred to as being *INTERCOSTAL*. Because the rigidity of an intercostal member is inevitably less than that of a continuous member (no matter how strong the connection between them), the more important members of the framework are continuous.

In the transverse system of framing, the transverse members are continuous and most of the longitudinal members are intercostal. A vessel constructed on this system has accordingly great transverse strength.

The longitudinal system of framing involves a large number of closely spaced continuous longitudinal members, with which are associated widely spaced transverse framing units, which are notched in the way of the longitudinal frames to which they are secured.

The scantlings (dimensions) of the various structural members of a ship, as laid down in the rules of any classification society, have been determined on a strictly scientific basis supported by long practical experience. They bear a close relationship to the estimated maximum stresses that will affect the members when the ship is in service.

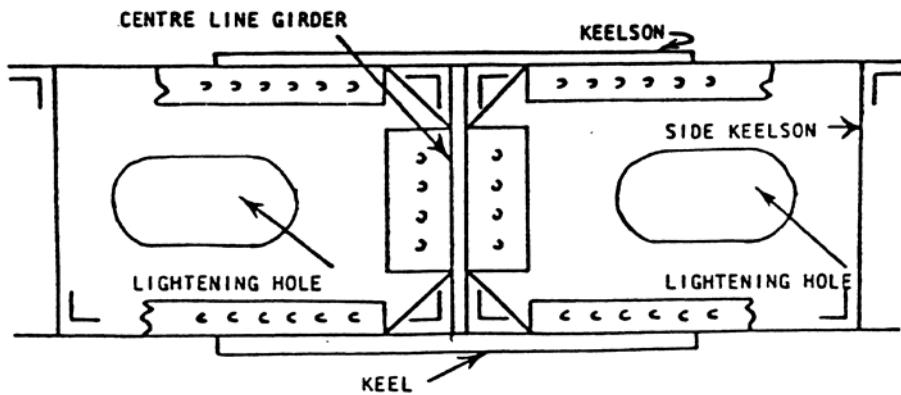


Figure 14
Transverse Section Through Typical Keel Structure

The framework of a ship is built up on what is her most important longitudinal girder, namely the keel structure. Figure 14 is a sketch of a transverse section through a typical keel structure.

It will be observed from Figure 1 that the keel structure is formed by a heavy girder consisting of the central line of STRAKE of bottom plating known as the keel strake; a continuous series of plates set up vertically in the middle line of the ship to form the center-line girder; and surmounting the center-line girder the upper member known as the KEELSON.

These three longitudinal members are rigidly connected together by means of angle bars or equivalent welded joints.

At closely spaced intervals equivalent to that of the transverse framing (in the case of a ship built on the transverse system), INTERCOSTAL FLOOR PLATES are connected to the keel girder as illustrated in Figure 14. Fore-and-aft members which fit intercostally between the floor plates are known as SIDE KEELSONS. The number of side keelsons depends upon the breadth of the ship.

The boundaries of the cellular system of floors, keel and keelsons, are formed by the MARGIN PLATES. These are continuous longitudinal members set more or less at right angles to the shell plating in the vicinity of that part of the hull known as the TURN OF THE BILGE. The margin plates are connected to the vertical members of the transverse framing by means of triangular brackets. The spaces between the TANKSIDE BRACKETS and the margin plate and the shell plating, form the BILGES, which provide for drainage from the cargo carried in the hold.

Large holes known as LIGHTENING HOLES are cut in the keelsons and intercostal floors and tank side brackets. These serve the purpose of reducing the weight of the structure without materially reducing its strength. At the same time, they provide the means for communication between the cells of the double-bottom tanks for water ballast or fuel, or for personnel when inspecting, cleaning, or maintaining the tanks. Access to the double-bottom tanks is provided by manholes which are fitted with covers. These are cut in the inner bottom and are found in the holds.

The details at the margin of a double bottom tanks are illustrated in Figure 15.

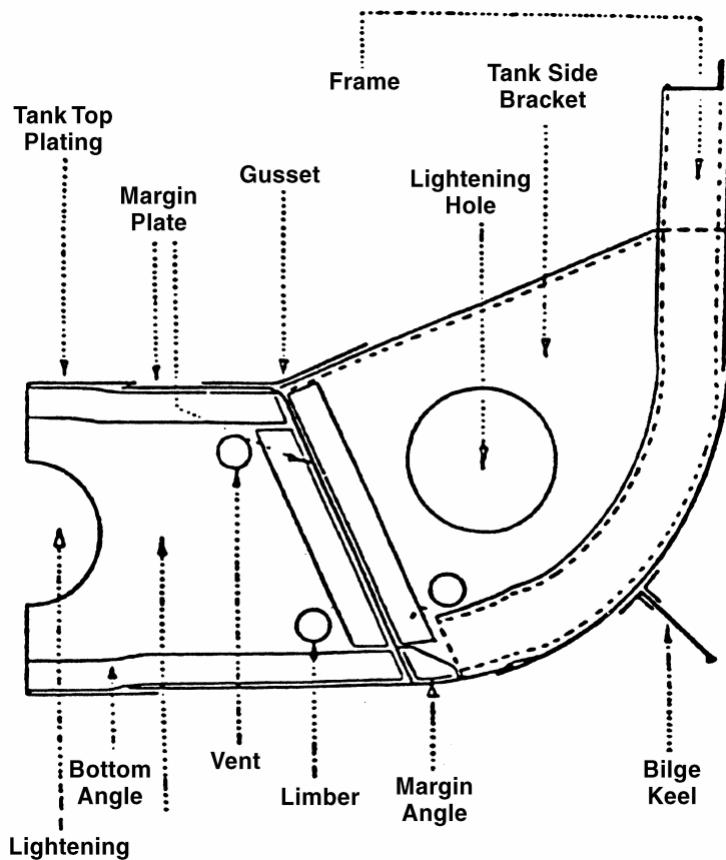


Figure 15
Details at the Margin of a Double Bottom Tank

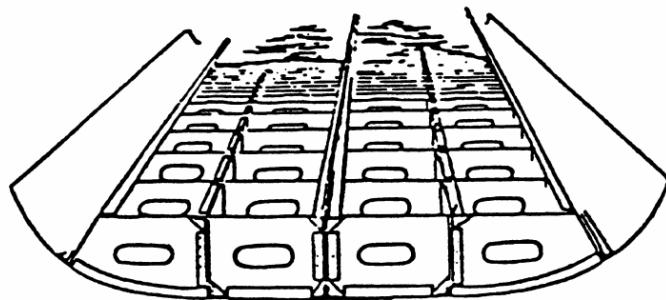


Figure 16
Part of the Bottom Structure of a Ship

The vertical members of the sides of a ship's framework are known as **FRAMES**. The tops of corresponding frames are connected by means of beam knees to the beams, the latter being the transverse members which support the deck plating. Both beams and frames are usually in the form of heavy bulb-angle sections, the purpose of the bulb on the outer edge of the transverse flange being to provide rigidity in the simplest manner possible.

The outer covering or skin of the ship is formed by the shell and deck plating. This is made up of fore-and-aft lines of plates known as **STRAKES**. The thickness of shell and deck plating is a function of their position relative to the ship's neutral axis. It is clear that those strakes which occupy the corners of the box-like longitudinal ship girder, and the bottom and deck strakes, have the greatest bending stresses to overcome when the ship is in service. These are, accordingly the thickest strakes. The names of the more important strakes of the shell and deck plating are given in Figure 17

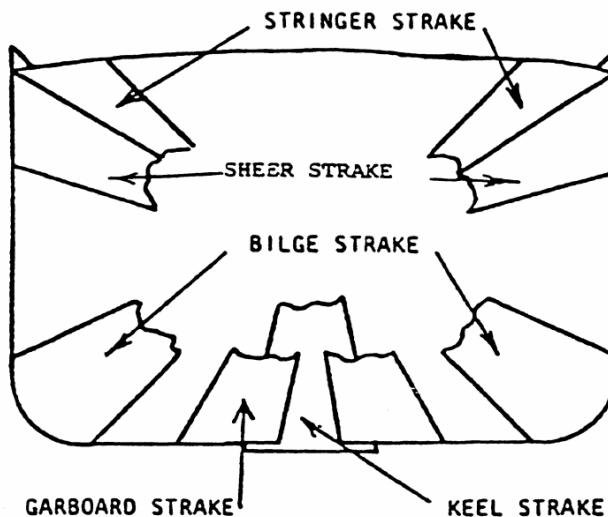


Figure 17
Names of Important Strakes of the Shell and Deck Plating

The strakes of plating are usually lettered for identification purposes, stoke A denoting the starboard stoke, port or starboard, stoke B the stoke adjacent to the starboard stoke, stoke C the next, and so on.

The girth of a ship is greatest amidships and decreases towards the ends. For this reason, the widths of the strakes have to be reduced towards the ends of the ship, or alternately two adjacent strakes have to be replaced by one stoke. Both of these means are adopted in planning the plating scheme of a ship. A single stoke which replaces two strakes is known as a STEALER STRAKE. Inspection of the shell plating when the ship is in dry dock, or even when alongside, will reveal examples of stealers.

It is important when planning a plating scheme to arrange that the transverse joints, or butts as they are called, are spread out in the fore-and-aft line of the ship to avoid the unnecessary weakness which would result if too many butts occurred in the same or nearby frame spaces. It is necessary, in other words, to arrange suitable SHIFT OF BUTTS.

Important members of the ship's structure are the transverse WATERTIGHT BULKHEADS. These not only give great transverse strength, but divide the ship longitudinally into watertight compartments, so guarding against rapid foundering, should the shell plating be pierced. The number of watertight bulkhead that must be fitted according to the rules of the classification societies is a function of the ship's length. According to Lloyd's Rules, the foremost watertight bulkhead must be fitted not less than a twentieth of the length of the ship from the stem. This bulkhead is called the COLLISION BULKHEAD. Part of the space forward of the collision bulkhead forms the FOREPEAK, which is utilized for the carriage of water ballast, fresh water, or oil fuel. A similar compartment at the after end of the ship, known as the AFTERPEAK, is bounded by the aftermost watertight bulkhead, known as the AFTERPEAK BULKHEAD.

Watertight bulkheads are always fitted immediately before and abaft the machinery space, so that all ships that have their propelling machinery located near the mid-length must have at least four watertight bulkheads. For vessels whose lengths exceed a certain minimum, additional bulkheads are required.

The openings in the deck of a ship which are required for the purpose of allowing cargo to pass into or out of the holds, are

known as HATCHWAYS. They are bounded on all four sides by vertical plates well secured to the deck, and known as COAMINGS.

It is necessary that the lack of strength in the deck in the vicinity of hatchways is made good. Thus, the deck plating in the vicinity of the coamings is usually of increased thickness; doubling plates are fitted at hatchway corners; and portable beams are provided for the space between the fore-and-aft coaming plates.

Before a ship proceeds to sea, and especially when there is cargo on board, the hatchways must be covered adequately to prevent the entry of water into the holds. The process of battening down a hatch way involves the fitting of portable hatchboards which are covered by tarpaulin hatch covers. The tarpaulin covers are kept in place by side battens which engage in hatch-coaming cleats, and the battens are held in place by wooden wedges. Many ships now, however, are fitted with integral steel hatch covers which are easier to operate and increase the structural strength of the ship.

In addition to machinery compartments, cargo holds, and spaces for oil fuel, solid fuel, water ballast, or fresh water, other compartments which serve as storerooms for the ship's equipment and consumable stores are required. In addition, many cargo vessels are provided with DEEP TANKS which extend from side to side throughout the depth of the ship. These tanks, which are bounded by water-tight bulkheads, may be used for water ballast or for the carriage of liquid cargo such as latex, wine, or edible oil.

For the purpose of dividing the cargo-carrying space of a ship into a relatively large number of compartments, many ships are fitted with decks additional to the uppermost or main deck. These are known as tween decks.

The oil tanker is one of the few ship types in which the cargo directly rests on the skin of the ship, without the interposition between it and the sea of any other structure such as double bottom. The carriage of petroleum in bulk necessitates special precautions being taken to meet the difficulties which accompany the transport of such a cargo. The propelling machinery is fitted aft, beneath which is a double bottom space for the accommodation of the oil fuel. The main cargo space in the present-day tanker is subdivided longitudinally by twin oil tight bulkheads and transversely by a number of oil tight bulkheads throughout the length, thus giving several sets of

three tanks. To reduce the risk of leakage of oils or vapor into other compartments, a pair of bulkheads which form cofferdams are fitted at each end of the oil cargo range. These cofferdams are well ventilated.

The cargo oil-pumping arrangements are quite extensive, as a number of different grades of oil have to be loaded, transferred from tank to tank, and discharged by a pipe network without risk of contamination of one grade by another. There are two cargo handling pipe arrangements in common use (a) the Ring Main System, and (b) Suction Mains. The former consists of a cast-iron pipeline running round the entire cargo tank range; the size depends on the tank capacities and pumping rates desired. The ring main is cross-connected by a single pipeline in each of three tanks abreast, and thus opposite wing tanks are directly connected. From each cross-over, there is a branch pipe, having a suction strum at its end, led into each of the three abreast tanks. Sluice valves controlled by a handwheel at the upper deck make it possible to isolate the cargo tanks. Any set of tanks may be isolated by means of master valves. The ring main system operates in conjunction with pump rooms situated within the tank range.

The other system in common use consists of suction mains running fore and aft through the cargo tanks. One section main goes to the foremost tank and the others to intermediate positions, each main dealing with a set of tanks which are also interconnected.

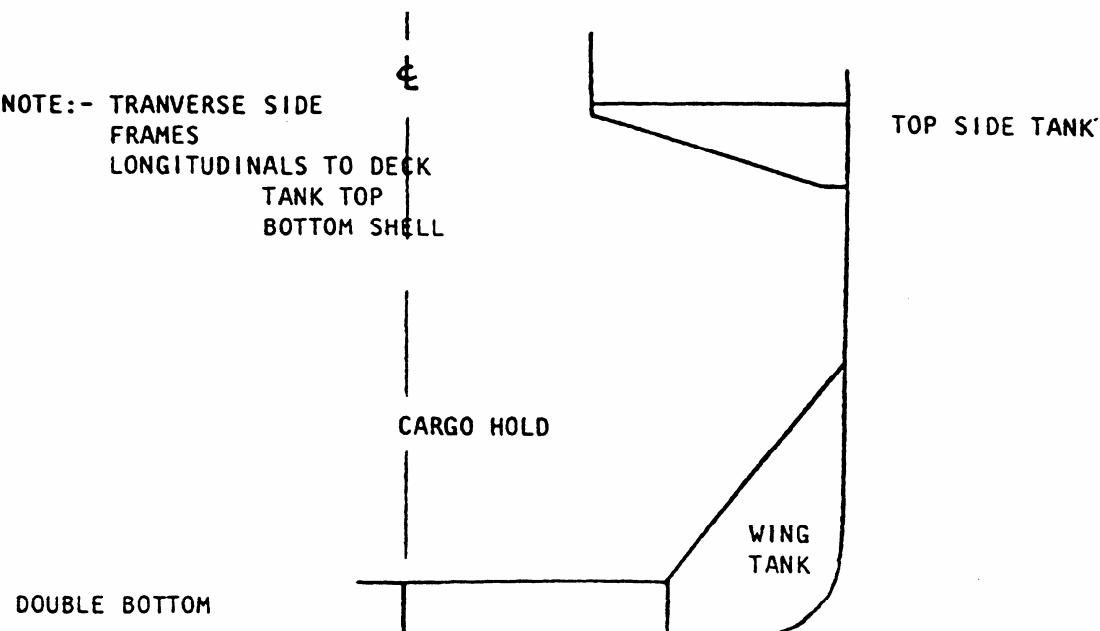


Figure 18
Outline Section of a Bulk Carrier

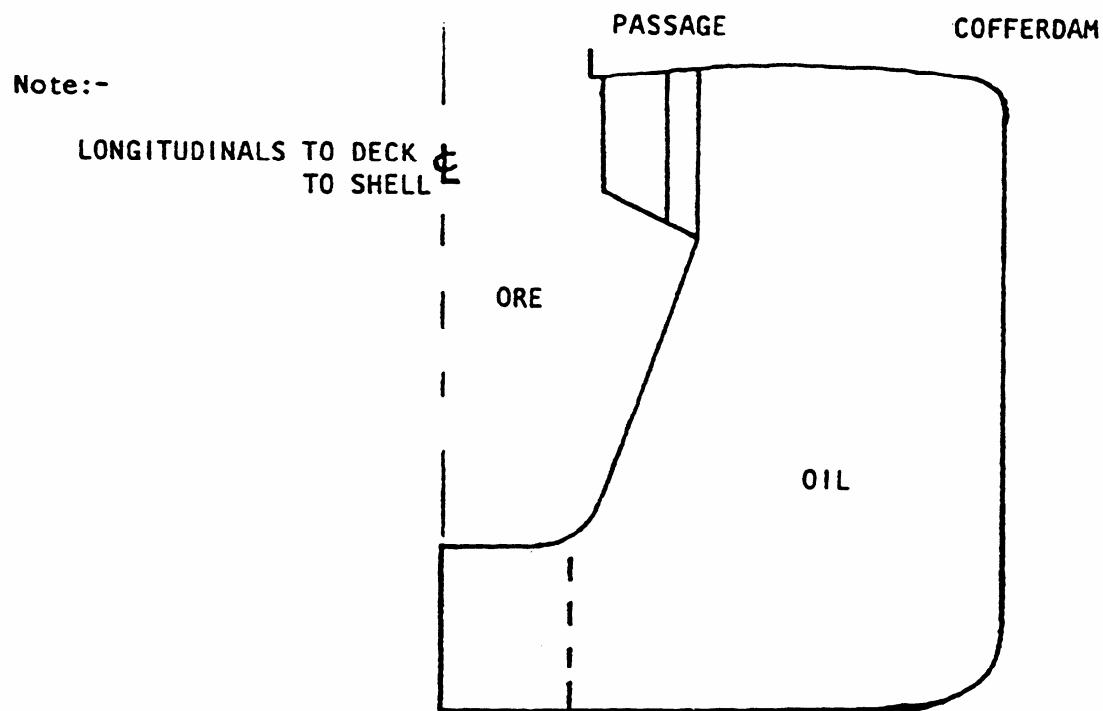


Figure 19
Outline Section of Combined Ore and Oil Carrier

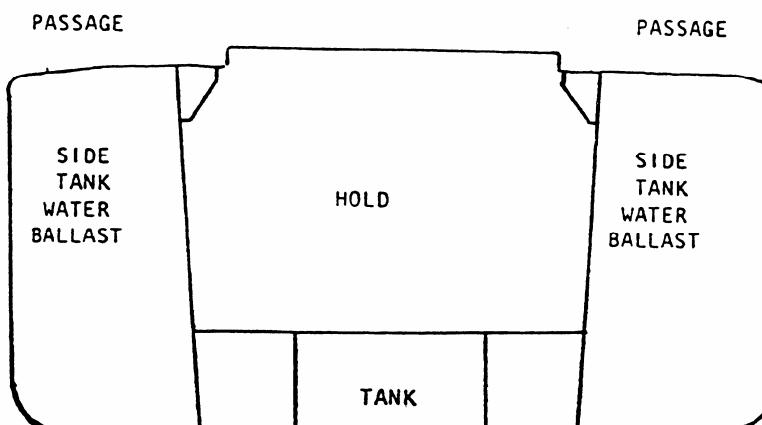


Figure 20
Outline Section of Ore Carrier

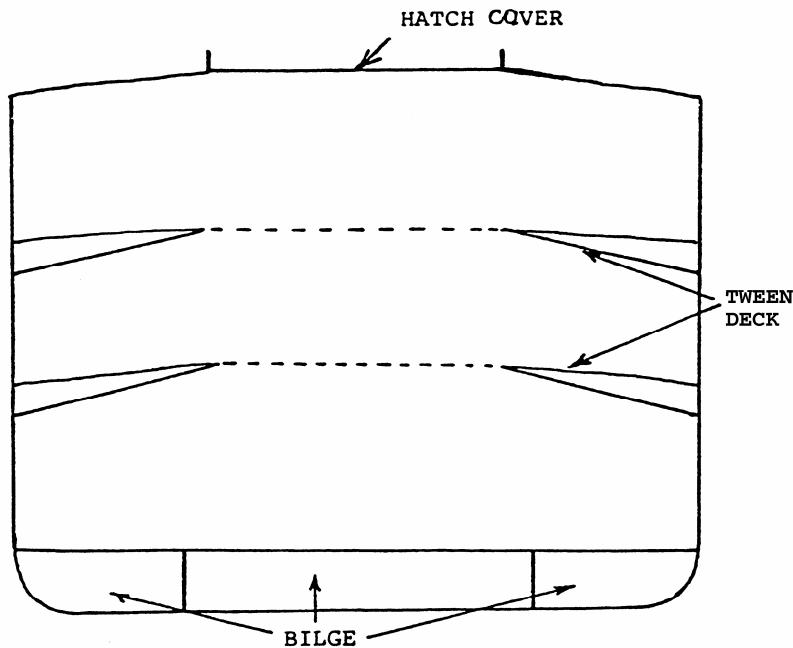


Figure 21
Outline Section of Cargo Vessel

Tanks for heavy oils, molasses, or other viscous fluids are fitted with heating coils in order that the fluids may be sufficiently liquefied to run freely to the pump suctions.

When oil vapor comes into contact with air, an explosive mixture is formed and is dangerous. Consequently, adequate provision has to be made to ensure that any foul gas which has accumulated from the oil has a ready means of escape.

A modern trend is towards concentrating the accommodation and navigating bridge on the poop of the ship. This eliminates the midships house and creates advantages which are of an economic, structural and safety nature.

Many tankers spend a very high proportion of time at sea. A crude-oil carrier may be up to 330 days of each year at sea. This creates problems for those who sail in tankers, and, to attract officers and seamen, accommodations for the entire complement is of the highest order. In many cases, single-berth cabins are provided for each member of the crew, and air-conditioning is available throughout the accommodation spaces. Amenities include swimming pools, libraries, radios, and film shows.

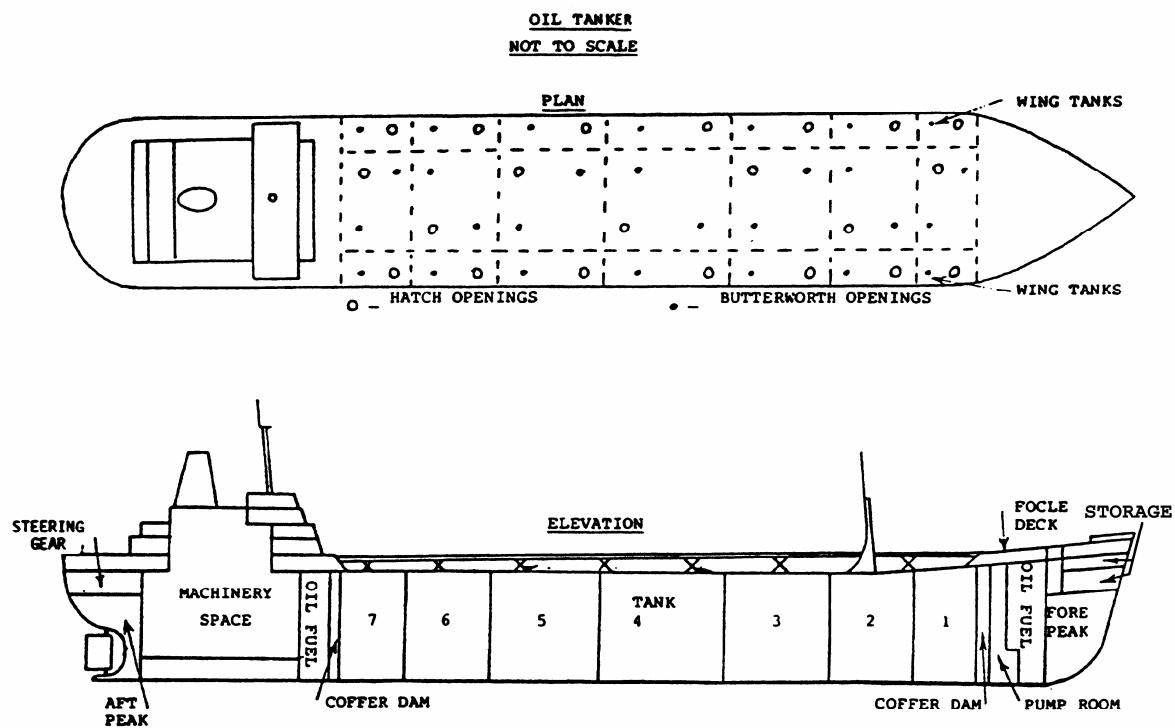


Figure 22
Schematic of Oil Tanker

Section 2: Glossary of Marine Technology

ABAFT (aft of)	Towards the stern from amidships.
ACCOMMODATION LADDER	A ladder fastened to a platform attached to the side of the ship.
AFT	Towards, at, or near the stern.
AFTER BODY	That portion of the hull abaft amidships.
AFTER PEAK	The compartment at the stern abaft the aftermost watertight bulkhead.
AMIDSHIPS	The portion of the ship at half its length.
ANCHOR	Used to hold a ship stationary when afloat, to which is attached the chain cable.
APERTURE	The space between the rudder post and propeller post for the propeller.
ATHWARTSHIP	Across the ship transversely, at right angles to the fore and aft center-line.
AWASH	Level with the surface of the water.
BACKSTAY	A wire stay fitted aft from the mast as a support.
BALLAST	Any solid or liquid weight placed in a ship to increase the draught to change the trim or to regulate the stability.
BALLAST TANK	A watertight compartment to hold water ballast.
BAR KEEL	A solid keel of steel, rectangular in section, the lengths of which are scarfed together, and attached to the garboard strake of shell plating.
BARGE	A flat-bottomed vessel for carrying cargo. When non-propelled, is termed a "dumb-barge."
BATTEN	To batten down is to secure the hatchway tarpulin
BEAM, PANTING	Fitted in the fore part of the ship to prevent vibration.
BEAM KNEE	The connection between the beam and the frame of a ship.
BEAMS	The athwartship steel rolled sections supporting the deck plating.

BERTH	Where a ship is tied up or docked.
BETWEEN DECKS	The space between any two adjacent decks.
BEVEL	The angle between the flanges of a frame or other member of the structure. When greater than a right angle, open bevel; when less, closed.
BILGE KEEL	An external fin fitted at the round of bilge to reduce rolling.
BILGE STRAKE	Course of shell plating at the bilge.
BITT	Fitted for the purpose of securing ropes; also called a bollard.
BOTSWAINS CHAIR	A wooden seat in which a man may be hoisted, aloft or lowered over the ship's side.
BOLLARD	Fitted for the purpose of securing ropes.
BOOBY HATCH	A covered entrance or companionway leading down to the tween decks.
BOOT TOPPING	A protective composition applied to the shell plating between the light and load waterlines.
BOTTOM	The section of the outer hull below the high load line.
BOW STOPPER	Used to check the chain cable running outboard.
BREAK	The end of partial superstructure such as a poop, bridge, or forecastle where it drops to the deck below.
BREAKWATER	Fitted on the weather deck forward and so shaped as to cause the water shipped on the deck to run off quickly.
BREASTHOOK	A triangular plate bracket joining port and starboard side stringers at the stern.
BULKHEAD	A transverse or longitudinal division of a ship.
BULWARK	The plating fitted for protection at the sides of a ship on and above the weather deck.
BUTT	The joint formed when two parts are placed edge to edge; the end joint between two plates.
BUTT STRAP	A strap that overlaps the butt between two plates.
BUTTERWORTH	A machine for tank MACHINE washing and cleaning when required is fitted in opening.

BUTTERWORTH	A circular section of OPENING deck plating in cargo and tankers which can be removed to use machine.
BUTTOCKS	The fore and aft sections giving the longitudinal form of a ship used on the line plan of a ship.
CAISSON	The watertight structure fitted to the entrance of a dry dock.
CAMBER	The amount of curvature in a deck, also called round of beam.
CAPSTAN	A revolving device with a vertical axis used for heaving-in mooring lines.
CARGO BATTENS	Strips of wood fitted inside the frames to keep cargo away from hull steelwork, also called sparring.
CARGO PORT	Opening in ship's side for loading and unloading cargo.
CARLING	A steel section fitted fore and aft between beams.
CAT WALK	See Flying Bridge.
CAULKING	The filling of the seams of wood planks with oakum. Method of closing butts and seams of steel plating to make them watertight.
CEILING	Wood covering placed over the tank top for its protection.
CHAIN LOCKER	Where the cables are stowed at the fore end of a ship.
CHINE	The intersection of the straight sides, or ends with the flat bottom of a barge.
CLEAT	A fitting having two horns around which ropes may be made fast, a clip on the frames to hold the cargo battens in place.
COAMING, HATCH	The vertical plating bounding a hatchway.
COFFERDAM	Narrow space between two bulkheads or floors that prevents leakage between adjoining compartments.
COMPANION	The permanent covering to a ladderway.
COUNTER	The overhanging portion of the stern.
COWL	A hood-shaped top to a ventilator.
CRADLE	The supporting structure to carry the ship on the sliding ways for launching.

DAVITS	The supports under which the lifeboats are stowed and from which they are launched overboard.
DEAD FLAT	The portion of ship's structure that maintains the midship form.
DEADLIGHT	A hinged or portable internal steel cover fitted to a side light.
DEADRISE	A thwartship rise of bottom from keel to bilge.
DEADWEIGHT	The difference in displacement between the light and load waterlines.
DECK FREEBOARD	Deck to which the freeboard is measured.
DECKHEAD	The roof of a tank.
DECLIVITY	Inclination of ways on which ship slides during launching.
DEEP TANKS	Tanks extending from top of double bottom up to or higher than the lowest deck. May be used for dry cargo, water ballast, or liquid cargo.
DERRICK	A wood spar or steel tube used for discharging.
DISPLACEMENT	The weight of water displaced by the ship.
DISPLACEMENT	The displacement of the LIGHT ship complete and ready for sea, but excluding cargo, fuel, fresh water and stores.
DISPLACEMENT LOAD	The displacement when the ship is floating at the maximum permissible draught.
DOG	A clip for securing a door or hatch cover.
DOG SHORES	The preventative shores fitted between sliding and ground ways.
DOUBLE BOTTOM	The space between the outer and inner bottoms used for water ballast, fresh water, oil fuel, etc.
DOUBLING	A stiffening or second plate to provide additional strength.
DRAUGHT	The depth of water at which the ship floats.
DRAUGHT MARKS	Cut in on the stem of sternpost. The marks are at every 12 inches, the figures being cut 6 inches in depth.
DUNNAGE	Battens fitted in the hold for the protection of the cargo.
DUTCHMAN	A piece of wood or steel used to cover up a defective joint.

ELEPHANTS FEET	Then end of the main suction pipe in the cargo tanks of tankers. It is so named from its shape.
EVEN KEEL	When the draughts of the ship are the same forward and aft.
FAIR	To smooth or fair up a ship's lines.
FAYING SURFACE	The surface between two adjoining parts.
FENDERS	Rubbing pieces on the sides of the ship as a means of protection.
FIDLEY	The top of the boiler casing.
FLARE	The spreading out of the hull form from the vertical plane.
FLOORS	Transverse vertical plates in the double bottom.
FLUSH DECK	An upper deck without side to side erections.
FLYING BRIDGE	A raised walkway in cargo tankers running fore and aft from accommodation forecastle.
FOREBODY	That portion of the ship's body forward of the midship section.
FORECASTLE	The superstructure on the upper deck at the fore end of a ship.
FOREFOOT	The lower end of a vessel's stem which curves to meet the keel.
FORE PEAK	The watertight compartment at the forward end.
FREEBOARD	The distance from the waterline to the upper surface of the freeboard deck at side.
FREEING PORT	Openings in the bulwark plating from freeing deck of water.
GANGWAY	A ladderway used for boarding a ship.
GARBOARD	The strake of bottom shell plating adjacent to the keel plate.
GASKET	Flexible material for making doors or covers watertight.
GIRTING	To measure the distance round the girth.
GOOSENECK	A ventilator turned over at the head to prevent the entry of water.

GROUNDWAYS	The fixed ways on which the sliding ways attached to the ship move when a ship is being launched.
GUDGEONS	Bosses on the rudder post to take the rudder pintles about which the rudder turns.
GUNWALE	The junction of the upper deck with the shell plating.
GUNWALE BAR	The angle bar at the gunwale.
HATCHWAY	Opening in a deck through which cargo is loaded and unloaded.
HAWSE PIPE	Tube through which anchor chain is let.
HOGGING	When a vessel drops at the extremities. The opposite is sagging.
HOLDS	Spaces below deck for stowage of cargo.
INBOARD	Inside the ship.
INNER BOTTOM	Plating forming the top of the double bottom, also called tank top.
INTERCOSTAL	A longitudinal girder, not continuous.
ISLAND	A side to side erection but detached from other erections. The combination of a poop, bridge, and forecastle is termed a three island ship.
JACOB'S LADDER	A portable rope or wire ladder used over the ship's sides.
KEEL BILGE	External plate fitted at right angles to shell plating at bilge to reduce rolling.
KING POST	Vertical post fitted to support derrick; also called samson post.
KNEE BEAM	Bracket connecting beam and frame.
KNUCKLE	An abrupt change in direction of plating.
LAGGING	Material used for insulation.
LANDING	Longitudinal laps of plating.
LAP	A joint in which one part overlaps the other.
LIGHT WATERLINE	The draught of the ship in the light condition.
LIGHTENING HOLE	A hole cut in a structural member to reduce weight.

LIGHTER	An open non-propelled barge.
LIMBER HOLE	A drain hole.
LINER	A merchant ship engaged on a direct regular service.
LINES	The plans that show the form of the ship.
LIST	Inclination of ship from the upright.
LOAD WATERLINE	This corresponds to the ship's maximum draught.
LOG BOOK	The official book containing the records of the voyage inserted by the master of the ship.
LONGITUDINALS	For and aft structural members.
LOUVRE	A small ventilator.
MacGREGOR HATCH	A steel hatch folding cover.
MANHOLE	A hole in tank top, etc. to provide access.
MARGIN PLATE	The outer boundary of the double bottom.
MIDSHIPS	Middle of the ship's length.
MOORING RING	Oval casting set in the bulwark plating through which the mooring lines are passed.
MOULDED LINE	The outside edge of the frame and is the line which appears on the lines plan.
OFFSETS	Term used for co-ordinates of a ship's shape or form.
ORLOP	The lowest deck.
OUTBOARD	Towards the ship's side; outside the hull.
OVERHAND	The amount of stern projecting beyond the after perpendicular.
PEAK TANKS	The compartments at the extreme ends of the ship which are normally used as a ballast tank.
PILLARS	Support to the decks.
PINTLES	The pins that hinge the rudder to the gudgeons on the rudder post.

PITCH	The distance a propeller will advance in one revolution.
PITCHING	The action of a ship in moving to the crest and descending into the trough of a wave.
PLIMSOLL MARKS	The freeboard marks on the ship's sides.
PLUMBER BLOCKS	The supports to the propeller shaft fitted in the tunnel.
POOP	The after superstructure on the upper deck.
POPPETS	The built-up vertical supports to the ends of the ship on the launching ways.
PORt SIDE	The left side of a ship when looking forward.
PREVENTER	An additional stay to support the mast.
PROPELLER	A revolving screw like device that drives the ship through the water.
QUADRANT	The fitting attached to the rudder head and connected to the steering gear.
RAIL	The wood member on top of the bulwark.
RAKE	The inclination from the vertical of the masts, funnel, etc.
REAMING	The process of making a rivet hole larger.
RIBBANDS	Battens holding the frames in position ready for plating.
RUDDER	A device used to steer a vessel.
RUDDER POST	The aft post of the sternframe to which the rudder is attached.
RUN	The immersed body aft of the parallel body.
SADDLE TANKS	Tanks situated on the sides of bulk cargo holds usually under the deck head.
SAGGING	When a vessel drops at the middle of length. The opposite to hogging.
SCANTLINGS	The thickness of plating, etc.
SCUPPERS	Drains from decks to carry off rain or sea water.
SCUTTLES	Side lights or portholes.
SETTLING TANK	Oil-fuel tank used for separating entrained water from the oil.

SHEATHING	The wood planks covering a deck.
SHEER	The longitudinal curvature of the deck at side between the ends of the ship.
SHEER PLAN	A plan showing the profile of the ship.
SHEER STRAKE	The strake of shell plating at deck level.
SHELL EXPANSION	A plan showing the disposition and thickness of all plates comprising the shell plating.
SHELL PLATING	The plate forming the outer side of the hull.
SHIFTING BOARDS	Portable wood planking fitted fore and aft in holds to prevent the shift of rain or similar cargo.
SHORE	A prop used for support in the building berth or in dry dock.
SILL	The height of an opening above the deck.
SKYLIGHT	A framework over accommodation or engine with glass inserted to admit light and air to the space below.
SLIP	The building berth.
SOUNDING PIPE	A pipe led from the upper deck to the bottom of a tank or double bottom and used to ascertain the depth of water or liquid therein.
SPECTACLE FRAME	The casting which projects from the ship's sides to take the bearings of the propeller shafts of a twin screw ship.
STANCHION	Vertical column supporting decks or girders also called a piller.
STANDING RIGGING	Fixed rigging supporting the masts.
STARBOARD	The right-hand side of a ship when looking forward, opposite to port.
STEERING GEAR	The gear which turns the rudder.
STEM	The casting at the extreme fore end of a ship.
STERN	The aftermost end of a ship.
STERNPOST	The casting at the aft end of a ship in a way of the propeller.

STERN TUBE	The bearing which supports the propeller shaft where it emerges from the ship.
STOW	To put away, to stow cargo in a hold.
STRAKE	A continuous course or row of plates on deck or shell.
STRINGER	The stake of deck plating at the ship's side.
STRUM	A strainer fitted to the end of a suction pipe.
TALL SHAFT	The aftermost length of shaft to which the propeller is attached.
TARPAULIN	Waterproof canvas cover secured over non-watertight hatch covers.
TEMPLATE	A mould or pattern.
THRUST RECESS	A small compartment at the fore end of the tunnel at the engine room to accommodate the thrust block.
TOP HAMPER	An undue amount of superstructure above the weather deck.
TOPSIDES	The upper side of a ship above the water.
TRAMP	A merchant ship not confined to definite ports, but sails to and from any port.
TRANSOM	The aftermost transverse side frame.
TRANSVERSE	At right angles to the fore and aft center-line.
TRIM	The difference in draught forward and aft.
TUMBLE HOME	The inclination inboard of the upper sides of a ship.
TWEEN DECKS	The space between two adjacent decks.
ULLAGE	The quantity a tank or oil compartment lacks being full.
WARPS	Ropes used to haul a ship into position.
WELL	The open deck space between erection.
WINCH	A machine used for hoisting and lowering cargo.
WINDLASS	The machine used for raising the anchor and chain cable.

COMMON FOULING ORGANISMS

Animals

Acorn Barnacle (*Balanus balanoides*)

The acorn barnacle is the most common animal fouling organism found on ships. The adult stage has the form of a cone-shaped shell consisting of six neatly fitted plates forming an encircling ring, with an opening at the top, which is closed by four folding doors. When the barnacle is alive on a ship in dry dock, these doors may be seen to open and a bunch of feathery limbs is pushed out. This "fan" is a kind of casting net with which the barnacle captures the minute floating objects on which it feeds.

When the acorn barnacle is scraped off the hull surface, it generally leaves a circular plate of lime attached to the paint. These plates resemble fish scales, and should not be confused with the encrustations of Polyzoa.

The life cycle of the acorn barnacle is similar to that of most animal fouling organisms and is worth describing here. The eggs develop inside the parent's shell and hatch into the sea as milky clouds of nauplius larvae (fig. 23). The British Zoologist, Hilary Moore, after studying barnacles found around the Isle of Man, estimated that there was a yearly production of a billion larvae released in an area covering just over half a mile of shore.

After floating near the surface for some time, the nauplius larva grows a pair of shells, which almost encases the body, and develops six pairs of swimming legs. This second stage is known as the "cypris" (fig. 24).

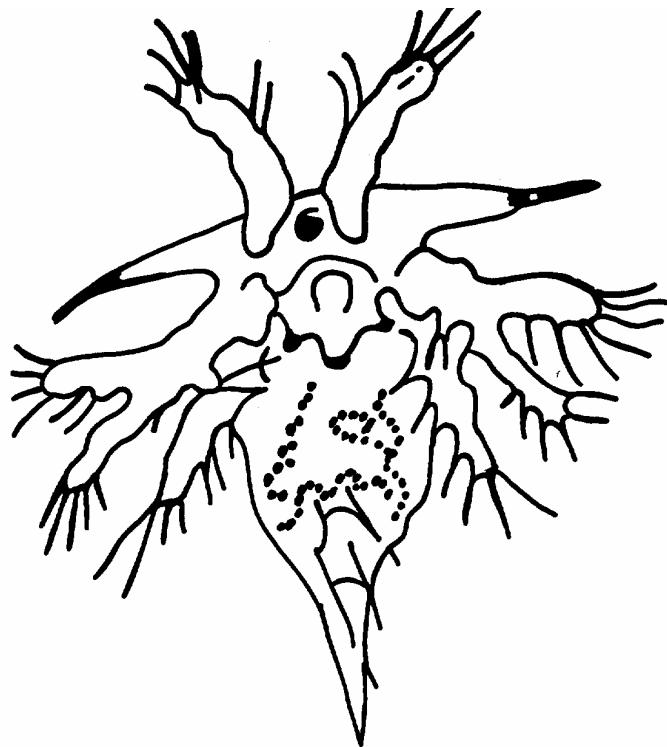


Figure 23
Acorn Barnacle, Nauplius Larvae Stage

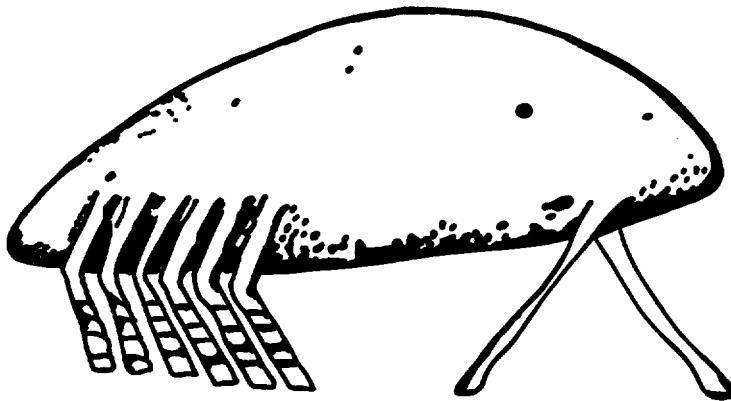


Figure 24
Acorn Barnacle, Cypris Stage

At the end of its larval life, the cypris develops two suckers on the head, which enable it to settle on a selected surface. It has been observed that the larva dives to a solid surface, such as a rock, a ship's bottom, or a floating plank, touching down and rising repeatedly. When the larva has found a suitable spot, it attaches itself and commences the cement formation (fig. 25) which produces the adult barnacle (fig. 26). Within twelve hours, a minute, but perfectly shaped shell, is formed.

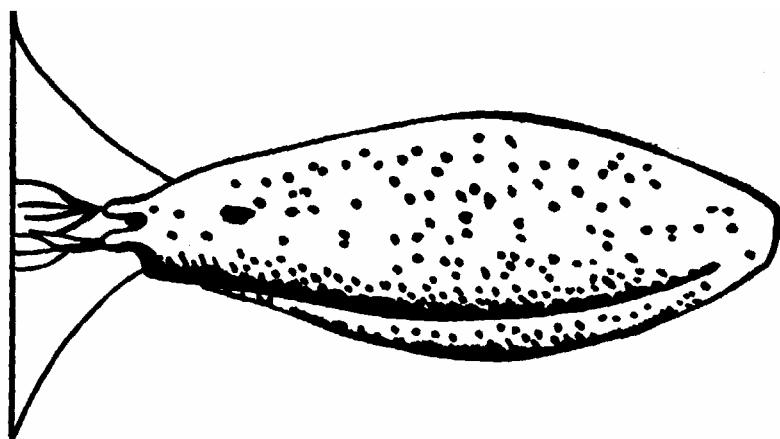


Figure 25
Cement Formation Stage

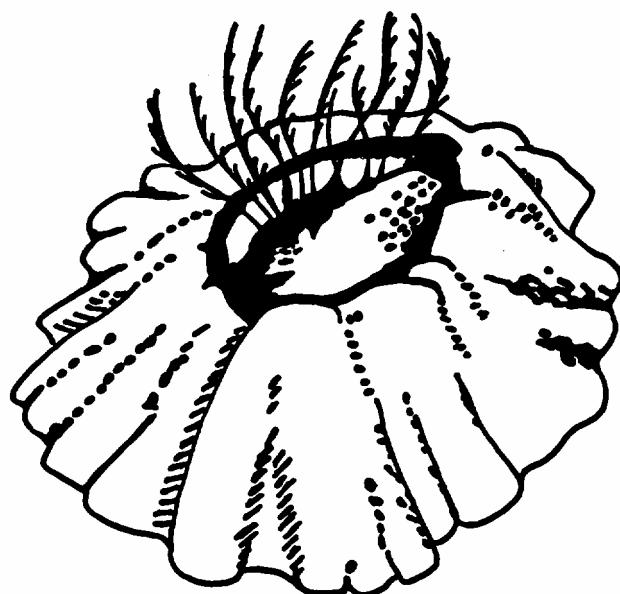


Figure 26
Adult Barnacle

As it is often noticed that barnacles have only settled on areas not painted with Antifouling Composition (in way of blocks, etc.), this indicates that the larvae are highly selective about their choice of a suitable area on which to settle. It would be too much of a coincidence if one concluded that these barnacles had found their way to such areas by chance. The larval life of a barnacle, before settlement, is up to about three months. In spite of the hard shells that enclose it, the barnacle is not related to shellfish, as was once supposed, but is a crustacean, and therefore, related to crabs and lobsters.

The periods when reproduction, and therefore larval settlement, take place are influenced chiefly by the temperature

of the water. Whereas in tropical climates, the reproductive cycle may be continuous throughout the year; in temperate climates it may cease altogether during the winter months. On raft tests in the British Isles, fresh settlements usually occur only between April and September.

Tropical Acorn Barnacles

The acorn barnacles found in tropical, or sub-tropical waters, are easily distinguished from the British species because they usually have either purple stripes, or small spines running down the shell. Vessels visiting the Persian Gulf are often heavily fouled by the purple-striped variety. During the warm summer of 1959, many vessels dry-docked in Liverpool with healthy, living specimens of this species still attached to their hulls. They do, however, normally die on entering Northern Waters.

There is also an Australian species (*Elminius Modestus*) now breeding in large numbers on the South Coast of England. These resemble *Balanus balanoides*, but their shell consists of only four plates instead of six.

Goose Barnacles (*Lepas Sp.*)

Goose barnacles, sometimes called ship barnacles, or stalked barnacles (fig. 27) are easily distinguishable from acorn barnacles because they are attached to the hull by a thick, muscular stalk. This stalk, which may vary from an inch to a foot in length, sometimes remains after the animal has died and the shell has fallen off. The main body is enclosed in a shell consisting of five pieces hinged together.

The goose barnacles' habitat is the high seas and it mainly fouls vessels which are anchored in deep waters. Its name is derived from a curious myth, widely believed in the middle ages, according to which the barnacle goose was supposed to be produced from these barnacles, attached to driftwood, and cast upon the shore. The larval history of these stalked barnacles is similar to that of acorn barnacles, which are found nearer to the shore.

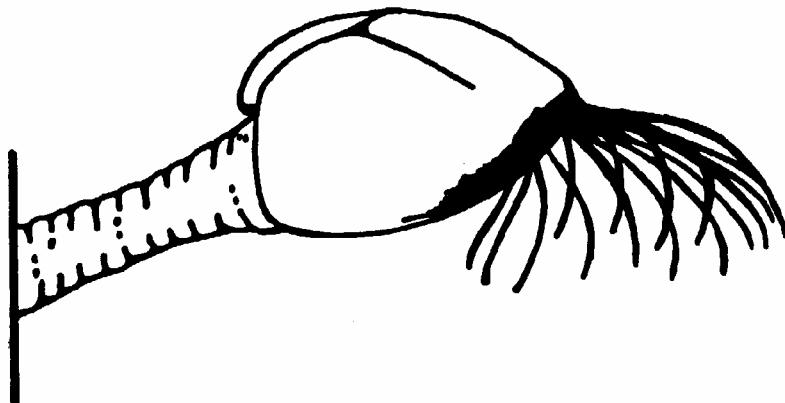


Figure 27
Goose Barnacle

Shipworms or Teredo Worms (*Teredo navilis*)

The shipworm (fig. 28) does not foul ships by attachment, but nevertheless is a true menace to all wooden craft. If small holes (similar to woodworm) are noticed on the bottom of a wooden vessel, it is safe to assume that the vessel has been attacked by shipworms or gribble.

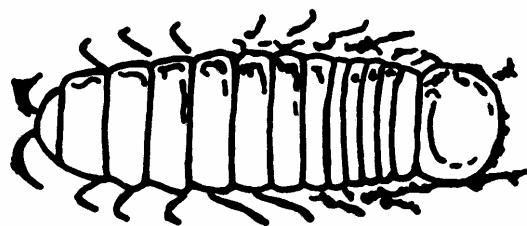
The shipworm's place in history is secure. It was the scourge of the Roman Galley's, and of the sea-going ancient Greeks and Phoenicians. Despite its long and slender body, the shipworm is a mollusk and related to shell fish and sea snails. The larval stage of the shipworm must find a wooden surface on which to settle, or it soon dies. The familiar burrowing begins as soon as the larva has attached, and can cause immense damage. The adult shipworm is little thicker than a pencil lead, but may reach a foot in length. With shipworms, prevention is definitely better than cure and all wooden vessels, in warm waters, should be protected by suitable paints or by copper sheathing. Once inside, there is little indication of its existence, or of the destruction that may be taking place.



Figure 28
Shipworm

Gribble (*Limnoria lignorum*)

Unlike the previous wood-borer, the Gribble (fig. 29) is a crustacean and therefore related to barnacles. The free-swimming larvae settle and almost immediately start to bore into the wooden surface after attachment. Unlike the Teredo which bores along the grain of the wood, the Gribble penetrates the timber to a depth of about 2 inches and then returns to the surface to select a fresh spot. The animal itself, usually the female, may be found at the end of the boring.



*Figure 29
Gribble*

Tubeworms (or Bristle Worms)

Tubeworms are often found in patches and are referred to as white coral. Technically, this is incorrect as they are not related to the coral family. They are actually small worms which built white, limy tubes which usually lie flat against the surface, but sometimes project outwards at the open end. In the larval form, the tubeworms are microscopic, free-swimming organisms, which at a certain stage of development, attach themselves very firmly to a suitable surface. They often foul propeller blades and once attached have a great resistance to movement. The tubeworm is, however, sensitive to Antifouling Compositions and hence, their presence indicates poor toxic properties. The shells of tubeworms remain attached to a ship long after the animal is dead, but become very brittle. There are four species common to Great Britain.

Mussels (*Mytilus Sp.*)

The only shellfish which foul ships are mussels and oysters. The shell is formed from two halves called valves, and cannot be mistaken for other forms of fouling. They are frequently found on the various underwater gratings of the ship. If the hull itself is fouled by shellfish, it is safe to say that the Antifouling coating has broken down, since they are very easily poisoned.

In estuarine waters, mussels and oysters can only settle on vessels when the current is weak. Unlike the oyster, which fixes itself by calcareous secretion from one of its valves, the mussel attaches by means of the bunch of filaments called a byssus. These filaments harden at once on contact with water and serve to anchor the mussel permanently or temporarily to the substrate. The byssus is very strong and can withstand a pull of up to thirty-four pounds.

One mussel may produce up to 500,000 larvae, which are already equipped with small shells when released. After swimming about for a few days, they fix themselves and grow quickly. Growth rate is determined by various factors; the light turbulence in the sea, availability of food, and temperature. Fresh water and muddy conditions are favorable for growth, whereas in rough seas the organ of attachment, the byssus, develops at the expense of the mussel itself. Under favorable conditions, they grow to one or two inches in nine or ten months.

They draw a current of water through their bodies from which they extract oxygen and the minute organisms on which they feed. The shells will remain firmly attached to the hull after the animal has died.

Starfish (Asterias rubens)

Starfish are not actually fouling organisms, but are included here because they are sometimes found on vessels which are heavily fouled by mussels or oysters. Examination will reveal, however, that the starfish are attached to the shellfish and not to the hull surface, as the starfish feed on mussels and oysters. The starfish attaches each of its five legs firmly to the shell and can exert a long, steady, pull to force apart the two valves of the shell and allow it to devour the contents.

Polyzoa (or Bryozoa)

Polyzoa are common fouling organisms, and appear as paper-thin living encrustations which will not, however, impair the speed of a vessel. They are normally found in small patches which have a net-like, or honeycomb structure (fig. 30) and may be mistaken for the bases of barnacles which have fallen off. There is also a branching form of Polyzoan, but this is very seldom encountered as a fouling organism (fig. 31).

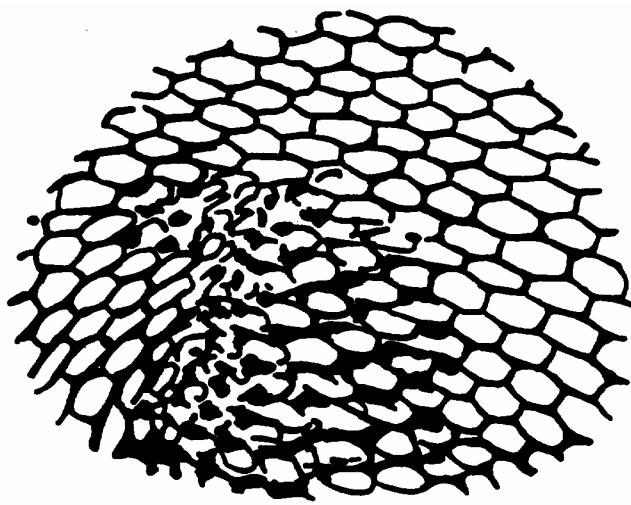


Figure 30
Polyzoa (Honeycomb Structure)

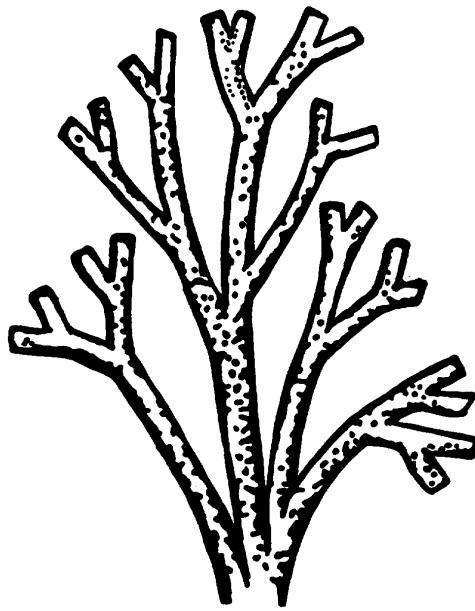


Figure 31
Polyzoa (Branching Form)

Soft Bodied Animals

Hydroids

The Hydroid is an important fouling organism because it attaches itself firmly and is often very resistant to antifouling compositions. A plant-like animal of the jellyfish group, the hydroid usually is found in patches or clumps of knobbed stalks which are stiffer than those of fouling brown weeds. Certain hydroids with branched stalks strongly resemble brown weeds, but seaweeds almost always collapse against the hull when water is withdrawn whereas the wiry hydroids stand out from the hull (figs. 32 and 33).



Figure 32
Hydroid (Branching Form)

Hydroids are not often found on ships in irregular service because the movement of the ship through the water generally prevents appreciable attachments. They are, however, one of the most difficult types of fouling to prevent under stationary conditions as they are more resistant to toxic paints than are most other fouling organisms. The most common Hydroid in British waters is *Tubularia* which has a striking pink head. This head consists of minute tentacles which are used for feeding. These tentacles disappear under unfavorable conditions, such as fresh or very cold water but the familiar gray wiry stalks remain.

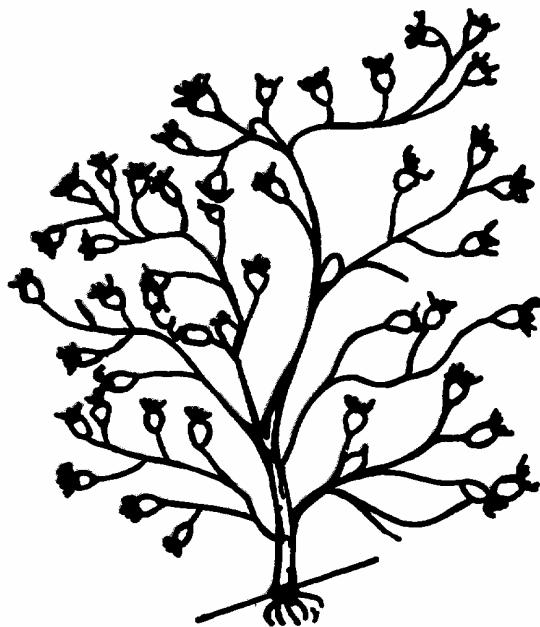


Figure 33
Hydroid (Alternate Appearance)

Sea Squirts (Ascidians)

Sea squirts (figs. 34 and 35) have leathery saclike bodies which when touched squirt spurts of water from two spout-like openings. They are often found on ships which have been moored for a long time in infested water, but would soon become detached from a fast moving vessel. The main fouling season in Great Britain is between July and October.

The sea squirt is usually attached to plate landings on the flats of the vessel. The process of attachment terminates in a metamorphosis producing the adult animal. Sea squirts obtain food from the seawater by passing it through an elaborate system of internal structures. Fresh water means certain death and the sea squirt falls off leaving no trace on the hull.

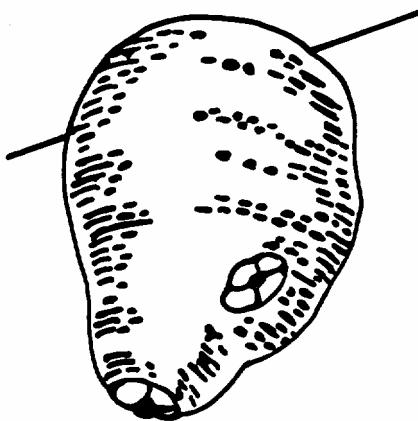


Figure 34
Sea Squirt



Figure 35
Sea Squirt (Alternate View)

Colonial Sea Squirts and Sponges

In the colonial or compound type of sea squirt (fig. 36), many individuals live together embedded in a tough spongy substance. This form resembles colonial sponge formations (fig. 37), but the many openings are surrounded by a starlike, or petal-like marking. Single purse sponges (fig. 38) resemble single sea-squirts, but have only one opening at the base.

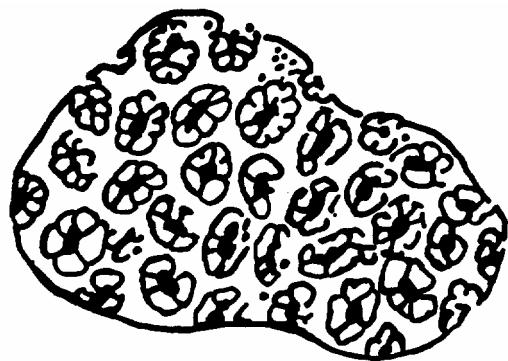


Figure 36
Colonial (Compound) Sea Squirt

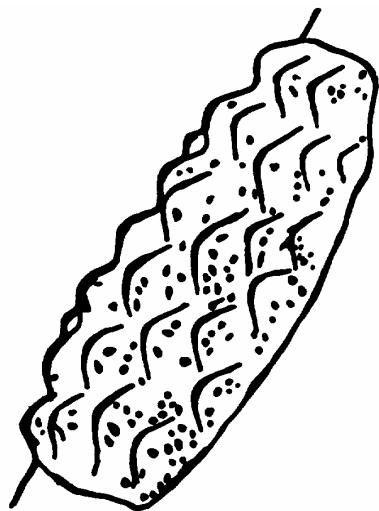


Figure 37
Colonial Sponge

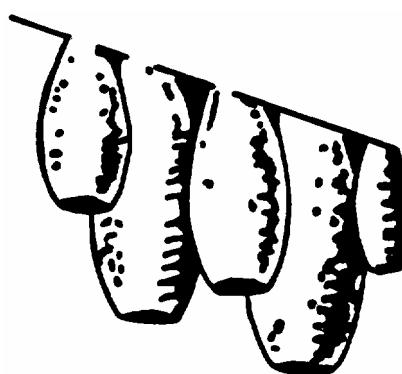


Figure 38
Single Purse Sponge

Sea Anemone (*Anthozoa*)

The Sea Anemone (figs. 39 and 40) is not generally mentioned as a fouling organism, but they are sometimes found on small vessels which have been laid up in shallow waters.

A peacefully feeding Sea Anemone strongly resembles a chrysanthemum, but if seen on the bottom of a dry vessel, this illusion of flower-like beauty is dispelled and we would see a rather flabby barrel-shaped object which resembles a sea squirt. The "flower petals" are numerous tentacles which the creature expands, in feeding, to capture small animals. They are often delicately and beautifully colored, even when closed and dry, and are easily distinguishable from sea squirts because they lack the spouts noticeable on the latter, and have tentacles.

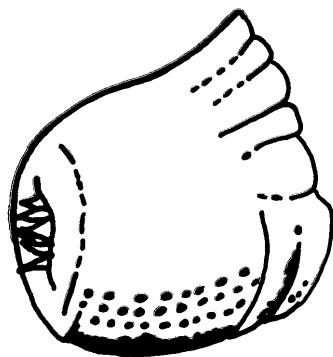


Figure 39
Sea Anemone (Closed)

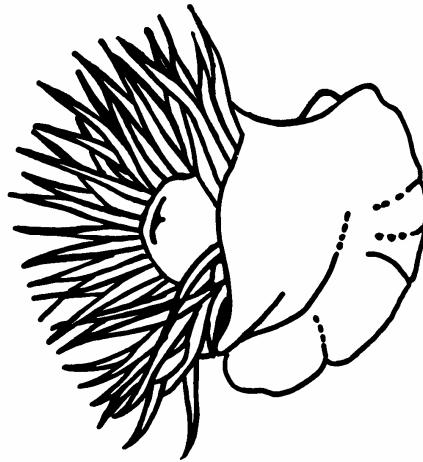


Figure 40
Sea Anemone (Open)

Plants

Seaweeds

Botanists divide seaweeds into Green (*Chlorophyceae*), Brown (*Phaeophyceae*) and Red (*Rhodophyceae*). All the same, a warning is necessary that some Reds look more brown than red, and that many Brown are olive-green.

Seaweeds reproduce by spores, not by seeds, and some of these spores are capable of swimming. Attached by means of holdfasts, the algae do not have roots, and obtain all their food from the surrounding sea water. No seaweed can grow at a depth greater than that which the sun's rays can penetrate. The "Greens" need most sunlight for healthy growth, and the "Reds" least.

Diatoms, which are microscopic types of seaweed, mingle with bacterial slimes and are very resistant to antifouling compositions. These forms often settle on areas which are still toxic to other organisms, and by sealing in the poisons, enable other fouling to occur. According to the species of which they are composed, these slimes vary in color and appear green, brown, red, and black. The most common diatoms are *Schizonema*, *Achnanthes* and *Licmophora*, and can be identified only by microscopic examination.

There are about 700 species of seaweeds in British Waters, and identification is a matter for experts. The following notes may, however, be a slight help.

Green Seaweeds

The familiar "grass" which is found on the sides of vessels may consist of various species of green algae. As green seaweeds depend on plenty of light for their growth, they always occur near to the waterline, thinning off towards the bilge-keel. Large oil tankers have been particularly susceptible to green weed fouling. Recent developments with organo-metallic antifouling have almost eliminated this problem.

Enteromorpha (fig. 41) is the most common of all fouling seaweeds, and its long green-like filaments grow very rapidly in favorable conditions.

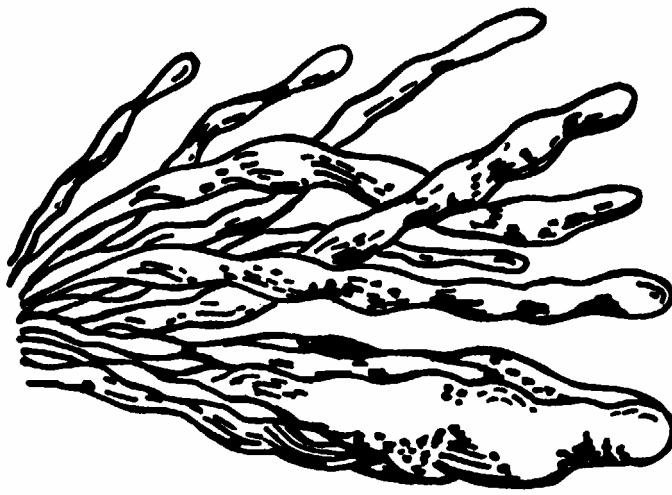


Figure 41
Enteromorpha

Large, flat, leaf-like seaweeds called "sea lettuce" (Ulva) (fig. 42) only attach to vessels which are stationary for long periods. Other green weeds responsible for fouling are Urospora, which has unbranched hair-like threads, and Cladophora (fig. 43), which occurs in tufts and is richly branched



Figure 42
Ulva

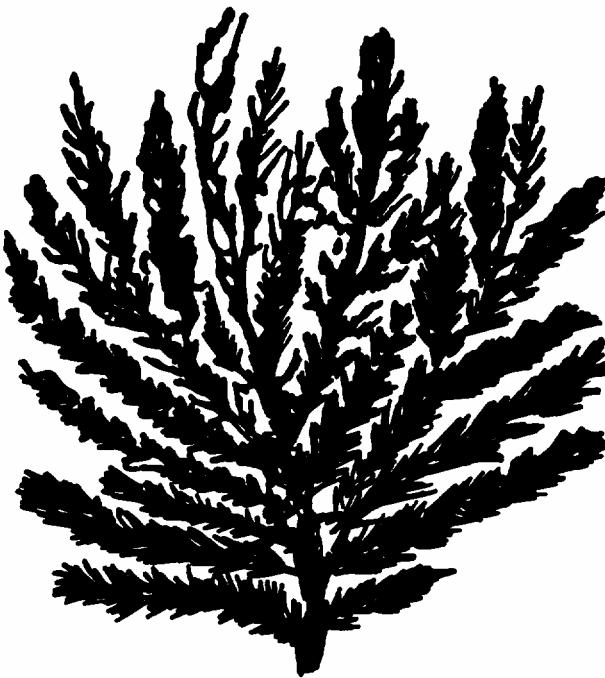


Figure 43
Cladophora

Brown Seaweeds

Brown weeds sometimes mingle with green weeds near the waterline of a vessel, but are more often found lower down near the bilge-strakes. The most common fouling weed in this group is the richly branched species, *Ectocarpus* (fig. 44). If the vessel enters fresh water, this weed loses its brown color and becomes a greenish yellow. Large, flat oarweeds (*Laminaria*) and bladder-wrack (*Fucus*) (figs. 45 and 46) are only found on vessels which have been laid up prior to dry docking. The *Laminarias* flourish in the dimness of deep waters, and are usually found on the vessel's flats. The broad, flat, leathery frond is frayed into long ribbons and its surface is very smooth and deep brown in color.

The bladder-wrack is so called because of the swellings, or vesicles, on the main stems which contain oxygen and other gases secreted by the plant. These act as floats for the plant, holding it away from its holdfast. The bladder-wrack, once attached, can endure the friction of a ships' movement for a period, but long voyages clean the hull.

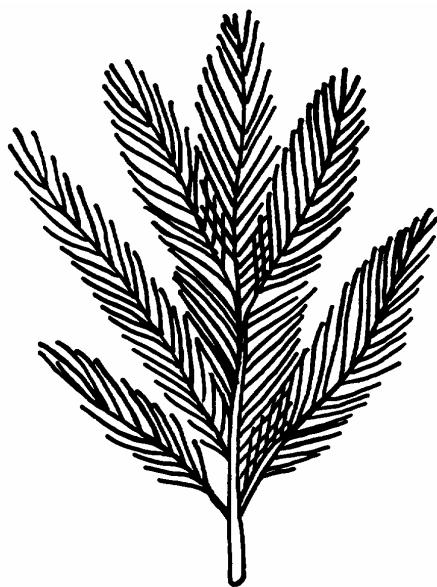


Figure 44
Ectocarpus

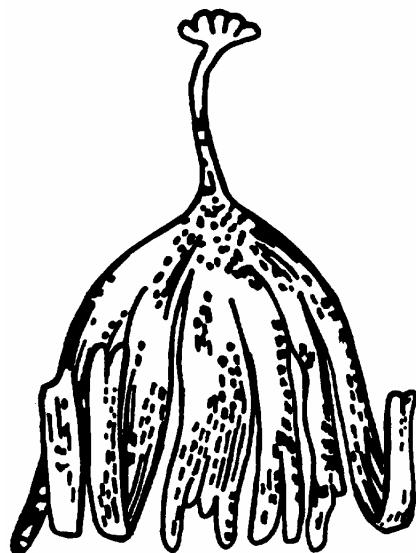


Figure 45
Oarweed (Larminaria)

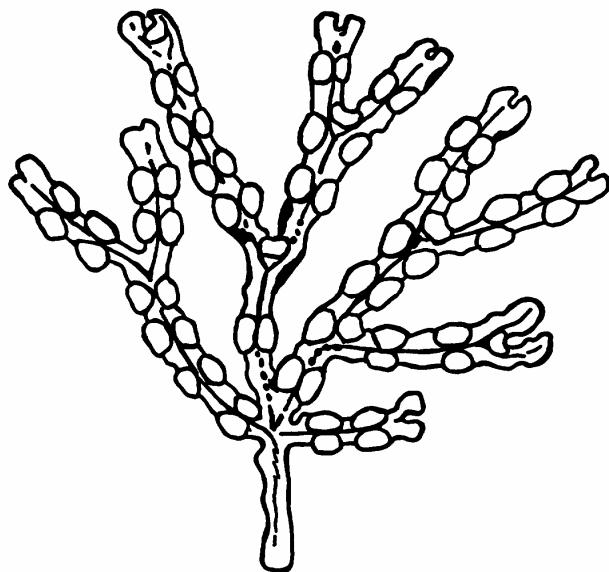


Figure 46
Bladder-Wrack (*Fucus*)

Red Seaweeds

The Red Seaweeds which foul ships are usually Ceramium or Polysiphonia (figs. 47 and 48). Both are richly branched and grow in thicker clumps than hydroids. Polysiphonia is a reddish-brown color and Ceramium is dark purple. They are both uncommon, and seldom grow to any size. Polysiphonia lanosa seems unable to attach to a firm surface and its dark red balls of finely divided fronds are only found clinging to larger weeds.

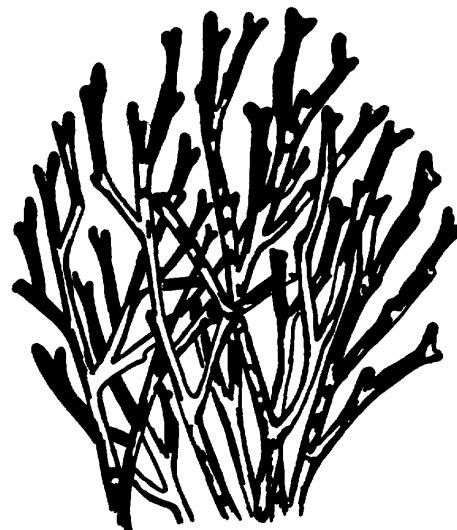


Figure 47
Polysiphonia

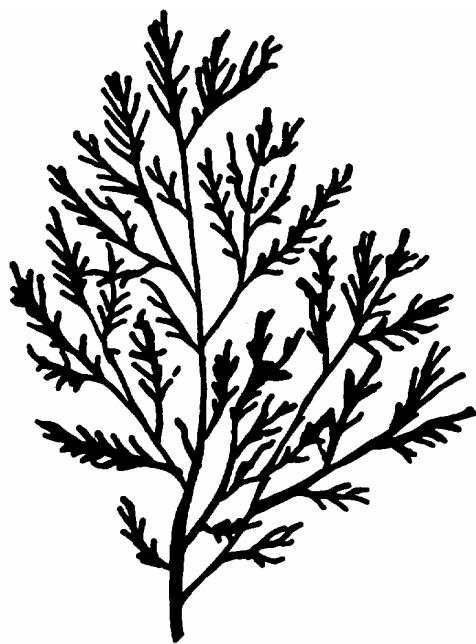


Figure 48
Ceramium

Bridges and Fixed Structures

“Old age, neglect, and continual battering by today’s increasing number of larger trucks have taken a heavy toll on roads and bridges,” according to the U.S. Department of Transportation, which also reported that nearly one-half of all highway bridges in the United States are deficient.

“If not repaired soon, about half of the 43,000 mile (46,000 km) interstate highway system in the United States will have to be rebuilt.”¹

There are more than 234,000 miles of highways and roads that need major repairs that will cost U.S. taxpayers \$212 billion. Almost 164,000 bridges are rated deficient or obsolete and need an investment of \$786 billion to return them to reasonable condition.

Highway structures and bridges and the various coatings applied to them are subject to many potentially damaging forces and they suffer from:

- Vibration from traffic
- Abrasion from traffic and, in some areas, windborne sand and other abrasive particles
- Corrosion attack from:
 - Salts used to de-ice the road
 - Humidity
 - Water spray and splashing
 - Leakage from vehicles containing chemically active materials

¹“Under Investment: A Silent Earthquake,” *Roads and Bridges*, September 1996.

New construction and coating operations continue on highway structures and bridges; however, in many areas, maintenance coating operations have begun to constitute the greatest part of the total amount of coating work performed.

Some items the coating inspector should look for when inspecting field maintenance coating work on highway bridges and fixed structures include:

- Cleaning and repair of :
 - Drains
 - Floor expansion devices
 - Bearings
- Checking of:
 - Rivets
 - Bolts
 - Other joining materials for tightness
 - Repair or replacement of faulty joining materials (if required by specification)
 - Tarps and shields to ensure that they are installed as required by the specification to protect the roadbed and passing vehicles from being spattered, defaced, or otherwise damaged
- Locate corrosion:
 - On the structure under open joints
 - At the ends of girders and flanges
 - On lower flanges
 - In crevices
 - At forged areas
 - In open spots where water and debris may collect

It is generally accepted that the more difficult an area is to get to, the more likely it is that it was not properly cleaned, if at all, and not coated properly in the first place. Consequently, it is most important to inspect those areas very carefully.

The inspector should be on the job site at all times to ensure that the cleaning and coating operations are being performed in strict accordance with the specifications.

Quite frequently, a contractor will subcontract portions of the work. It is important that the coating inspector observe the activities of the subcontractor as well those of the general contractor.

Illustrated here are typical examples of corrosion, coating defects, and coating operations on highway structures and bridges.

The first two illustrations are areas in need of maintenance or repair:

- Corroded girder



Figure 49
Corroded Girder

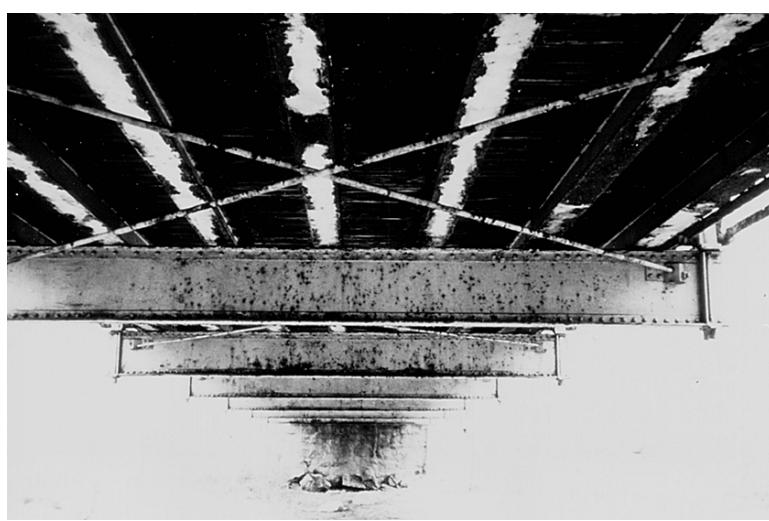


Figure 50
Corroded Girder



Figure 51
Corroded Girder

- Corroded bolts



Figure 52
Corroded Bolts

Next is repair work being performed on a corroded section.

Any inspector involved in bridge coating operations must be able to work at great heights on a consistent basis.



Figure 53
Working "Up High"

Shown below is an inspector performing a dolly pull-off adhesion test on a coated section of a bridge.



Figure 54
Pull-off Adhesion Tester

Pulp and Paper Industry



Figure 55
Paper Plant

Paper is a semi-synthetic product made by chemically processing cellulosic fibers. The largest quantity of paper in the U. S. is made from soft woods such as spruce, hemlock, pine, etc. Some is also made from hardwoods such as poplar, oak, etc., as well as from synthetic fibers.

Paper technology involves the following basic steps:

- Chipping the wood
- Manufacture of chemical or mechanical pulp by digestion in acidic or alkaline solutions, which separates the cellulose from the lining
- Beating the pulp to break down the fibers and permit proper bonding when the sheet is formed
- Addition of starches, resins, clays, and pigments to the liquid stock (called "furnish")
- Formation of the sheet continuously on a fourdrinier machine where the water is screened out and the sheet is dried by passing over a series of heated rolls
- High speed calendaring for brightness and finish
- Coating by machine application or by brush

There are two major types of pulp:

- Groundwood or mechanical pulp, which is merely finely divided wood without purification and is made into newsprint, and cheap manila papers
- Chemical pulp which includes:
 - Soda process pulp which is obtained from the digestion of wood chips (mostly poplar) by caustic soda (sodium hydroxide)
 - Sulfite process pulp (mostly spruce and other coniferous woods) obtained by digestion with a solution of magnesium, ammonium or calcium disulfite containing free sulfur dioxide
 - Sulfate process (kraft) pulp obtained by digestion of softwoods (pine) with a mixture containing caustic soda, sodium carbonate, and sodium sulfate. The carbon present reduces the sodium sulfate to sodium sulfide, which becomes the digesting agent. Sulfate pulps are known as kraft pulp because of their strength (Kraft is German for strength) and they are used in making wrapping paper, packaging, container board, etc.

There are two basic areas in a paper plant:

- Atmospheric area (dry side)
- Immersed area (wet side)

The atmospheric or dry side consists mainly of :

- Structural steel
- Piping and pipe racks
- Storage tanks
- Process equipment
- Reinforced plastic ducts, piping and vessels

High-performance, weather-resistant and chemical-resistant coatings are required to protect steel and concrete in the dry area against:

- Atmospheric moisture
- Chemical fumes and chemical fallout
- Occasional spill of process water and chemicals

The interior of tanks, piping, and process vessels describes the immersed or wet area. These areas are in continuous contact with:

- Water-clean or contaminated chemicals such as:
 - Acids
 - Alkalies
 - Oxidizing agents

High performance chemical resistant coatings are required to protect steel and concrete in this area against the splash and spillage of chemicals.

Process operations in a paper plant include:

- Wood chipping
- Pulp manufacturing
- Pulp bleach area
- Primary recovery area
- Lime recovery
- Blow down area
- Paper making area

Wood Chipping

Steel and concrete must be protected against water and wood chips with weather-resistant and abrasion-resistant coatings.

Pulp Manufacturing Area

In the sulfite process, elemental sulfur is burned to form sulfur dioxide, the basic raw material for the sulfate acid liquor. This liquor is an aqueous solution of calcium bisulfite or calcium and magnesium bisulfites containing large amounts (4 % to 6%) of free sulfur dioxide.

It is prepared from sulfur dioxide and limestone (calcium carbonate), dolomite, (a carbonate of calcium and magnesium) or lime (calcium oxide) by counter current extraction.

Fumes from this operation can attack exposed steel; spillage of the liquor can attack concrete. High performance coatings are required to protect the steel and concrete.

Pulp Bleach Area

Chemicals used to bleach the pulp are strong oxidizing agents and are quite corrosive. They include:

- Chlorine
- Sodium chlorate
- Chlorine dioxide
- Sodium hypochlorite

High performance coatings based on:

- Furan resins
- Epoxy and epoxy novolac resins
- Vinyl esters
- Polyesters

are frequently used to protect steel and concrete in these areas.

Primary Recovery Area

In this area, the spent black liquor from the pulping process is burned (concentrated) in large furnaces until the sodium salts (sodium hydroxide, sodium sulfate sodium sulfide) of the various acids separate out and are skimmed off.

In the recovery process, corrosive alkaline dusts may be emitted. These dusts combined with moisture on exposed steel can cause serious corrosion. The steel and concrete must be protected with high performance coatings.

Lime Recovery Area

Slaked lime (calcium hydroxide) is used in part of the recovery process which results in large quantities of calcium carbonate and calcium sulfate. These materials are recycled, and are calcined to produce quicklime (calcium oxide). Lime is highly alkaline and if it accumulates on exposed steel, it can absorb moisture and create a corrosive condition.

Blow Down Area

Pulp from the primary cooker in the pulp process is blown into a blow pit or blow tank. This operation generates steam that may contain some organic solids and chemicals such as sodium sulfide and sodium hydroxide. Sodium sulfide in the presence of moisture on bare steel can create corrosion. Structural steel must be protected with high performance coatings.

Paper Making Area

In the final stage of paper making, very large paper making machines produce the finished product—paper. In this process, steam and water are given off which can create corrosion products on unprotected steel nearby and any unprotected steel in the interior roof area of the covered plant.

The paper manufacturing process is very critical. Any contamination, such as rust entrained condensation, or rust scale from a corroded overhead beam that could be deposited on the finished product could result in serious damage to the paper or even a plant shutdown.

Newspaper plants generally are well protected in all areas before service with select, high performance, chemical- and

heat-resistant coatings. Maintenance can be a serious challenge. Abrasive blasting, commonly used in many chemical plants generally cannot be tolerated in a paper making facility. Abrasive contamination could be extremely damaging to most of the process equipment or pulp produced.

In many cases, coating maintenance is done during a plant shutdown, or during an overhaul period.

Because of the high incidence of corrosion in pulp and paper mills, much of the overhead structural work, ducts, piping for chemicals, scrubbers, and water treatment facilities now are fabricated using corrosion resistant glass reinforced plastics.

For reference only

Additional notes on:

- The fourdrinier machine

The fourdrinier machine is equipped with a traveling polyester wire mesh belt onto which the slurry of fiber and water is run from the headbox. The sheet is formed almost instantaneously with most of the water draining through the interstices of the wire.

After leaving the machine, the sheet (called the web) passes through the press section of the machine where a series of rollers express enough of the remaining water to hold the sheet together. The sheet then moves into a multi-roller drying section. The dried sheet (4% to 6% moisture content) is then fed to a high speed calendar for compaction and finishing.

- Waste liquors

Waste liquors, which are quite corrosive are generated in the sulfite and sulfate pulp process. They include:

- Black liquor or liquid digester waste (called spent sulfate liquor) containing sulfonated liquid rosin acids and other waste-wood components from which tall oil is made
- Green liquor, a solution made by dissolving chemicals recovered in the alkaline pulping process in water
- White liquor is made by adding caustic soda to sodium sulfide solution

Power Industry

There are several segments to the electric power industry, each with its own unique concerns. These segments include:

- Nuclear plants
- Oil, gas, or coal-powered steam plants
- Hydroelectric plants
- Geothermal plants

Each of these segments have some common areas of concern, which include their need to protect:

- Steel structures, including:
 - Electric distribution towers
 - Aboveground piping and pipe racks
 - Exterior of storage tanks
- Concrete structures, including:
 - Neutralization pits
 - Secondary containment facilities

In most power plants, coatings are required to protect the exterior of equipment and structures. Many of the operating parts of power plants are open structures where steel and concrete are exposed to the atmosphere. Coatings used on these exposed areas vary from low to high performance materials depending upon the geographical location and the corrosive nature of the atmosphere.

The generator buildings and control stations are enclosed and are not exposed to weathering and/or severe corrosion.

Nuclear Power Plants

Except for the exterior steel and concrete areas, the coating of a nuclear power plant is quite different than that of the other power generating segments.

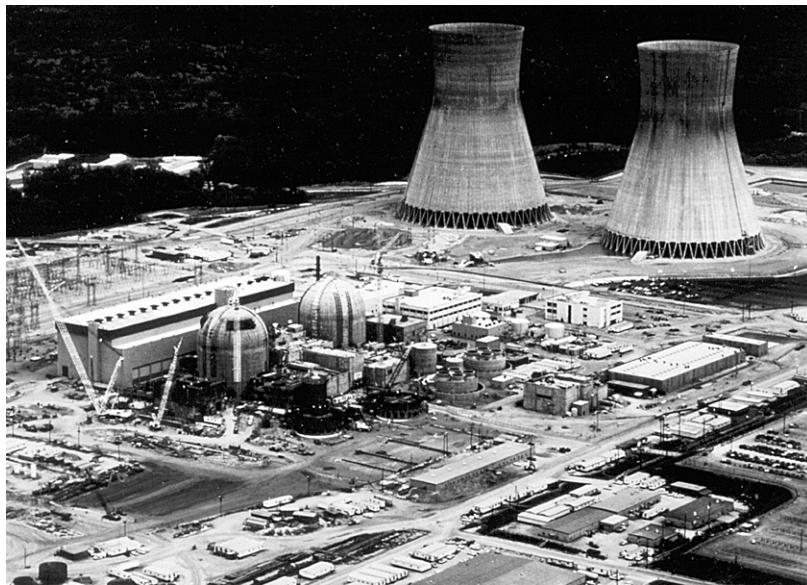


Figure 56
Nuclear Power Plant Under Construction

Generally, the intent is to select coatings that will last 40 years. In itself, this indicates a need for high performance coatings. Coatings in a nuclear plant, for the most part, are for standby protection, except in the areas where the coated surface may be exposed directly to water such as in the:

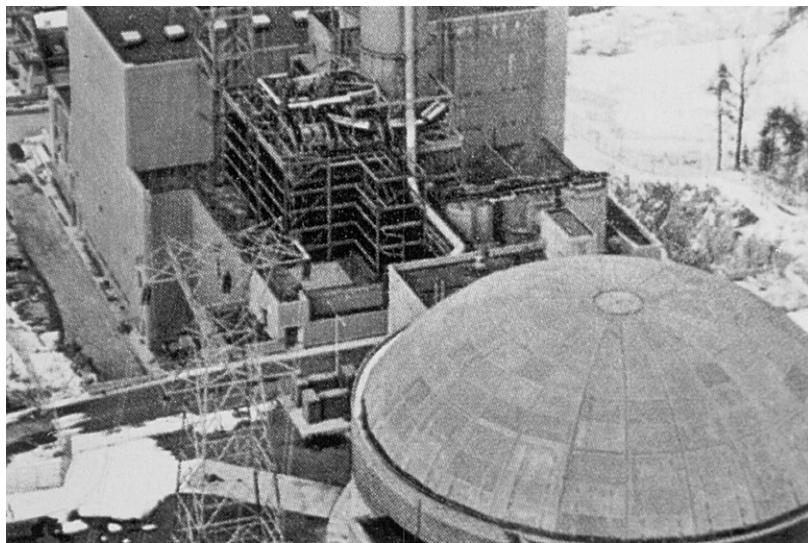


Figure 57
Nuclear Power Plant—Top of Reactor

- Interior of the torus
- Quenching mechanism
- Fuel storage areas

The major portion of coatings used in these plants serve to prevent penetration by any radioactive material to the concrete structures or onto any bare steel areas that may be difficult to decontaminate.

The coating provides the *decontaminating surface* and, except in the reactor area where it is subject to radioactivity, it acts as standby protection. These coatings are subject primarily to wear from ordinary use and/or foot traffic.

Because of the demand for high-quality standby protection, these coatings must pass a number of severe tests before they can be used in areas where there is a possibility of radioactive contamination. Two major pertinent tests are:

- Design basis accident (DBA)
- Loss of control accident (LCA)

These tests simulate conditions that could exist if a power reactor “goes critical” with a failure of some of its mechanical components. The critical nature of the required coating tests becomes apparent when it is realized that a relatively thin coating must withstand accident conditions and still provide a surface that can be decontaminate well enough to allow repair and resumption of power generation.

Since the beginning of the nuclear age, concrete has been the principal building material for all nuclear plants and facilities. This includes the:

- Original plants for the development and extraction of plutonium
- Experimental reactors
- Heavy water plants
- Nuclear fuel plants
- Present-day atomic power plants

The amount of concrete in a nuclear power plant is massive, both in tonnage used and exposed surface area. A typical plant will use several *hundreds of thousands of tons* of concrete, resulting in millions of square feet of exposed area to coat.

Concrete is used not only as a structural material, but as a basic shield against high density radiation. Such structures include:

- Concrete tanks to house small experimental reactors

- Concrete holding basins for hot uranium slugs from the original uranium pile
- Storage areas for spent uranium fuel
- Massive underground chemical plants where all equipment is operated and maintained by remote control
- Concrete containment areas around the primary nuclear reactor

Concrete is a unique material for many industrial applications but it has a weakness, and that is its porosity. Most radioactive materials if allowed to come in contact with a bare, uncoated concrete surface, are quickly absorbed by it. Radioactive materials may take the form of a:

- Solution
- Solid
- Powder
- Gas, in some cases

Once absorbed, these materials are not easily removed; generally, destruction of the concrete is required. Consequently, the concrete surfaces must be improved to eliminate porosity. This may be accomplished by the use of high performance coatings.

The magnitude of the problem with concrete can be recognized with the knowledge that the concrete area to be coated in a nuclear plant is two to five times the area of steel to be coated.

In any one of these nuclear plants, there are hundreds of thousands of square feet of complex surfaces to be coated that range from very critical to less critical areas. None the less, the concrete surfaces must be coated to eliminate any porosity that could allow the penetration and retention of radioactive materials.

Special coatings have been developed to protect the concrete from contamination. These materials must pass some rigorous tests for nuclear accidents and must be capable of being easily decontaminated.

Some requirements of a coating system in nuclear service may include:

- Resistance to chemicals under service conditions
- Readily decontaminated surface
- Impermeable barrier to radioactive substances
- Strong adhesion and good abrasion resistance
- Fire retardance
- Resistance to deterioration by radiation
- Good film continuity with absence of pinholes
- Limitation of hydrogen evolution
- Good thermal conductivity
- Easily repaired
- Ability to withstand loss of control accident

Quality control of surface preparation and coating operations in a nuclear power plant is quite rigorous, and coating inspection procedures are very strict.

Application of coatings to concrete and coating maintenance are closely controlled by the Nuclear Regulatory Commission (NRC) and the American National Standards Institute (ANSI). The ASTM Committee D 33 has developed several standards relating to coatings and inspection procedures used in this industry.

ASTM Publication SP-750, Manual of Coating Work for Light-Water Nuclear Power Plant Primary Containment and Other Safety Related Facilities addresses coatings in nuclear power plants in detail.

Some coatings-related standards for nuclear facilities include:

ANSI N101.4-1972	Quality Assurance for Protective Coatings Applied to Nuclear Facilities
ANSI N5.9-1967	Protective Coatings (Paints) for the Nuclear Industry
ANSI N101.2-1972	Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities
ANSI N45.2-1971	Quality Assurance Program Requirements for Nuclear Power Plants
ASTM D 4138	Dry Film Thickness of Protective Coatings by Destructive Means
ASTM D 4121	Photographic Documentation of Coating/Lining Defects and Failures

Oil- and Coal-Fired Electric Power Plants

Oil-Fired Power Plants

One of the largest areas in an oil-fired electric power generating plant is the oil storage tanks. All of these tanks must be coated on the exterior with a coating selected according to the geographical location of the plant. The more severe the atmospheric conditions, the greater the need for high performance coatings. In many cases, the interiors of these oil tanks are coated with materials selected according to the type of oil used.



Figure 58
Oil-fired Power Plant



Figure 59
Oil-fired Power Plant

Coal-Fired Power Plants



Figure 60
Coal-fired Plant

In coal-powered plants, the coal is moved by an extensive conveyor system, which frequently is subject to salt (sodium chloride) and acidic conditions. Most coal contains some sulfur and salt.

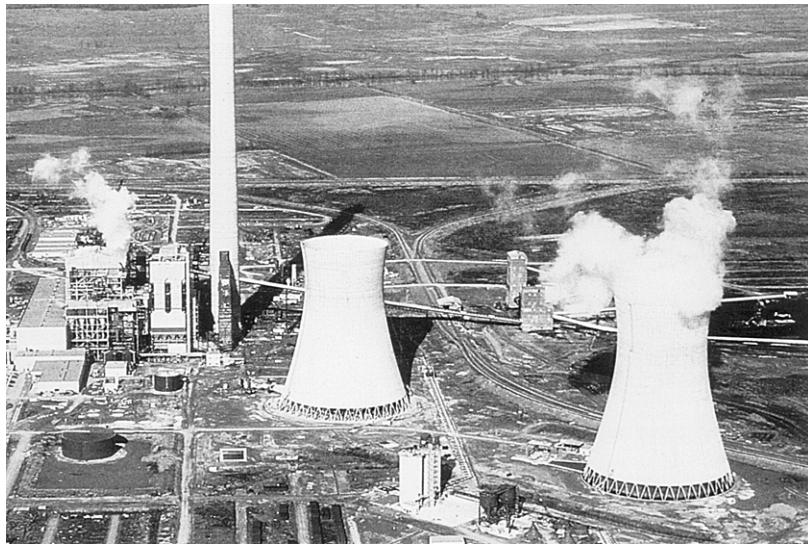


Figure 61
Coal-Fired Power Plant

As coal dust accumulates on the surrounding steel structures, it absorbs moisture. The sulfur oxidizes, forming a mild acid that can attack any unprotected steel and concrete.

In addition to its acidic nature, coal is cathodic to steel. A corrosion cell can develop in the areas where coal is in direct contact with steel in the presence of moisture. Generally these areas are localized and pitting corrosion occurs.

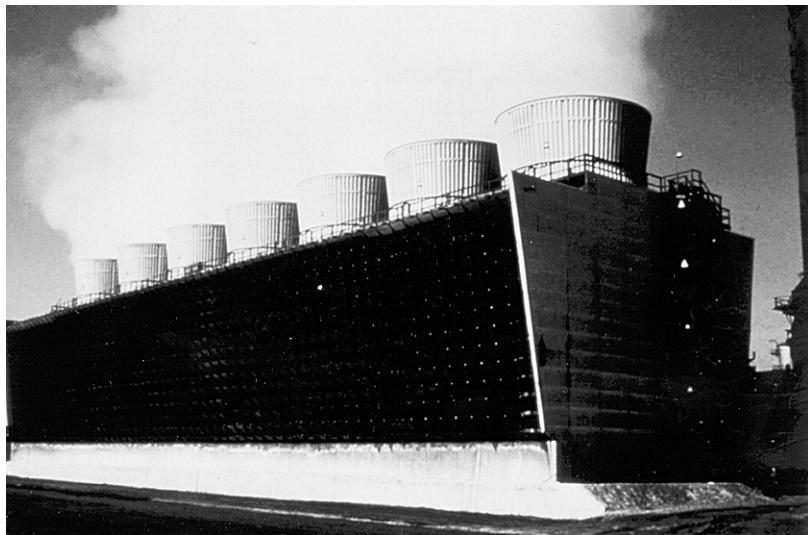


Figure 62
Cooling Tower



Figure 63
Cooling Tower

Heat exchangers, cooling towers, and circulating water piping are common to both oil- and coal-fired power plants. The cooling towers and most of the piping are located aboveground and are subject to corrosion problems.

Oil- and coal-containing sulfur emit fumes containing some sulfur dioxide, which combines with moisture in the air to form mild sulfuric acid. If the acid accumulates on unprotected steel, a corrosion cell can develop. In areas of high humidity, the oil- and coal-fired plants require the use of high performance coatings on all exposed steel surfaces.

Some plants located near marine environments may use salt water for cooling purposes. If steel piping is used to transport the salt water, it generally must be lined with a high performance coating to protect the steel from the water.

Generally these plants have extensive water treatment facilities to supply deionized and oxygen-free water for boiler make-up. Again, high performance coatings may be required for the interior and the exterior of the equipment.

Hydroelectric Plants

Hydroelectric plants are usually situated next to large dams or other similar structures that can supply large volumes of flowing water. The steel areas on the dams and power houses are exposed to water and high humidity and may require high performance coatings for protection. Such areas include:

- Rotary drum gates
- Floating drum gates
- Tainter gates
- Simple lift gates
- Trash racks

These structures require high performance coatings to protect against rapid moving oxygenated-water and to withstand abrasion from floating debris, often including ice floes.

Geothermal Plants

Geothermal plants are relatively new compared to oil- or coal-fired plants and only a few exist. In these facilities, there is considerable waste steam, often creating significant amounts of soluble chemical salts and some hydrogen sulfide. These materials can attack exposed and unprotected areas such as:

- Piping
- Structural steel
- Tanks
- Water processing equipment
- Concrete surfaces

These surfaces—steel and concrete—require protection provided by high performance coatings.

Chemical and Petrochemical Industry

A chemical is defined as a substance with a distinct molecular composition that is produced by or used in a chemical process.

A petrochemical is an *organic* component derived from the raw materials petroleum or natural gas. The term petrochemical also is applied to ammonia because the hydrogen used to form the ammonia is derived from natural gas. Thus synthetic fertilizer such as ammonium nitrate, or calcium nitrate are considered to be petrochemical.

Some materials that are derived from sources other than petroleum or natural gas, frequently are called petrochemicals. Toluene and xylene, which can be produced from coal tar and petroleum, generally are grouped with other true petrochemicals.

Frequently, the chemical industry is considered synonymous with the petrochemical industry. In this discussion, we will consider them as two separate industries:

- The chemical industry, which includes products other than petrochemical, such as sodium chloride, caustic soda (sodium hydroxide), etc.
- The petrochemical industry, which includes products derived from petroleum or natural gas

Both industries are quite complex, consisting of many varied process units, structures, etc. However, some equipment and facilities are common to both industries, such as piping, pipe racks, cooling towers, storage tanks, etc. To the untrained eye, a petroleum refinery may appear the same as a caustic soda plant.

Chemical Industry

Corrosion in chemical plants or processes may range from zero to an extreme, with no two plants having identical problems. Often, this is due to the difference in the manufacturing process for the same type product, and in some cases, due to a difference in the maintenance philosophy between companies.

An example of this is salt (sodium chloride)—the second highest-volume chemical produced which can be produced in one of three ways from:

- Solid deposits (underground mines)
- Brine wells (natural brines)
- Evaporation of sea water

Salt from Mines

In a salt mine, the salt is mined directly from huge underground deposits where the humidity is very low and no corrosion exists. This type salt is very pure.

Salt from Brine Wells

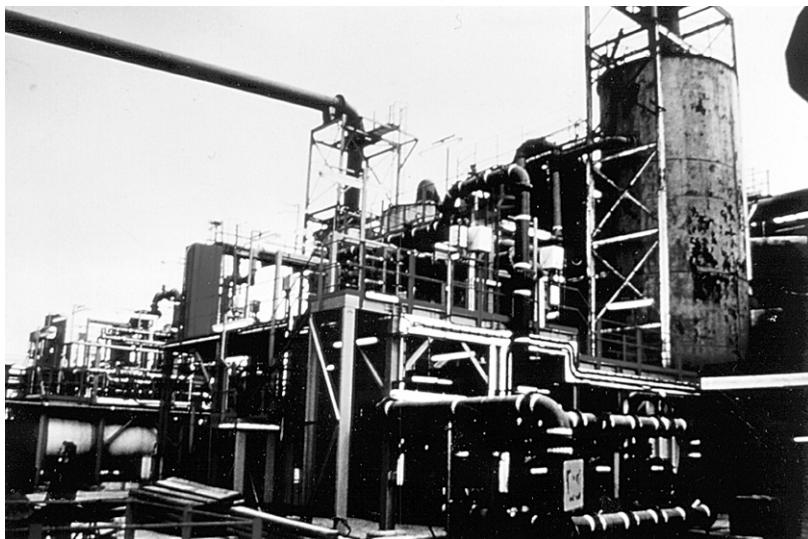
Natural brine from wells is pumped into holding tanks or ponds, where evaporation and crystallization takes place. Purification, if required, is done by recrystallization.

Structural steel, holding vats, and equipment must be protected against the salt vapor with a protective coating. Concrete surfaces should be protected with a high performance coating to prevent the chloride ion from contacting the reinforcing bar (rebar); otherwise the rebar will be allowed to corrode ultimately resulting in spalling of the concrete.

Salt from the Sea

Salt is obtained from sea water (2.6 % concentration) in central New York, Newfoundland, the Great Salt Lake and the Gulf Coast. The salt water is pumped into holding ponds or tanks. There, solar evaporation of the water takes place, the salt crystallizes and is purified by recrystallization. Structural steel, and concrete exposed to the salt vapor should be protected with high performance coatings.

For the most part, chemical plants are open-work structures exposed to the weather and to airborne contaminants. These contaminants may be generated within the plant itself or may come from other chemical plants nearby.



*Figure 65
Small Chemical Plant*

Plants located in areas of high humidity and/or near the seacoast may experience the most severe corrosive conditions. Protection of exposed steel and concrete surfaces must be protected by proper selection and use of high performance coatings.

Environmental regulations in the U. S. and in many parts of the world have served to reduce chemical pollution from smoke, fumes, and effluents.

This reduced pollution coupled with the use of high performance coatings has helped reduce maintenance costs and loss of steel due to corrosion.

Some common areas in chemical plants where corrosion may be a serious problem include:

- Piping and pipe racks
- Cooling towers
- Storage tanks
- Water and waste water treatment facilities

Pipe Racks

Pipe racks are designed to be compact and occupy a minimum of space. They usually are constructed of structural shapes, welded or bolted together and are a myriad of edges, corners, and other sharp protrusions.



Figure 66
Piping

Piping may be closely spaced and joined with bolted flanges or by welding. The annular space between flanges should be sealed from atmospheric moisture and rainfall.

Before service, these facilities should be properly cleaned and coated with high performance coatings. The configuration of the installations can create serious maintenance problems.

Cooling Towers

Almost all chemical plants have cooling tower facilities, some very extensive. Cooling towers can create serious corrosion problems, not only within the area of the tower, but also in adjacent areas that are subject to:

- High humidity and water spray
- Soluble salts from the cooling tower water condensate
- Fallout of airborne contaminants onto surfaces that may be damp

Some towers minimize the use of steel and may use redwood, glass reinforced plastics, and/or concrete. Steel, if used, and concrete should be protected with high performance coatings.

Storage Tanks

Storage tanks offer much surface area exposed to the atmospheric moisture and airborne contaminants. Coatings should be selected to withstand atmospheric conditions at the specific site.



Figure 67
Storage Tanks

General purpose coatings may be used on the exterior of tanks in rural areas, generally in dry climates. High performance coatings may be required for tanks located in areas of high humidity, near the seacoast, and/or where fallout of atmospheric pollution may be severe.

Water and Waste Water Treatment Facilities

Some chemical plants use large amounts of water in their operations and may be required to treat process water containing wastes prior to disposal.

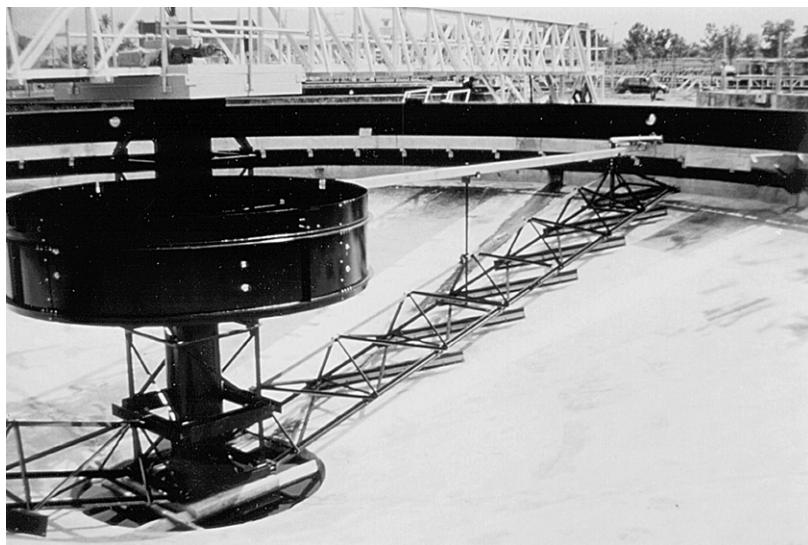


Figure 68
Water Treatment Facility

Steel storage tanks, concrete neutralization pits, and treatment facilities require protective coatings that are resistant to water, raw or treated, and that are resistant to chemicals used in processing water for use in plant operations or in treatment of waste water for further use or for disposal.

Petrochemical Industry

Corrosion in the petrochemical industry begins with the downhole production of crude oil that often contains the following under high temperatures and pressures:



Figure 69
Oil Work Over Rig

- Carbon dioxide
- Hydrogen sulfide
- Salt water
- Liquid petroleum fractions of crude oil



Figure 70
Offshore Oil/Gas Platform

Specially formulated high-bake coatings, including phenolics, commonly are used in downhole tubing and piping.

Crude oil mixtures may be transported by pipeline to field storage tanks en route to a refinery or diverted directly to a refinery for processing.



Figure 71
Crude Oil Pipeline

Generally, the oil pipelines do not require internal coating unless the crude contains high amounts of hydrogen sulfide. Prior to installation, these pipelines may be lined and coated with FBE or epoxy coatings.



Figure 72
Internally-coated Pipe

Salt water generally is recovered with the crude oil. In storage, the heavier salt water drops out of the crude oil and remains in

contact with the tank bottom until it can be drained off, disposed of, or pumped back into a disposal well. Some salt water will almost always be in the bottoms of these tanks.

These steel tank bottoms and 2-3 feet (0.6 to 0.9 m) up the sides from the bottom, must be coated with a high performance coating such as coal tar epoxy, epoxy, novalac epoxy, or polyester, etc. The coating must be resistant to salt water and the crude oil in the event of incidental contact.

Corrosion, if allowed to take place, could eventually destroy the bottom. In this case, the tank bottom must be replaced with a new coated steel bottom or with a thick (to 120 mils [0.36 mm]) polyester or epoxy coating reinforced with glass fibers or glass mat.

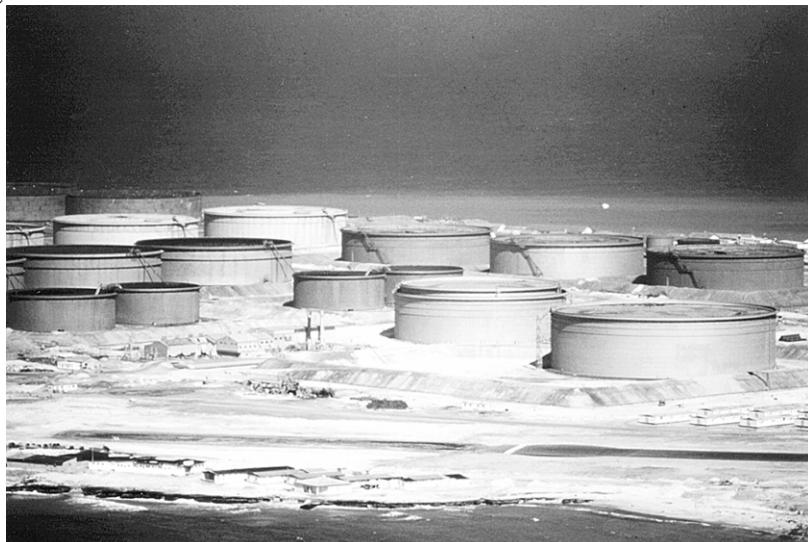


Figure 73
Crude Oil Tank Farm

Crude oil generally is stored in tanks fitted with a fixed roof. In the case of crude containing high amounts of hydrogen sulfide (this type oil is called sour crude), the oil is stored in tanks equipped with a floating roof.



Figure 74
Crude Oil Storage Tanks

This type roof is almost always in contact with the crude oil to minimize the evolution of the hydrogen sulfide which could quickly attack any unprotected steel.



Figure 75
Crude Oil Storage—Floating Roof—Tank Empty

The underside of the roof, fixed or floating, must be coated with a high performance coating that is resistant to the oil, petroleum liquids, and to hydrogen sulfide in the crude oil.

Hydrogen sulfide in the presence of moisture can be very corrosive to the steel. In the vapor space of the tank, hydrogen sulfide could attack the steel and develop rust scale. This scale may fall to the bottom of the tank, and in the presence of moisture on any exposed steel areas, could set a corrosion cell resulting in severe pitting of the steel.

The top and bottom interior of these tanks must be properly coated *before* being placed in service. Hydrogen sulfide, if allowed to permeate the steel roof interior, is extremely difficult to remove even by repeated abrasive blasting. Generally, maintenance and repair and/or replacement of a tank bottom is less costly than replacement of the roof.

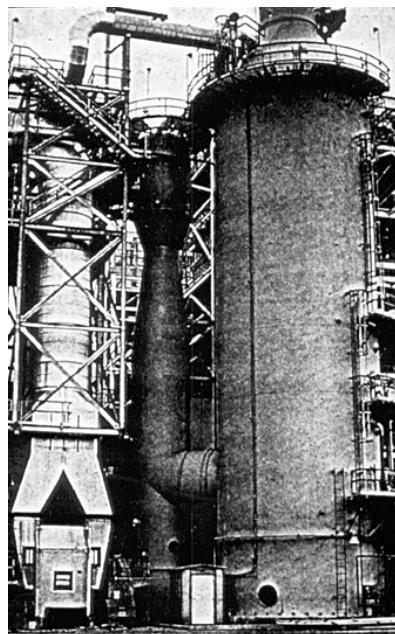


Figure 76
Catalytic Cracker

In a refinery, crude oil feedstock is subjected to:

- High temperature catalytic cracking
- Fractionation and distillation
- Other special treatments

to make various products such as:

- Gasoline
- Kerosene
- Diesel oil
- Aviation gasoline
- Lubricating oils
- Waxes and greases
- Heating oil, etc.

These products are contained within the process towers, tanks, and piping. In some cases, high performance coatings are used in these storage areas. These high performance coatings

(linings) must protect the steel and, at the same time, must not cause any contamination to the product contained.



Figure 77
Refinery Work Farm—Wide Shot

Equipment in a refinery consists primarily of:



Figure 78
Storage Tank

- Tanks
- Piping



Figure 79
Piping

- Pumps
- Reactor vessels



Figure 80
Process/Reactor Vessels

- Catalytic cracking units
- Fractionation, and distillation towers

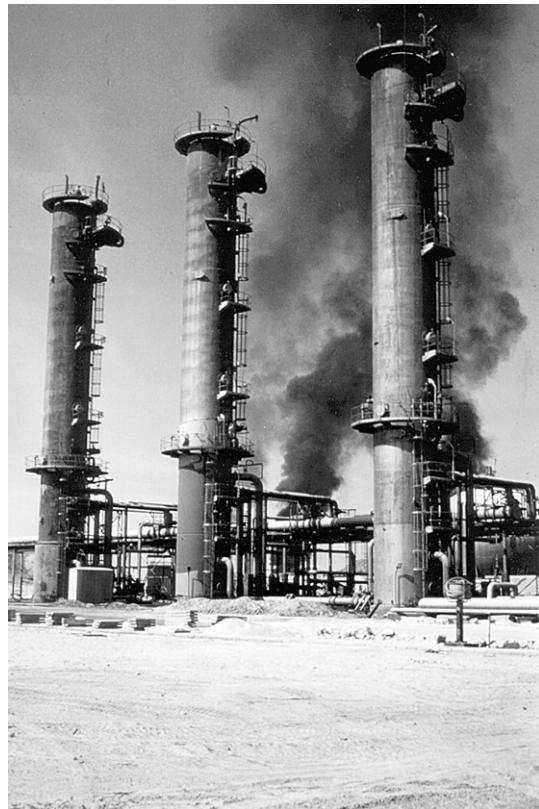


Figure 81
Fractionation Tower

- Pollution control facilities



Figure 82
Pollution Control Facilities

- Water treatment facilities

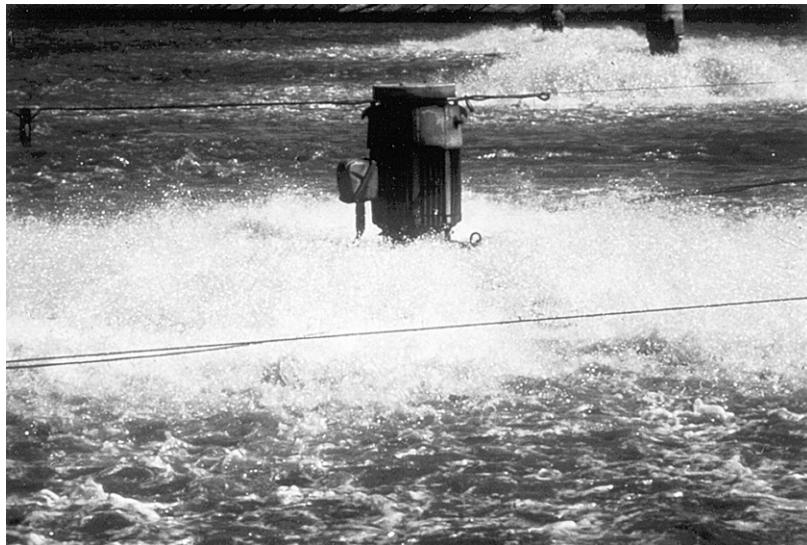


Figure 83
Water Treatment

- Concrete neutralization pits
- Structural steel and concrete

These areas, many of which are insulated, are exposed to the weather and require protective coatings. The selection of the coatings depends on the in-service temperature requirements and resistance to the atmospheric conditions. The more severe the environment, the greater the need for high performance coatings.

The steel under insulation should be protected with coatings that will withstand the operating temperature of the facility, and be resistant to any moisture penetrating through the insulation to the steel substrate.



Figure 84
Natural Gas Pipeline

Buried pipelines transporting chemicals, crude oil, refined products and/or natural gas must be coated on the exterior with an adequate protective coating along with supplementary cathodic protection.

Natural gas lines may be coated on the interior for protection against hydrogen sulfide or they may be coated to improve the flow of gas thereby reducing compressor requirements.

The Fertilizer Industry

Phosphoric Acid and Phosphates

The phosphate fertilizer industry is a very extensive industry worldwide. The primary function of this particular industry is to produce usable phosphate products from natural phosphate rock.

The first material produced from the rock is phosphoric acid, which can be produced in one of two ways:

- The wet process which uses sulfuric acid to dissolve the phosphate rock
- The dry process which uses an electric furnace to produce elemental phosphorus. This phosphorus is later oxidized to an oxide of phosphorus which is then hydrolyzed with water to produce agricultural grade and also high quality (food grade) phosphoric acid.

Agricultural grade phosphoric acid, which amounts to almost 80% of all phosphoric acid produced worldwide, is made by the wet process. Almost 50% of all sulfuric produced worldwide is consumed in the production of phosphoric acid.

The production and the prevalent use of these acids create highly corrosive conditions in and around the phosphoric acid manufacturing facilities. Consequently, high performance coatings are required for protection of all structural steel and process equipment and in some other critical areas, the concrete surfaces.

The primary use of phosphoric acid is in the production of fertilizers in the form of:

- Superphosphate (Calcium phosphate)
- Ammonium phosphate
- Crude (unrefined) phosphoric acid

It may be interesting to note that the many areas of the now fertile Imperial Valley were developed from the use of phosphoric acid to neutralize the high alkalinity of the soils and at the same time add phosphate to soil for nutrients.

Superphosphate is produced by the digestion of limestone rock in hot phosphoric acid. The superphosphate dust combined with moisture is corrosive to steel and all structural steel and equipment handling this material require the use of high performance coatings.

Ammonia Fertilizers

Another fertilizer process is the production of ammonia. In this process, nitrogen is extracted from the atmosphere and is oxidized in the presence of natural gas and high pressure steam to yield ammonia and nitric acid.

Ammonia can be combined with nitric acid to produce ammonium nitrate, a highly hygroscopic material. In the presence of moisture, ammonium nitrate can attack unprotected steel.

High performance coatings are vital for protection in ammonium nitrate plants, against oxides of nitrogen, nitric acid and any accumulation of ammonium nitrate dust.

Sulfuric Acid

Sulfuric acid, the highest volume-produced chemical in the U.S., is one of the most widely-used chemicals worldwide. It may be produced from:

- Hydrogen sulfide extracted from natural gas
- Elemental sulfur which is burned to produce sulfur dioxide

The production of sulfuric acid is carried out at high temperatures. Special heat-resistant, high-performance coatings are needed to protect steel structures in these acid plants.

Most sulfuric acid plants can be plagued with leaks and spills of produced acids, especially concentrated sulfuric acid, that attack both steel and concrete. For optimum protection, acid-proof brick and grouts based on:

- Furan
- Vinyl esters
- Certain epoxy resins

- Silicate cements

are used to protect areas such as:

- Floors
- Trenches and troughs
- Pump bases
- Other similar areas

Extreme corrosion is possible in many areas of these acid plants and the best possible protection is required for both steel and concrete surfaces.

Water and Wastewater (Sewage) Treatment Plants

The water and wastewater industry is probably the largest of all industries worldwide. In many parts of the world, this industry is highly regulated in order to protect the health and well being of mankind by controlling the growth and spread of any harmful bacteria.

Steel and concrete surfaces in these facilities are continually exposed to moisture, water, certain chemicals and hydrogen sulfide(in sewage) which can create and promote corrosion.

Generally, high performance coatings are used to protect these surfaces against corrosion and coating inspection frequently is required, more often on rework than on new construction.

We will discuss briefly some of the elements of these facilities and will point out areas that usually require coatings.

Water System-Overview

A water supply system consists of the following elements:

- Water source
- Treatment facilities
- Storage
- Distribution facilities (piping)
- Users

A wastewater system consists of the following elements:

- Collection and transfer facilities (piping and lift stations)
- Treatment facilities
- Discharge of treated materials

Basic Corrosion Concerns

Coating materials used in water systems must be resistant to water and the chemicals used in treatment, such as:

- Chlorine gas
- Ferric chloride
- Slaked lime(calcium hydroxide)

Corrosion Control in System Components

- Intake Structures

Piping or open canals convey water from the source (wells, rivers, lakes, etc.) through intake structures to the treatment plant. The intake structures generally are fitted with traveling screens designed to remove large objects from the water stream. Coatings used on the screens must be resistant to water and abrasion.

- Treatment Facilities

Components of a typical water treatment plant include steel and/or concrete structures, such as:

- Clarifiers
- Flocculators
- Settling tanks
- Thickeners
- Filters

These components require high performance coatings that are resistant to:

- Water
- Chemicals
- Abrasion

Water Storage Facilities

After the water has been properly treated(sanitized), it is then transported to steel or concrete storage tanks.

Steel Tanks



Figure 85
Elevated Water Storage Tank

In the United States, coatings used on the interior surfaces of a steel storage for potable water must comply with government (federal or state) regulations. The individual states may elect to comply with the National Sanitation Foundation Standard #61(NSF #61) governing potable water, or they may elect to adopt their own more stringent standards. Currently 30 of the 50 states in the US have adopted NSF # 61.

The coating used must protect the steel surfaces from the water and also must not contaminate the water being stored

After proper cure the coating system may be inspected for voids or pinholes with a holiday detector in accordance with NACE International Standard RP0188 *Discontinuity (Holiday) Testing of Protective Coatings*.



Figure 86
Concrete Water Storage Tank

Generally, the coated area from the (high) water overflow line down to and including the tank bottom is inspected for holidays. Frequently, the coated area of the dome is also inspected for holidays, however, because of the complexity of the roof support beams, it usually is not practical to inspect these surfaces. If any pinholes are found, they must be properly marked and repaired.

After application and proper cure, the coating must be disinfected in accordance with American Water Works Association(AWWA).Standard C 652 for Disinfection of Water-Storage Facilities. This standard describes disinfection of water-storage facilities that:

- are newly constructed
- have been entered for construction or inspection, or continue to show coliform bacteria during normal operation.

Generally, disinfection is performed to remove bacterial contamination; however, disinfection also helps remove any coating reaction products left on a freshly coated surface that could impart any taste or odor to the water

Essentially, disinfection is done by injecting chlorine gas into the water in the tank or by adding sodium or calcium hypochlorite to the water to obtain a specified level of chlorine per liter. The chlorinated water is then held in the tank to the overflow level for a specified amount of time.

Alternatively, a more concentrated (200 mg/L) solution of sodium or calcium hypochlorite is applied by brush or spray to

the coated surfaces that would be in contact with water when the tank is filled to the overflow elevation. After 30 minutes, potable water can be introduced into the tank.

Frequently, the tank may be equipped with a cathodic protection system(usually impressed current)in accordance with NACE International Standard RP0388 *Impressed Current Cathodic Protection of Internal Submerged Surfaces of Steel Storage Water Storage Tanks*. In that event, the coating system, the coating must also be resistant to cathodic disbondment.

Exterior surfaces of the tank should be protected with good weather (ultraviolet) resistant coatings.

Concrete Tanks

Water storage tanks may be constructed of concrete rather than steel. Generally, these type tanks are left uncoated, although bag liners are occasionally used. If bag liners are used, or if the interior is to be coated then:

- Exposed tie wires should be removed and the area sealed over
- Bugholes should be filled, and any cracks repaired
- The concrete surface should be brought up to grade

The surface should be free any surface defects such as protrusions that could damage or puncture the bag lining. Before application of the coating, the surface should be cleaned to remove all form release oils, dirt etc., and then abraded by light abrasive blasting.

The specifications may reference NACE International Standard RP0892 *Linings Over Concrete for Immersion Service for this type operation*.

The coating system selected should conform to the same government regulations(NSF # 61) for lining steel water-storage tanks.. After the coating has reached final cure, it may be inspected for holidays and necessary repairs made. Then the coated areas are disinfected in accordance with AWWA C 652

Distribution System

- Gray cast iron
- Ductile iron
- Steel
- Concrete lined steel
- Concrete
- Asbestos cement(a/c)
- Plastic

Pipelines may be:

- Coated and lined in a stationary coatings yard, or coated in the field alongside the ditch; coated pipelines may be lined in place(*in situ*):
- Polymeric and require no lining
- Coated on the exterior and further equipped with cathodic protection

Sewage Treatment Facilities

Typical elements of a sewage treatment facility include:

- Collection and transfer facilities(piping and lift stations)
- Intake structures
- Grit chambers
- Sludge filters
- Aerators/digestor chambers
- Effluent flow lines

Collection systems

Generally, sewage flows by gravity from residential areas into a sewer trunk line, then to a lift station. At the lift station, sewage is pumped to the next higher level where it may flow by gravity or may be pumped directly to the intake structure of the sewage treatment plant.

Piping from residential areas may be made of:

- cast iron or ductile iron
- high density polyethylene(PE), or polyvinyl chloride(PVC)
- concrete

Sewer trunk lines generally are made of concrete or they may be of vitreous clay. Due to its high cost, vitreous clay once widely used to transport sewage is now less frequently used.

Sewer trunk lines are used to connect residential developments with established neighborhoods. These lines often extend several miles in length. During this period of development (often 2 to 10 years), these trunk lines operate at partial capacity and as a result, until they run full, there is a void or vapor space at the top interior of the line. If this area is left uncoated, hydrogen sulfide gas in the sewage can combine with moisture to form sulfurous and sulfuric acid that can cause deterioration of the concrete pipe.

Frequently, these lines are coated using epoxy, coal tar epoxy, or elastomeric polyurethanes, before being placed in service.

The lift stations may be brick lined, or they may be constructed of concrete, and then lined with rigid PVC, epoxy, coal tar epoxy, or elastomeric polyurethanes.

Intake Structures

These structures may be ceramic or concrete. The concrete intake structures generally are coated with epoxy or coal tar epoxy.

Grit Chambers

Grit chambers usually are constructed of concrete and the interior surfaces are subject to attack from:

- Hydrogen sulfide and moisture which forms sulfurous/sulfuric acid
- High amounts of sulfate reducing bacteria(spora-vibro disulfurica)

The interior surfaces of these chambers may be protected with:

- PVC sheet lining
- Polyamine cured epoxy or coal tar epoxy(*polyamine* epoxies are more resistant to the bacteria and hydrogen sulfide than are *polyamide* epoxies)

Aeration/Digestor Chambers

These units generally are made of concrete and frequently only the interior surfaces above level of the liquid are coated. These units use surplus oxygen to *oxygenate* the sewage, i.e. to promote the action of bacteria to break down the sewage.

Sludge Filters

These facilities are designed to remove the treated liquid and concentrate the solids into a sterile sludge. Sludge filters are equipped with steel rakes that usually are protected with coal tar epoxy coatings. Sometimes these rakes are made of stainless steel and these generally are not coated. The interior of the steel walls are coated with coal tar epoxy to the top of the overflow. The overflow ring itself and the area above the overflow exposed to the atmosphere are usually coated with conventional epoxy coatings.

The heavy sludge is removed to a lagoon or holding basin where the sterile material is thoroughly dried and made available for sale as a fertilizer in bagged or bulk form.

Summary

Some problems of corrosion and methods of corrosion control are common to the water treatment and wastewater treatment systems. In both systems, many surfaces are in continuous contact with water. High performance coatings must be selected for steel and concrete surfaces and should be properly applied ***prior*** to the facilities being placed in service.

Chemicals used in water and wastewater facilities impact on coating performance, consequently long-term performance of protective coatings may best be obtained by:

- Proper selection of coatings
- Adequate surface preparation
- Proper coating application
- Inspection by a competent inspector

Coating inspection can be a vital component of the coating operation. In many cases, inspection is not required on new construction, and the inspector often finds himself inspecting rework or rehabilitation projects. In either event, the inspector can provide the valuable service to the client to ensure that the coating specifications are properly enforced.

Once these facilities commence operation, the owners should establish a timely routine inspection and coating maintenance program in order to prolong the life of the coatings.

Passive Fireproofing Materials

Passive fireproofing means insulating systems designed to deter heat transfer from a fire to the structure being protected. These are generally coatings such as mineral-based or organic resin-based products but also include insulating panels or blankets. In most cases passive fire protection materials are used in conjunction with "active" systems such as water sprays, sprinklers and deluge, foam generation and inert gas suppression.

The need for passive fireproofing arises from at least one of the following:

- Fire risk assessment carried out by both public and private bodies.
- Enforcement of fire safety codes resulting from risk assessment.
- The absence of active systems or unavoidable delays in their activation.
- Requirements for personnel protection (safe areas, evacuation etc.).
- Protection of assets.

The human and economic costs of fire damage can be significantly reduced if not eliminated by the use of a suitable passive protection system.

Structural Fire Protection

When exposed to fire all commonly used structural materials lose some of their strength. Concrete cracks and spalls, timber depletes by charring and steel quickly loses its load bearing capacity. Such structural members can be protected to some extent by the application of specialist fireproofing products.

Most fireproofing work is performed on structural steel, in both industry and commercial applications. Many systems are also suitable for the protection of other construction materials such as reinforced concrete (which is of particular interest for the protection of tunnel linings).

It is important not to confuse these specialist fireproofing materials with other materials such as refractory products, which can withstand high temperatures but have poor insulating properties, or thermal insulation that is not designed to resist fire temperatures.

The key parameters to be considered for structural protection include:

Fire Protection Standards

Required levels of protection are normally specified in terms of time and temperature on the basis of one or more criteria, which may include statutory requirements, design considerations and insurance cost implications. It can vary from a few minutes to several hours but is usually in the form of 15-minute increments. The duration is established by a time rating, in hours or minutes, which is determined by testing in accordance with an approved standard. Some of the more commonly specified test standards are listed below:

STANDARD	COUNTRY	DESCRIPTION
ASTM E-119 (UL 263)	U.S.A.	Cellulosic or wood fire ; used since 1903; ratings for $\frac{3}{4}$, 1, 1 $\frac{1}{2}$, 2, 3 and 4 hours
BS 476 Parts 20-24	U.K.	Cellulosic or wood fire (similar to ASTM E-119)
DIN 4102	GERMANY	Cellulosic or wood fire (similar to ASTM E-119)
ISO 834	INTERNATIONAL	Cellulosic or wood fire (similar to ASTM E-119)
UL 1709	U.S.A.	Hydrocarbon fire; developed in the early 1970's

Fully stressed steel loses its design margin of safety at temperatures of around 550 °C, and most fire standards have taken 538 °C (1000 °F) as the critical temperature level. Hours of protection are therefore defined as the number of hours of exposure to fire while maintaining steel temperatures below 538 °C (1000 °F).

Earlier fire standards based on tests that simulate a cellulosic or wood fire are now considered inadequate for hydrocarbon fire scenarios. The cellulosic or 'A' class fire test curve is characterized by a relatively slow temperature rise to around 945 °C (1733 °F) after 60 minutes (fig. 1).

In hydrocarbon fires the temperature rises rapidly to 900 °C (1652 °F) within 4 minutes and significantly higher overall temperatures are reached (between 1100 °C and 1200 °C [between 2012 °F and 2192 °F]). The hydrocarbon or 'H' class fire test curve (fig. 1), as developed by Underwriters Laboratories in their UL 1709 "Rapid Temperature Rise" standard, is now a common reference in high risk environments, such as petrochemical complexes and offshore platforms, with a typical rating of 2 $\frac{1}{2}$ hours (equivalent to 3 hours per ASTM E-119).

More recently, attention has been focused on jet fire scenarios in which leaking high pressure flammable gases or vapors ignite to produce intense, erosive jet flames that can reach speeds of 335 mph (150 meters per second). A "J" class fire test standard has been developed by the Norwegian Fire Research Laboratory for use in Norway and the UK.

**Comparison of Typical 'Cellulosic' and
'Hydrocarbon'
Time/Temperature Curves**

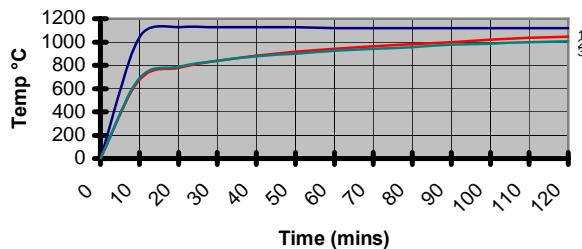


Fig. 1 (1 = hydrocarbon curve. 2 = BS 476. 3 = ISO 834.)

Very few statutory regulations exist governing the fire protection requirements within the high-risk petrochemical and chemical process industries. In most cases, the responsibility for risk assessment and provision of adequate fire protection rests with the Owner and Operator and their Insurer.

Some improvements have been made recently, such as in Italy where the prevention and protection from fire of pressurized LPG storage tanks (of over 5000 kg capacity) is regulated by specific norms.

Critical Temperature

Critical Temperature is normally specified but will always be based on one of the following:

- **Collapse** - the temperature at which a structural member loses its load bearing capacity. If the member is part of the main structure, it follows that the load also needs to be considered when determining the protection requirements. Steel loses about 75% of its strength at 600 °C so for heavily loaded structural components, 400 °C has been unofficially adopted as a standard.
- **Insulation** – although a rating (e.g. ‘A60’ or ‘H90’) may be specified by a designer or imposed by a statutory requirement, the insulation criteria is always the same. The back-face temperature shall not exceed an average temperature rise of 139 °C within the designated time period nor at any one point exceed a temperature rise of 180 °C.
- **Hazardous process requirements** – typically used for the storage of highly combustible materials, the critical temperature depends on the vessel wall thickness, construction details and content.

Governing Authority

Authorities governing fire regulations may be an independent certifying authority, such as Lloyds, DNV (Det Norske Veritas) or Bureau Veritas, or a government body, such as the Health and Safety Executive in the UK or the Ministero dell’Interno in Italy. Regulations are also produced by maritime bodies, professional associations and private organizations (especially oil companies).

In the civil construction field the requirement for fire protection is manifested in building codes and regulations. These are usually governmental statutory documents, and are often sponsored by insurance associations, the fire services, scientific institutes and industrial associations.

Structural Details

The nature of the structural member(s) to be protected influences the type and quantity of fireproofing to be applied. Important factors to consider include:

- **Construction material** – different materials have different critical temperatures (e.g. steel, aluminum, concrete, etc.)
- **Configuration of the components** – universal beams and columns, hollow sections, channels, etc.
- **Exposure** – whether the member would be exposed to fire on three or four sides.
- **Section factor (Hp/A)** – this is an extremely valuable concept that has enabled a still limited amount of fire test data to be used for the definition of protection requirements of a very wide range of steelwork.

Any steel member with a large perimeter (Hp) will receive more heat than one with a smaller perimeter. Furthermore, the greater the cross sectional area (A) of the member, the more heat it can absorb (known as the “heat sink” effect). In other words, a large, thin member will heat up much more quickly than a small, thick one. Hp/A is therefore a useful indicator of the rate at which a section will heat up in a fire and the higher its value; the more protection will be required.

Most suppliers of passive fireproofing can provide tables giving the thickness of material required to provide a fire protection rating in a hydrocarbon fire for various Hp/A values.

- **Location** - some materials may be unsuitable for specific situations. For example, thick film Intumescent coatings produce potentially harmful gases when they react in a fire and are therefore not generally used for enclosed accommodation or work areas.
- **Service conditions** – consideration must be given to the whole range of agents and forces that the protection will be required to resist during its service life (collectively referred to as “pre-fire durability”). These include weather conditions (in particular rain, humidity and ultraviolet rays); corrosive environment (soluble salts, sulfides, nitrates etc.) and physical-mechanical service conditions (service temperature, vibration and flexure, impact and abrasion etc.).

Another potential consideration is the weight loading (per unit area) of the fireproofing itself, which is of particular importance in the offshore industry.

Passive Fireproofing Materials

A wide range of fireproofing materials is available, from inorganic mineral based products to thermally reactive organic formulations.

The main classes of material used are:

- Cementitious products
- Subliming materials
- Intumescent materials
- Fibrous materials
- Composites

Cementitious Products

These include concrete, gunite, lightweight vermiculite based mixes, gypsum, calcium silicate and magnesium oxychloride.

All cementitious fireproofing materials function as heat absorbers by the evaporation of water bound into the coating matrix. The heat of a fire has to drive out water at the surface of the coating before it can penetrate the coating interior and reach the protected substrate. As the water is heated to boiling point it forms steam, which both repels the fire and absorbs heat. The temperature behind the surface being dehydrated cannot greatly exceed 100 °C [212 °F].

Cementitious materials are usually white or pale in color. This reflects the heat of the fire thus improving the efficiency of protection.

Cementitious materials are essentially inorganic and therefore will not burn. No additional smoke or toxic fumes are produced in a fire which makes them suitable for internal use in living quarters and work areas.

Concrete is the oldest form of passive fire protection for structural steel. Concrete used for the purpose of fire protection may be specified to meet the following requirements:

- Type 1 Portland cement conforming to ASTM C 150.
- Commercial high silica sand with clean, sharp and hard particles conforming to ASTM C 33.
- Sharp and angular aggregate ranging in size from 6 mm to 13 mm (0.25 to 0.5 inches) and conforming to ASTM C 33.
- Clean water free from oils, acids, salts, alkalis or other substances that could damage the concrete.
- Minimum compressive strength after 28 days of 210 kg/cm² (3000 psi).

50 mm (2 inch) thickness of concrete prepared to the above specification will provide a 2-hour rating to BS476 Part 8 or ASTM E-119. The steel is usually boxed or shuttered and the concrete poured in place. Most specifications require the installation of a reinforcement mesh supported by welded studs in the middle section of the coating.

Advantages of concrete are that it is

- hard and durable
- relatively cheap as a material
- easy to install and repair.

Disadvantages are that:

- it is heavy
- installation costs are high especially on smaller beams
- it is liable to spall in a hydrocarbon fire
- there is the risk of hidden corrosion caused by water ingress via the small gap left against the steel when it sets. It is very important to properly seal all terminations to prevent this happening.

Shotcrete, a mixture of cement, sand and proprietary materials, is an alternative to concrete that can be spray applied thus making the installation more cost effective. It is also lighter than poured in place concrete. Steel reinforcement is required and it presents the same risks of hidden corrosion as concrete.

Lightweight cementitious fireproofing materials vary, with nominal density values of 500-550 kg/m³ for offshore use and 700-900 kg/m³ for onshore applications. The weight contribution for onshore applications is therefore about 0.8 kg/mm/m². Due to their lower density and high porosity they do not spall in a hydrocarbon fire. Typically, a 2-hour fire rating to ASTM E-119 can be achieved with 25 mm (1 inch) thickness.

They are produced as factory controlled cement (usually Type 1 Portland) and vermiculite premixes which are combined with potable water before being spray applied to a suitably prepared steel surface. Reinforcement mesh (galvanized and/or plastic-coated steel) is installed in the middle third of the coating. The system is completed with a semi-permeable topcoat that protects against ingress from rainfall, cleaning water, chemical spills and sprinkler deluge systems.

The topcoat must have a high water vapor permeability to allow moisture to escape from the substrate (fireproofing material) without causing blistering of the final coating. A penetrating water repellent primer is sometimes applied prior to topcoating. As with concrete, proper sealing of all terminations (typically polysulfide or silicone rubber mastics) is necessary to prevent water infiltrating the micro-fissures between the fireproofing material and steel substrate.

As well as possessing excellent fire resistance characteristics, these products are also relatively cheap and high quality finishes can be obtained by skilled applicators. Being stable, non-reactive mineral compounds they do not present a health hazard during application, service life or in a fire.

Possible disadvantages stem from this type of material's high porosity, which may lead to the absorption of potentially damaging substances (e.g. acids) that can weaken the vermiculite-cement's physical resistance and create the conditions for substrate corrosion. These difficulties are overcome however by the use of a suitable anticorrosive treatment prior to fireproofing and the application of specialist topcoats as described above.

Magnesium oxychloride - chemical formula $3\text{Mg}(\text{OH})_2 \bullet \text{MgCl}_2 \bullet 8\text{H}_2\text{O}$ - has a nominal density of 1000 kg/m³ and is therefore classed as a lightweight cementitious product. It too is porous although the equilibrium water uptake appears to be only 32%. Topcoating is required for the same reasons as vermiculite-cements. The source of water is from a solid-state formula that breaks down in a heat reaction to release hydrogen and oxygen which combine to form water vapor. Magnesium oxide, a white chalky material, remains to insulate against the flames.

Gypsum, plaster, calcium silicate and other cementitious materials are usually supplied as panels which are fixed to the structure with either steel wire or nailed to a timber cradle. Advantages of this type of system include attractive appearance, ease of installation and no particular surface preparation requirements. However, they are not suitable for exterior use due to poor weathering characteristics and installation can be time consuming.

Subliming Materials

These products act by the process of phase change from a solid directly to a gas without going through the liquid stage. Specially formulated compounds are incorporated in organic matrices of a plastic or elastomeric nature. The sublimation process is endothermic which means that heat is absorbed and removed from the material. The effect is enhanced by the addition of other fire retardant additives that enhance the endothermic reaction.

During a fire, the chemical compounds react to form a carbonaceous substance which is turned into a lightweight char by the freeing of non-flammable gases. The resulting layer has very low thermal conductivity and thus resists heat flow to the substrate. These reactions continue for periods that are determined by the thickness applied. 9 mm – 10 mm ($\frac{3}{8}$ inch) is a typical thickness to achieve a 2-hour rating to ASTM E-119.

Reinforcement mesh is recommended to ensure that the material stays in place during the reaction and to reduce the possibility of disbonding along the coating/steel plane due to the different thermal expansion coefficients of the coating material and steel substrate.

These materials offer high levels of fire protection for low applied thicknesses, which means a low weight contribution (about 1.25 kg/mm/m²). Most are epoxy resin based, and have good anticorrosive properties.

Disadvantages are limited to their relatively high cost and more demanding application requirements than cementitious products.

Intumescence Materials

These products are classified as either intumescence mastic or thin film Intumescence coatings.

Intumescence mastics are usually based on epoxy, vinyl or other elastomeric resins and contain an agent that intumesces when exposed to heat.

Intumescence is a complex process in which, under the heat of the flame, the solid coating is converted into highly viscous liquid. Simultaneously, endothermic reactions are initiated that result in the release of inert gases with low thermal conductivity. These gases are trapped inside the viscous fluid where cross-linking reactions take place between the polymer chains. The result is the expansion or foaming of the coating, sometimes up to 8 times the initial thickness, to form a low density, carbonaceous insulating char. This layer of char absorbs a large part of the heat generated by the fire thus maintaining the protected structure's temperature within the critical limit established for the specified time.

As with subliming products, the coating continues to react until all its components are used up and consequently the protection rating is given by the thickness applied. Typically, 8 mm – 9 mm ($\frac{3}{8}$ inch) provides a 2-hour rating to ASTM E-119.

Intumescence mastics are hard and durable and the epoxy resin based products in particular provide exceptional protection from corrosion. This is due to their very high adhesion to the substrate and resistance to impact, abrasion and vibration damage. High tensile and compressive strengths can be obtained and weather resistance is excellent.

Reinforcement mesh is almost always installed for the same reasons as with subliming materials (holding the char in place and reducing shear stress on the coating/steel interface).

Intumescence mastics are costly and skilled operators must carry out application in carefully controlled conditions. Additionally, these coatings have more stringent surface preparation requirements than cementitious materials, and their reactivity makes them unsuitable for certain applications, such as enclosed living areas.

Thin film intumescents were introduced as early as the 1930's and are generally solvent or water based single pack coatings, applied by spray or brush-roller at thickness close to 3 mm ($\frac{1}{8}$ inch). They are often referred to as "fire retardant paints" rather than "fireproofing" materials due to their inferior fire resistance compared to intumescence mastics. Many thin-film intumescence coatings are unsuitable for exterior

use and test ratings are limited to cellulosic fires only. Advantages of these products include:

- they are available in a wide range of colors
- they are inexpensive
- they are relatively easy to apply.

Fibrous Materials

Boards and blankets of mineral wool and ceramic fiber are sometimes used as passive fireproofing systems, especially where thermal insulation is an additional requirement. Inorganic binders that do not burn out during the initial stages of the fire are recommended.

Mineral wool is rated to 850 °C (1560 °F) and ceramic fiber to 1150 °C (2100 °F). As ceramic fiber is more expensive than mineral wool they are often used in combination. Mineral wool fibers can be sprayed with an adhesive to provide protection to structural steelwork.

All fibrous materials absorb water easily and are therefore recommended for internal use only except where they can be adequately clad with metal sheeting with all the joints sealed.

Composite Materials

Composite fire protection panels are produced with various types of materials from different (fire resistant) classes. Panels may consist of a metallic cladding, often stainless steel, a cementitious board (typically plaster or gypsum) and mineral or ceramic fibers sandwiched in between. These panels may have “A”, “B” or “H” ratings as required. They are generally fixed to structural members with steel binding wire or bolted to a supporting frame or cradle.

Application of Selected Passive Fireproofing Materials

It is well known that most coatings are only as good as their application, and fireproofing materials are no exception. All of those factors that contribute to the success or failure of a protective coating application – ambient conditions, operator skill and experience, equipment suitability and efficiency, adequate surface preparation and so on – must be considered when passive fireproofing systems are specified. Some considerations include:

Scope of Work

One of the first and most important requisites of a successful application is to thoroughly understand the protection requirements in terms of fire rating, choice of materials, extent of fireproofing, application conditions and so on. Ideally most, if not all, of this information will be made available in a project dedicated fireproofing specification. A good specification will contain details of all of the following:

- Scope of the specification and project description
- Detailed drawings showing extent and specific requirements of fireproofing for all types of structure and equipment to be protected
- Reference documents (other applicable job specifications, standards, codes and regulations)
- Responsibilities (of owner, material supplier and applicator)
- Definitions (typically of fire hazardous areas and equipment)
- Fire protection rating(s) required
- Specific requirements (for different types of structure and equipment)
- Material requirements (standards for material components, suitability of different material types etc.)
- Application requirements (surface preparation standards, ambient conditions, reinforcement system, sloping for water shed and sealing of terminations, topcoat, etc.)
- Quality Assurance and Quality Control requirements (certification and records required)
- Guarantee (to be supplied by the applicator alone or jointly with the material supplier)
- Safety requirements

As in all cases, it is of fundamental importance that the interested parties (owner, supplier and applicator) are sure of exactly what is required. Any doubts should be sufficiently aired and resolved prior to commencement of the works.

Ambient Conditions

These are of critical importance for a successful application, especially when intumescent epoxies are used, as they are particularly sensitive to high humidity.

As a general rule, exterior application should be performed in good weather conditions – dry, moderate temperatures and low to medium relative humidity. If these conditions do not prevail and the job must be done anyway, then *adequate weather protection must be provided*. This may require total encapsulation of the structure and installation of specialist dehumidifying and heating equipment.

The cost impact of these measures may be considerable (up to 20% of the contract value) and must be understood and agreed by the owner and applicator prior to start-up.

In very hot, dry conditions lightweight cementitious products can suffer from rapid water evaporation, which may result in cracking. This can be avoided by screening the work piece from strong radiant sunlight and drying winds. Another useful measure is to lightly wrap the coated members with either polythene sheet or sack-cloth (gunny sack), which should be wetted periodically.

Material Control and Storage

All materials should be supplied in suitable containers (drums or bags) complete with production batch numbers and conformance certificates. These numbers will subsequently be recorded on the quality control forms for each application in order to allow traceability for future reference. A “First In - First Out” storage system should be operated.

Cementitious materials should be stored off the ground, under cover and away from damp surfaces or areas of very high humidity in order to prevent the formation of lumps in the mix. Intumescent mastics should not be subjected to temperature extremes (below 0 °C [32 °F] or above 35 °C [95 °F]), which may damage the reactive components. Additionally, the material should be heated to between 27 °C [81 °F] and 30 °C [86 °F] for 24 – 48 hours prior to application to assist spray operations.

Masking

Masking is of particular importance for intumescent mastics, which are extremely difficult to remove in case of overspray. For the same reason, any masking tape should be carefully removed before the material has hardened.

Surface Preparation

As with all protective coating systems, a correctly prepared surface is the basis and prerequisite of a successful application.

Most intumescent mastic systems require that the substrate be blast cleaned to SSPC SP10 (Sa 2.5) and coated with an approved primer to a specific thickness (typically approx. 75 microns, 3 mils). Epoxy based primers are preferred as they tend to have higher bond strengths. If inorganic zines are used, care should be taken to obtain the specified curing conditions and it is good practice to apply a 20 – 30 micron [1 mil] epoxy tie-coat.

The main considerations for primers are that they should be fully cured and applied at the specified dry film thickness. Excessive film thickness increases the risk of disbonding between primer and intumescent mastic.

Surface preparation requirements for cementitious products are less severe. However, the importance of an effective anticorrosive treatment should not be underrated. Many owners now specify blast cleaning and priming as above to reduce the possible risks of subsurface corrosion. In addition to the anticorrosive primer, a 60 – 80 micron [2.5 to 3.2 mils] coat of water based synthetic latex emulsion is applied for use as a sealer over alkali sensitive primers and to provide a good key for the cementitious fireproofing.

Sometimes, the fireproofing material is applied in a boxed configuration by spraying it onto a metal lath that is previously fixed to the sides of the steel members. In these cases, as the fireproofing material is not in direct contact with the substrate, the latex

emulsion key coat is not required and the control of primer film thickness is less critical.

Mesh Reinforcement

Both lightweight cementitious and epoxy intumescent mastics require the installation of mesh reinforcement to reduce primer bond line fatigue during the system's service life and ensure retention of the coating in a fire. The correct installation of the reinforcement is therefore of prime importance to ensure the effectiveness of the whole system.

In most cases a galvanized or stainless steel welded cloth or chicken wire is installed at a distance equal to mid-depth of the coating by attachment to steel pins that are stud welded to the structure.

An exception is a recently developed knitted fabric mesh composed of treated carbon and glass yarns for use with intumescent mastics. The carbon yarns, which can withstand high fire temperatures, lay in a serpentine pattern parallel to the axis of the structural member. When the coating intumesces, they straighten out and allow the mesh to expand with the coating.

The carbon grid is strong enough to hold the insulating char in place for the duration of the protection. These fabric meshes are quicker and easier to install than metal mesh as no pinning is required – they are simply laid over the first sprayed coat (with a 50 mm [2 inch] overlap at the edges), so as to be within the middle third of the total thickness, and gently pressed in with a roller to ensure full encapsulation.

The main disadvantage is that they cost up to five times more than metal mesh, so careful consideration should be given to surface configuration and the extent of pinning that would be required.

When steel pins are used it is advisable to stud weld them prior to blasting and priming. This sequence eliminates the need for subsequent touch-up coating of the pin welds, which can be very time consuming.

Pins are normally fixed at 300 mm [12 inch] to 400 mm [16 inch] centers on a diamond or staggered pitch and should be able to withstand being bent once through an angle of 45 ° and back to their original position. This test should be included in the Quality Control Plan and performed on at least the first 20 pins welded each day.

Where pinning is not required, such as on hollow sections, or not permitted, as on LPG storage tanks, the mesh is simply fixed with steel tie wire along staggered joints. The metal mesh should be as tight to the steel as possible when applying low to medium thicknesses of intumescent mastics. This is to avoid having to apply excess material in order to cover protruding mesh.

In all cases, the fireproofing supplier's application instructions should include detailed drawings of mesh installation for different structural members.

Fireproofing Application

Once mesh installation is complete, application of the fireproofing material itself can begin. Both lightweight cementitious and intumescent mastic products are spray applied using specialist equipment. However, small areas, such as tie-ins and repairs, may be hand applied by trowel.

Some of the factors most likely to contribute to the success of the fireproofing application include:

Operator Skill and Experience

As a minimum requirement, the job supervisor and sprayer should have received documented specialist training by the material supplier. In all cases, workers must be trained and be capable of carrying out the activities required of them.

Depending on the type of surface, a typical team will consist of one sprayer, two or three trowellers and/or rollers and one machine operator.

Equipment

Lightweight cementitious materials are sprayed with electric or diesel powered high performance worm pumps with an integrated air compressor, such as the Putzmeister SP 11. These machines can spray up to 50 litres [13 US gallons] a minute. An important accessory is a water meter that allows precise control of the factory mix-water ratio.

As intumescent mastics are very heavy and viscous, they are most efficiently applied with purpose built hot spray plural component pumps. Unmixed components are pumped into separate pressurized heated tanks, equipped with air powered paddle mixers, where they are brought up to temperature, generally between 50 °C [120°F] and 70 °C [160 °F]. From here, the separate components are drawn into a fixed-ratio displacement pump, which establishes the correct mixture (in volume).

The two components, still separate, are then pumped through electric in-line heaters and on through heated hoses to a mixing manifold. At this point the components are mixed in an in-line static mixer and fed through a short whip line to the high-pressure (min. 500 bar, [7,000 psi]) airless spray gun. The required exit temperature for a good spray pattern is close to 60 °C [140 °F]. The prerequisite for trouble free operation of this type of pump is that the material is maintained at the correct temperature. It is therefore necessary to provide controlled heated storage for the material, and advisable to place the machine in a modified insulated container for work at low air temperatures.

The importance of keeping all spray equipment clean and efficient cannot be overstated, as down time is very costly. For this reason a skilled and experienced machine operator is a vital component of the team.

Quality Control

The supervisor should check the following points prior to start-up:

- Sufficient material is available near the pump to ensure continuity of application (it is important to check that all intumescent mastic to be applied is at the right temperature).
- The pump is clean and in good working order (safety and operational checks should be carried out before spraying commences).
- All necessary masking and mesh installation is complete.
- Surface temperature and ambient conditions.
- Density and slump tests for lightweight cementitious materials and ratio checks for intumescent mastics.

The supervisor or QC inspector if there is one, should record the results of the above checks and tests on job specific QC forms.

The adoption of a well thought out Quality Control Plan (QCP) can contribute significantly to the success of an application. The main requirements of a good QCP are that it includes all the checks and tests deemed necessary by the material supplier (ambient conditions, density and ratio checks, thickness checks, full encapsulation of reinforcement mesh etc.), areas to be treated are easily identifiable (preferably with the support of drawings) and the QC forms are user friendly in terms of design and the amount of information to record.

It is always a good idea to maintain good communications with the client's representative as work progresses. The preparation of a sample reference area that demonstrates the standard of work to achieve is also recommended.

Frequent thickness checks during the application are essential. As the fire rating is determined solely by the thickness of material applied, the applicator must keep this parameter under constant control. Fireproofing materials are expensive, and extra (unnecessary) thickness can be very costly!

ANNEX 1

RESOLUTION MSC.215(82)

(adopted on 8 December 2006)

**PERFORMANCE STANDARD FOR PROTECTIVE COATINGS
FOR DEDICATED SEAWATER BALLAST TANKS IN ALL TYPES OF SHIPS
AND DOUBLE-SIDE SKIN SPACES OF BULK CARRIERS**

THE MARITIME SAFETY COMMITTEE,

RECALLING Article 28(b) of the Convention on the International Maritime Organization concerning the functions of the Committee,

NOTING the amendments to regulations II-1/3-2 and XII/6 of the International Convention for the Safety of Life at Sea (SOLAS), 1974, as amended (hereinafter referred to as "the Convention") adopted by resolution MSC.216(82), concerning protective coatings of dedicated seawater ballast tanks and double-side skin spaces,

NOTING ALSO that the aforementioned regulation II-1/3-2 provides that the protective coatings referred to therein shall comply with the requirements of the Performance standard for protective coatings for dedicated seawater ballast tanks in all types of ships and double-side skin spaces of bulk carriers (hereinafter referred to as "the Performance standard for protective coatings"),

RECOGNIZING that the Performance standard for protective coatings referred to above is not intended to inhibit the development of new or novel technologies which provide for alternative systems,

HAVING CONSIDERED, at its eighty-second session, the text of the proposed Performance standard for protective coatings,

1. ADOPTS the Performance standard for protective coatings for dedicated seawater ballast tanks in all types of ships and double-side skin spaces of bulk carriers, the text of which is set out in the Annex to the present resolution;
2. INVITES Contracting Governments to the Convention to note that the Performance standard for protective coatings will take effect on 1 July 2008 upon entry into force of the amendments to regulations II-1/3-2 and XII/6 of the Convention;
3. REQUESTS the Secretary-General to transmit certified copies of this resolution and the text of the Performance standard for protective coatings contained in the Annex to all Contracting Governments to the Convention;
4. FURTHER REQUESTS the Secretary-General to transmit copies of this resolution and the Annex to all Members of the Organization which are not Contracting Governments to the Convention;
5. INVITES Governments to encourage the development of novel technologies aimed at providing for alternative systems and to keep the Organization advised of any positive results.

ANNEX

PERFORMANCE STANDARD FOR PROTECTIVE COATINGS FOR DEDICATED SEAWATER BALLAST TANKS IN ALL TYPES OF SHIPS AND DOUBLE-SIDE SKIN SPACES OF BULK CARRIERS

1 PURPOSE

This Standard provides technical requirements for protective coatings in dedicated seawater ballast tanks of all type of ships of not less than 500 gross tonnage and double-side skin spaces arranged in bulk carriers of 150 m in length and upwards¹ for which the building contract is placed, the keels of which are laid or which are delivered on or after the dates referred to in SOLAS regulation II-1/3-2 as adopted by resolution MSC.216(82).

2 DEFINITIONS

For the purpose of this Standard, the following definitions apply.

2.1 *Ballast tanks* are those as defined in the Guidelines for the selection, application and maintenance of corrosion prevention systems of dedicated seawater ballast tanks (resolution A.798(19)) and the Guidelines on the enhanced programme of inspections during surveys of bulk carriers and oil tankers (resolution A.744(18), as amended).

2.2 *Dew point* is the temperature at which air is saturated with moisture.

2.3 *DFT* is dry film thickness.

2.4 *Dust* is loose particle matter present on a surface prepared for painting, arising from blast-cleaning or other surface preparation processes, or resulting from the action of the environment.

2.5 *Edge grinding* is the treatment of edge before secondary surface preparation.

2.6 “*GOOD*” condition is the condition with minor spot rusting as defined in resolution A.744(18).

2.7 *Hard coating* is a coating that chemically converts during its curing process or a non-convertible air drying coating which may be used for maintenance purposes. It can be either inorganic or organic.

2.8 *NDFT* is the nominal dry film thickness. A 90/10 practice means that 90% of all thickness measurements shall be greater than, or equal to, NDFT and none of the remaining 10% measurements shall be below $0.9 \times \text{NDFT}$.

2.9 *Primer coat* is the first coat of the coating system applied in the shipyard after shop-primer application.

¹ This Standard applies only to dedicated seawater ballast tanks in all types of ships and double-side skin spaces in bulk carriers which are constructed of steel.

2.10 *Shop-primer* is the prefabrication primer coating applied to steel plates, often in automatic plants (and before the first coat of a coating system).

2.11 *Stripe coating* is painting of edges, welds, hard to reach areas, etc., to ensure good paint adhesion and proper paint thickness in critical areas.

2.12 *Target useful life* is the target value, in years, of the durability for which the coating system is designed.

2.13 *Technical Data Sheet* is paint manufacturers' Product Data Sheet which contains detailed technical instruction and information relevant to the coating and its application.

3 GENERAL PRINCIPLES

3.1 The ability of the coating system to reach its target useful life depends on the type of coating system, steel preparation, application and coating inspection and maintenance. All these aspects contribute to the good performance of the coating system.

3.2 Inspection of surface preparation and coating processes shall be agreed upon between the shipowner, the shipyard and the coating manufacturer and presented to the Administration² for review. The Administration may, if it so requires, participate in the agreement process. Clear evidence of these inspections shall be reported and be included in the Coating Technical File (CTF) (see 3.4).

3.3 When considering the Standard provided in section 4, the following is to be taken into account:

- .1 it is essential that specifications, procedures and the various different steps in the coating application process (including, but not limited to, surface preparation) are strictly applied by the shipbuilder in order to prevent premature decay and/or deterioration of the coating system;
- .2 the coating performance can be improved by adopting measures at the ship design stage such as reducing scallops, using rolled profiles, avoiding complex geometric configurations and ensuring that the structural configuration permits easy access for tools and to facilitate cleaning, drainage and drying of the space to be coated; and
- .3 the coating performance standard provided in this document is based on experience from manufacturers, shipyards and ship operators; it is not intended to exclude suitable alternative coating systems, providing a performance at least equivalent to that specified in this Standard is demonstrated. Acceptance criteria for alternative systems are provided in section 8.

² In accordance with SOLAS regulation I/6, for the purposes of this Standard, the Administration may entrust a recognized organization acting on its behalf to determine compliance with the provisions of this Standard.

3.4 Coating Technical File

3.4.1 Specification of the coating system applied to the dedicated seawater ballast tanks and double-side skin spaces, record of the shipyard's and shipowner's coating work, detailed criteria for coating selection, job specifications, inspection, maintenance and repair³ shall be documented in the Coating Technical File (CTF), and the Coating Technical File shall be reviewed by the Administration.

3.4.2 *New construction stage*

The Coating Technical File shall contain at least the following items relating to this Standard and shall be delivered by the shipyard at new ship construction stage:

- .1 copy of Statement of Compliance or Type Approval Certificate;
- .2 copy of Technical Data Sheet, including:
 - .2.1 product name and identification mark and/or number;
 - .2.2 materials, components and composition of the coating system, colours;
 - .2.3 minimum and maximum dry film thickness;
 - .2.4 application methods, tools and/or machines;
 - .2.5 condition of surface to be coated (de-rusting grade, cleanliness, profile, etc.); and
 - .2.6 environmental limitations (temperature and humidity);
- .3 shipyard work records of coating application, including:
 - .3.1 applied actual space and area (in square metres) of each compartment;
 - .3.2 applied coating system;
 - .3.3 time of coating, thickness, number of layers, etc.;
 - .3.4 ambient condition during coating; and
 - .3.5 method of surface preparation;
- .4 procedures for inspection and repair of coating system during ship construction;
- .5 coating log issued by the coating inspector, stating that the coating was applied in accordance with the specifications to the satisfaction of the coating supplier representative and specifying deviations from the specifications (example of daily log and non-conformity report (see annex 2));
- .6 shipyard's verified inspection report, including:
 - .6.1 completion date of inspection;
 - .6.2 result of inspection;
 - .6.3 remarks (if given); and
 - .6.4 inspector signature; and

³ Guidelines to be developed by the Organization.

.7 procedures for in-service maintenance and repair of coating system.

3.4.3 *In-service maintenance, repair and partial re-coating*

In-service maintenance, repair and partial re-coating activities shall be recorded in the Coating Technical File in accordance with the relevant section of the Guidelines for coating maintenance and repair⁴.

3.4.4 *Re-coating*

If a full re-coating is carried out, the items specified in 3.4.2 shall be recorded in the Coating Technical File.

3.4.5 The Coating Technical File shall be kept on board and maintained throughout the life of the ship.

3.5 Health and safety

The shipyard is responsible for implementation of national regulations to ensure the health and safety of individuals and to minimize the risk of fire and explosion.

4 COATING STANDARD

4.1 Performance standard

This Standard is based on specifications and requirements which intend to provide a target useful coating life of 15 years, which is considered to be the time period, from initial application, over which the coating system is intended to remain in “GOOD” condition. The actual useful life will vary, depending on numerous variables including actual conditions encountered in service.

4.2 Standard application

Protective coatings for dedicated seawater ballast tanks of all ship types and double-side skin spaces arranged in bulk carriers of 150 m in length and upwards shall at least comply with the requirements in this Standard.

4.3 Special application

4.3.1 This Standard covers protective coating requirements for the ship’s steel structure. It is noted that other independent items are fitted within the tanks to which coatings are applied to provide protection against corrosion.

⁴ Guidelines to be developed by the Organization.

4.3.2 It is recommended that this Standard is applied, to the extent possible, to those portions of permanent means of access provided for inspection not integral to the ship's structure, such as rails, independent platforms, ladders, etc. Other equivalent methods of providing corrosion protection for the non-integral items may also be used, provided they do not impair the performance of the coatings of the surrounding structure. Access arrangements that are integral to the ship structure, such as increased stiffener depths for walkways, stringers, etc., are to fully comply with this Standard.

4.3.3 It is also recommended that supports for piping, measuring devices, etc., be coated in accordance with the non-integral items indicated in 4.3.2.

4.4 Basic coating requirements

4.4.1 The requirements for protective coating systems to be applied at ship construction for dedicated seawater ballast tanks of all ship types and double-side skin spaces arranged in bulk carriers of 150 m in length and upwards meeting the performance standard specified in 4.1 are listed in table 1.

4.4.2 Coating manufacturers shall provide a specification of the protective coating system to satisfy the requirements of table 1.

4.4.3 The Administration shall verify the Technical Data Sheet and Statement of Compliance or Type Approval Certificate for the protective coating system.

4.4.4 The shipyard shall apply the protective coating in accordance with the verified Technical Data Sheet and its own verified application procedures.

Table 1 – Basic coating system requirements for dedicated seawater ballast tanks of all type of ships and double-side skin spaces of bulk carriers of 150 m and upwards

Characteristic/ Reference standards	Requirement
1 Design of coating system	
.1 Selection of the coating system	<p>The selection of the coating system shall be considered by the parties involved with respect to the service conditions and planned maintenance. The following aspects, among other things shall be considered:</p> <ul style="list-style-type: none"> .1 location of space relative to heated surfaces; .2 frequency of ballasting and deballasting operations; .3 required surface conditions; .4 required surface cleanliness and dryness; and .5 supplementary cathodic protections, if any (where coating is supplemented by cathodic protection, the coating shall be compatible with the cathodic protection system). <p>Coating manufacturers shall have products with documented satisfactory performance records and technical data sheets. The manufacturers shall also be capable of rendering adequate technical assistance. Performance records, technical data sheet and technical assistance (if given) shall be recorded in the Coating Technical File.</p> <p>Coatings for application underneath sun-heated decks or on bulkheads forming boundaries of heated spaces shall be able to withstand repeated heating and/or cooling without becoming brittle.</p>

.2	Coating type	<p>Epoxy-based systems.</p> <p>Other coating systems with performance according to the test procedure in annex 1.</p> <p>A multi-coat system with each coat of contrasting colour is recommended.</p> <p>The top coat shall be of a light colour in order to facilitate in-service inspection.</p>
.3	Coating pre-qualification test	<p>Epoxy-based systems tested prior to the date of entry into force of this Standard in a laboratory by a method corresponding to the test procedure in annex 1 or equivalent, which as a minimum meets the requirements for rusting and blistering; or which have documented field exposure for 5 years with a final coating condition of not less than “GOOD” may be accepted.</p> <p>For all other systems, testing according to the procedure in annex 1, or equivalent, is required.</p>
.4	Job specification	<p>There shall be a minimum of two stripe coats and two spray coats, except that the second stripe coat, by way of welded seams only, may be reduced in scope where it is proven that the NDFT can be met by the coats applied, in order to avoid unnecessary over-thickness. Any reduction in scope of the second stripe coat shall be fully detailed in the CTF.</p> <p>Stripe coats shall be applied by brush or roller. Roller to be used for scallops, ratholes, etc., only.</p> <p>Each main coating layer shall be appropriately cured before application of the next coat, in accordance with coating manufacturer’s recommendations. Surface contaminants such as rust, grease, dust, salt, oil, etc., shall be removed prior to painting with proper method according to the paint manufacturer’s recommendation. Abrasive inclusions embedded in the coating shall be removed. Job specifications shall include the dry-to-recoat times and walk-on time given by the manufacturer.</p>
.5	NDFT (nominal total dry film thickness) ⁵	<p>NDFT 320 µm with 90/10 rule for epoxy-based coatings; other systems to coating manufacturer’s specifications.</p> <p>Maximum total dry film thickness according to manufacturer’s detailed specifications.</p> <p>Care shall be taken to avoid increasing the thickness in an exaggerated way. Wet film thickness shall be regularly checked during application.</p> <p>Thinner shall be limited to those types and quantities recommended by the manufacturer.</p>

⁵ Type of gauge and calibration in accordance with SSPC-PA2:2004. Paint Application Specification No.2.

2 PSP (Primary surface preparation)		
.1	Blasting and profile ^{6,7}	<p>Sa 2½; with profiles between 30-75 µm</p> <p>Blasting shall not be carried out when:</p> <p>.1 the relative humidity is above 85%; or .2 the surface temperature of steel is less than 3°C above the dew point.</p> <p>Checking of the steel surface cleanliness and roughness profile shall be carried out at the end of the surface preparation and before the application of the primer, in accordance with the manufacturer's recommendations.</p>
.2	Water soluble salt limit equivalent to NaCl ⁸	≤ 50 mg/m ² of sodium chloride.
.3	Shop primer	<p>Zinc containing inhibitor free zinc silicate based or equivalent.</p> <p>Compatibility with main coating system shall be confirmed by the coating manufacturer.</p>
3 Secondary surface preparation		
.1	Steel condition ⁹	<p>The steel surface shall be prepared so that the coating selected can achieve an even distribution at the required NDFT and have an adequate adhesion by removing sharp edges, grinding weld beads and removing weld spatter and any other surface contaminant.</p> <p>Edges shall be treated to a rounded radius of minimum 2 mm, or subjected to three pass grinding or at least equivalent process before painting.</p>
.2	Surface treatment ⁶	<p>Sa 2½ on damaged shop primer and welds.</p> <p>Sa 2 removing at least 70% of intact shop primer, which has not passed a pre-qualification certified by test procedures in 1.3.</p> <p>If the complete coating system comprising epoxy-based main coating and shop primer has passed a pre-qualification certified by test procedures in 1.3, intact shop primer may be retained provided the same epoxy coating system is used. The retained shop primer shall be cleaned by sweep blasting, high-pressure water washing or equivalent method.</p> <p>If a zinc silicate shop primer has passed the pre-qualification test of 1.3 as part of an epoxy coating system, it may be used in combination with other epoxy coatings certified under 1.3, provided that the compatibility has been confirmed by the manufacturer by the test in accordance with 1.7 of appendix 1 to annex 1 without wave movement.</p>

6 Reference standard: ISO 8501-1:1988/Suppl:1994. Preparation of steel substrate before application of paints and related products – Visual assessment of surface cleanliness.

7 Reference standard: ISO 8503-1/2:1988. Preparation of steel substrate before application of paints and related products – Surface roughness characteristics of blast-cleaned steel substrates.

8 Conductivity measured in accordance with ISO 8502-9:1998. Preparation of steel substrate before application of paints and related products – Test for the assessment of surface cleanliness.

9 Reference standard: ISO 8501-3:2001 (grade P2). Preparation of steel substrate before application of paints and related products – Visual assessment of surface cleanliness.

.3	Surface treatment after erection ⁶	Butts St 3 or better or Sa 2½ where practicable. Small damages up to 2% of total area: St 3. Contiguous damages over 25 m ² or over 2% of the total area of the tank, Sa 2½ shall be applied. Coating in overlap shall be feathered.
.4	Profile requirements ⁷	In case of full or partial blasting 30-75 µm, otherwise as recommended by the coating manufacturer.
.5	Dust ⁹	Dust quantity rating “1” for dust size class “3”, “4” or “5”. Lower dust size classes to be removed if visible on the surface to be coated without magnification.
.6	Water soluble salts limit equivalent to NaCl after blasting/grinding ⁸	≤ 50 mg/m ² of sodium chloride. .
.7	Oil contamination	No oil contamination.

4 Miscellaneous

.1	Ventilation	Adequate ventilation is necessary for the proper drying and curing of coating. Ventilation should be maintained throughout the application process and for a period after application is completed, as recommended by the coating manufacturer.
.2	Environmental conditions	Coating shall be applied under controlled humidity and surface conditions, in accordance with the manufacturer's specifications. In addition, coating shall not be applied when: .1 the relative humidity is above 85%; or .2 the surface temperature is less than 3°C above the dew point.
.3	Testing of coating ⁵	Destructive testing shall be avoided. Dry film thickness shall be measured after each coat for quality control purpose and the total dry film thickness shall be confirmed after completion of final coat, using appropriate thickness gauges (see annex 3).
.4	Repair	Any defective areas, e.g., pin-holes, bubbles, voids, etc., shall be marked up and appropriate repairs effected. All such repairs shall be re-checked and documented.

5 COATING SYSTEM APPROVAL

Results from prequalification tests (table 1, paragraph 1.3) of the coating system shall be documented and a Statement of Compliance or Type Approval Certificate shall be issued if found satisfactory by a third party, independent of the coating manufacturer.

⁵ Type of gauge and calibration in accordance with SSPC-PA2:2004. Paint Application Specification No.2.

⁶ Reference standard: ISO 8501-1:1988/Suppl:1994. Preparation of steel substrate before application of paints and related products – Visual assessment of surface cleanliness.

⁷ Reference standard: ISO 8503-1/2:1988. Preparation of steel substrate before application of paints and related products – Surface roughness characteristics of blast-cleaned steel substrates.

⁸ Conductivity measured in accordance with ISO 8502-9:1998. Preparation of steel substrate before application of paints and related products – Test for the assessment of surface cleanliness.

⁹ Reference standard: ISO 8502-3:1993. Preparation of steel substrate before application of paints and related products – Test for the assessment of surface cleanliness.

6 COATING INSPECTION REQUIREMENTS

6.1 General

6.1.1 To ensure compliance with this Standard, the following shall be carried out by qualified coating inspectors certified to NACE Coating Inspector Level 2, FROSIO Inspector Level III or equivalent as verified by the Administration.

6.1.2 Coating inspectors shall inspect surface preparation and coating application during the coating process by carrying out, as a minimum, those inspection items identified in section 6.2 to ensure compliance with this Standard. Emphasis shall be placed on initiation of each stage of surface preparation and coatings application as improper work is extremely difficult to correct later in the coating progress. Representative structural members shall be non-destructively examined for coating thickness. The inspector shall verify that appropriate collective measures have been carried out.

6.1.3 Results from the inspection shall be recorded by the inspector and shall be included in the CTF (refer to annex 2 (Example of daily log and non-conformity report)).

6.2 Inspection items

Construction stage	Inspection items
Primary surface preparation	1 The surface temperature of steel, the relative humidity and the dew point shall be measured and recorded before the blasting process starts and at times of sudden changes in weather.
	2 The surface of steel plates shall be tested for soluble salt and checked for oil, grease and other contamination.
	3 The cleanliness of the steel surface shall be monitored in the shop-primer application process.
	4 The shop-primer material shall be confirmed to meet the requirements of 2.3 of table 1.
Thickness	If compatibility with the main coating system has been declared, then the thickness and curing of the zinc silicate shop primer to be confirmed to conform to the specified values.
Block assembly	1 After completing construction of the block and before secondary surface preparation starts, a visual inspection for steel surface treatment including edge treatment shall be carried out. Any oil, grease or other visible contamination shall be removed.
	2 After blasting/grinding/cleaning and prior to coating, a visual inspection of the prepared surface shall be carried out. On completion of blasting and cleaning and prior to the application of the first coat of the system, the steel surface shall be tested for levels of remaining soluble salts in at least one location per block.
	3 The surface temperature, the relative humidity and the dew point shall be monitored and recorded during the coating application and curing.
	4 Inspection shall be performed of the steps in the coating application process mentioned in table 1.
	5 DFT measurements shall be taken to prove that the coating has been applied to the thickness as specified and outlined in annex 3.

Construction stage		Inspection items
Erection	1	Visual inspection for steel surface condition, surface preparation and verification of conformance to other requirements in table 1, and the agreed specification shall be performed.
	2	The surface temperature, the relative humidity and the dew point shall be measured and recorded before coating starts and regularly during the coating process.
	3	Inspection shall be performed of the steps in the coating application process mentioned in table 1.

7 VERIFICATION REQUIREMENTS

The following shall be carried out by the Administration prior to reviewing the Coating Technical File for the ship subject to this Standard:

- .1 check that the Technical Data Sheet and Statement of Compliance or Type Approval Certificate comply with this Standard;
- .2 check that the coating identification on representative containers is consistent with the coating identified in the Technical Data Sheet and Statement of Compliance or Type Approval Certificate;
- .3 check that the inspector is qualified in accordance with the qualification standards in paragraph 6.1.1;
- .4 check that the inspector's reports of surface preparation and the coating's application indicate compliance with the manufacturer's Technical Data Sheet and Statement of Compliance or Type Approval Certificate; and
- .5 monitor implementation of the coating inspection requirements.

8 ALTERNATIVE SYSTEMS

8.1 All systems that are not an epoxy-based system applied according to table 1 of this Standard are defined as an alternative system.

8.2 This Standard is based on recognized and commonly used coating systems. It is not meant to exclude other, alternative, systems with proven equivalent performance, for example non epoxy-based systems.

8.3 Acceptance of alternative systems will be subject to documented evidence that they ensure a corrosion prevention performance at least equivalent to that indicated in this Standard.

8.4 As a minimum, the documented evidence shall consist of satisfactory performance corresponding to that of a coating system which conforms to the coating standard described in section 4, a target useful life of 15 years in either actual field exposure for 5 years with final coating condition not less than "GOOD" or laboratory testing. Laboratory test shall be conducted in accordance with the test procedure given in annex 1 to this Standard.

ANNEX 1

TEST PROCEDURES FOR COATING QUALIFICATION FOR DEDICATED SEAWATER BALLAST TANK OF ALL TYPES OF SHIPS AND DOUBLE-SIDE SKIN SPACES OF BULK CARRIERS

1 Scope

These Procedures provide details of the test procedure referred to in 5 and 8.3 of this Standard.

2 Definitions

Coating specification means the specification of coating systems which includes the type of coating system, steel preparation, surface preparation, surface cleanliness, environmental conditions, application procedure, acceptance criteria and inspection.

3 Testing

Coating specification shall be verified by the following tests. The test procedures shall comply with appendix 1 (Test on simulated ballast tank conditions) and appendix 2 (Condensation chamber tests) to this annex as follows:

- .1 for protective coatings for dedicated seawater ballast tanks, appendix 1 and appendix 2 shall apply; and
- .2 for protective coatings for double-side spaces of bulk carriers of 150 m in length and upwards other than dedicated seawater ballast tanks, appendix 2 shall apply.

APPENDIX 1

TEST ON SIMULATED BALLAST TANK CONDITIONS

1 Test condition

Test on simulated ballast tank conditions shall satisfy each of the following conditions:

- .1 The test shall be carried out for 180 days.
- .2 There are to be 5 test panels.
- .3 The size of each test panel is 200 mm x 400 mm x 3 mm. Two of the panels (Panel 3 and 4 below) have a U-bar welded. The U-bar is welded to the panel in a 120 mm distance from one of the short sides and 80 mm from each of the long sides.



The panels are to be treated according to this Standard, table 1.1, 1.2 and 1.3, and coating system applied according to table 1, paragraphs 1.4 and 1.5. Shop primer to be weathered for at least 2 months and cleaned by low pressure washing or other mild method. Blast sweep or high pressure washing, or other primer removal methods not to be used. Weathering method and extent shall take into consideration that the primer is to be the foundation for a 15 year target useful life system. To facilitate innovation, alternative preparation, coating systems and dry film thicknesses may be used when clearly defined.

- .4 The reverse side of the test piece shall be painted appropriately, in order not to affect the test results.
- .5 As simulating the condition of actual ballast tank, the test cycle runs for two weeks with natural or artificial seawater and one week empty. The temperature of the seawater is to be kept at about 35°C.
- .6 Test panel 1: This panel is to be heated for 12 h at 50°C and cooled for 12 h at 20°C in order to simulate upper deck condition. The test panel is cyclically splashed with natural or artificial seawater in order to simulate a ship's pitching and rolling motion. The interval of splashing is 3 s or faster. The panel has a scribe line down to bare steel across width.
- .7 Test panel 2: This panel has a fixed sacrificial zinc anode in order to evaluate the effect of cathodic protection. A circular 8 mm artificial holiday down to bare steel is introduced on the test panel 100 mm from the anode in order to evaluate the

effect of the cathodic protection. The test panel is cyclically immersed with natural or artificial seawater.

- .8 Test panel 3: This panel is to be cooled on the reverse side, in order to give a temperature gradient to simulate a cooled bulkhead in a ballast wing tank, and splashed with natural or artificial seawater in order to simulate a ship's pitching and rolling motion. The gradient of temperature is approximately 20°C, and the interval of splashing is 3 s or faster. The panel has a scribe line down to bare steel across width.
- .9 Test panel 4: This panel is to be cyclically splashed with natural or artificial seawater in order to simulate a ship's pitching and rolling motion. The interval of splashing is 3 s or faster. The panel has a scribe line down to bare steel across width.
- .10 Test panel 5: This panel is to be exposed to dry heat for 180 days at 70°C to simulate boundary plating between heated bunker tank and ballast tank in double bottom.

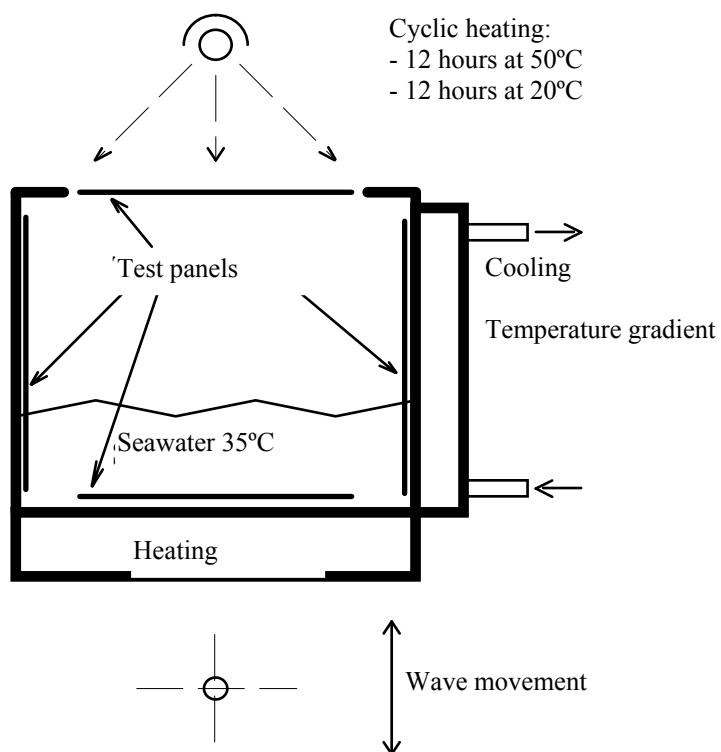


Figure 1
Wave tank for testing of ballast tank coatings

2 Test results

- 2.1 Prior to the testing, the following measured data of the coating system shall be reported:

- .1 infrared (IR) identification of the base and hardener components of the coating;
 - .2 specific gravity¹⁰ of the base and hardener components of the paint; and
 - .3 number of pinholes, low voltage detector at 90 V.
- 2.2 After the testing, the following measured data shall be reported:
- .1 blisters and rust;¹¹
 - .2 dry film thickness (DFT) (use of a template);¹²
 - .3 adhesion value;¹³
 - .4 flexibility¹⁴ modified according to panel thickness (3 mm steel, 300 µm coating, 150 mm cylindrical mandrel gives 2% elongation) for information only;
 - .5 cathodic protection weight loss/current demand/disbondment from artificial holiday; and
 - .6 undercutting from scribe. The undercutting along both sides of the scribe is measured and the maximum undercutting determined on each panel. The average of the three maximum records is used for the acceptance.

3 Acceptance criteria

- 3.1 The test results based on section 2 shall satisfy the following criteria:

Item	Acceptance criteria for epoxy-based systems applied according to table 1 of this Standard	Acceptance criteria for alternative systems
Blisters on panel	No blisters	No blisters
Rust on panel	Ri 0 (0%)	Ri 0 (0%)
Number of pinholes	0	0
Adhesive failure	> 3.5 MPa Adhesive failure between substrate and coating or between coats for 60% or more of the areas.	> 5 MPa Adhesive failure between substrate and coating or between coats for 60% or more of the areas.

¹⁰ Reference standard: ISO 2811-1/4:1997. Paints and varnishes. Determination of density.

¹¹ Reference standards: ISO 4628/2:2003. Paints and varnishes – Evaluation of degradation of coatings – Designation of quantity and size of defects, and of intensity of uniform changes in appearance – Part 2. ISO 4628:2003. Paints and varnishes – Evaluation of degradation of coatings – Designation of quantity and size of common types of defect – Part 3: Designation of degree of rusting.

¹² Nine equally distributed measuring points are used on panel's size 150 mm x 150 mm or 15 equally distributed measuring points on panel's size 200 mm x 400 mm.

¹³ Reference standard: ISO 4624:2002. Pull-off test for adhesion.

¹⁴ Reference standards: ASTM D4145:1983. Standard Test Method for Coating Flexibility of Preprinted Sheet.

Item	Acceptance criteria for epoxy-based systems applied according to table 1 of this Standard	Acceptance criteria for alternative systems
Cohesive failure	≥ 3 MPa Cohesive failure in coating for 40% or more of the area.	> 5 MPa Cohesive failure in coating for 40% or more of the area.
Cathodic protection current demand calculated from weight loss	< 5 mA/m ²	< 5 mA/m ²
Cathodic protection; disbondment from artificial holiday	< 8 mm	< 5 mm
Undercutting from scribe	< 8 mm	< 5 mm
U-bar	Any defects, cracking or detachment at the angle or weld will lead to system being failed.	Any defects, cracking or detachment at the angle or weld will lead to system being failed.

3.2 Epoxy-based systems tested prior to the date of entry into force of this Standard shall satisfy only the criteria for blistering and rust in the table above.

3.3 Epoxy-based systems tested when applied according to table 1 of this Standard shall satisfy the criteria for epoxy-based systems as indicated in the table above.

3.4 Alternative systems not necessarily epoxy-based and/or not necessarily applied according to table 1 of this Standard shall satisfy the criteria for alternative systems as indicated in the table above.

4 Test report

The test report shall include the following information:

- .1 name of the manufacturer;
- .2 date of tests;
- .3 product name/identification of both paint and primer;
- .4 batch number;
- .5 data of surface preparation on steel panels, including the following:
 - .5.1 surface treatment;
 - .5.2 water soluble salts limit;
 - .5.3 dust; and
 - .5.4 abrasive inclusions;

- .6 application data of coating system, including the following:
 - .6.1 shop primed;
 - .6.2 number of coats;
 - .6.3 recoat interval;¹⁵
 - .6.4 dry film thickness (DFT) prior to testing;¹⁵
 - .6.5 thinner;¹⁵
 - .6.6 humidity;¹⁵
 - .6.7 air temperature;¹⁵ and
 - .6.8 steel temperature;
- .7 test results according to section 2; and
- .8 judgment according to section 3.

¹⁵ Both of actual specimen data and manufacturer's requirement/recommendation.

APPENDIX 2**CONDENSATION CHAMBER TEST****1 Test condition**

Condensation chamber test shall be conducted in accordance with applicable standards.¹⁶

- .1 The exposure time is 180 days.
- .2 There are to be 2 test panels.
- .3 The size of each test panel is 150 mm x 150 mm x 3 mm. The panels are to be treated according to the Performance Standard, table 1, paragraphs 1, 2 and 3 and coating system applied according to table 1, paragraphs 1.4 and 1.5. Shop primer to be weathered for at least 2 months and cleaned by low pressure washing or other mild method. Blast sweep or high pressure washing, or other primer removal methods not to be used. Weathering method and extent shall take into consideration that the primer is to be the foundation for a 15 year target life system. To facilitate innovation, alternative preparation, coating systems and dry film thicknesses may be used when clearly defined.
- .4 The reverse side of the test piece shall be painted appropriately, in order not to affect the test results.

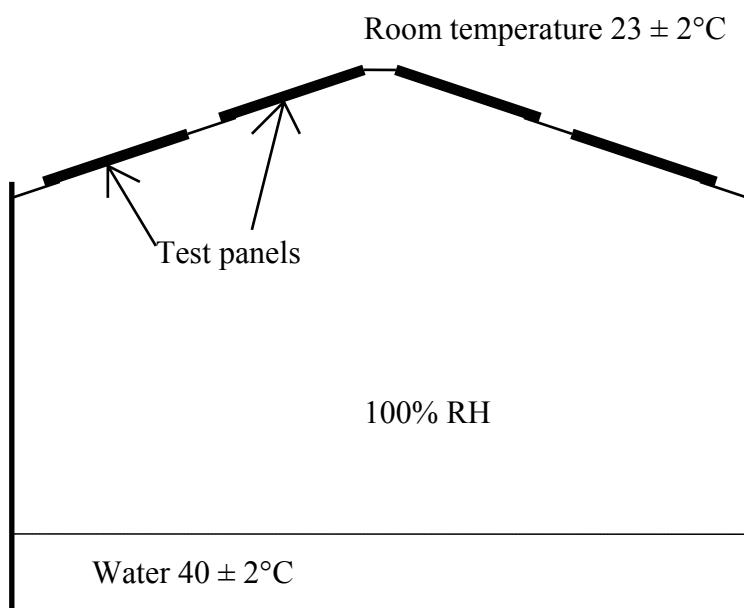


Figure 2
Condensation chamber

¹⁶ Reference standard: ISO 6270-1:1998 Paints and varnishes – Determination of resistance to humidity – Part 1: Continuous condensation.

2 Test results

According to section 2 (except for 2.2.5 and 2.2.6) of appendix 1.

3 Acceptance criteria

3.1 The test results based on section 2 shall satisfy the following criteria:

Item	Acceptance criteria for epoxy-based systems applied according to table 1 of this Standard	Acceptance criteria for alternative systems
Blisters on panel	No blisters	No blisters
Rust on panel	Ri 0 (0%)	Ri 0 (0%)
Number of pinholes	0	0
Adhesive failure	> 3.5 MPa Adhesive failure between substrate and coating or between coats for 60% or more of the areas.	> 5 MPa Adhesive failure between substrate and coating or between coats for 60% or more of the areas.
Cohesive failure	> 3 MPa Cohesive failure in coating for 40% or more of the area.	> 5 MPa Cohesive failure in coating for 40% or more of the area.

3.2 Epoxy-based systems tested prior to the date of entry into force of this Standard shall satisfy only the criteria for blistering and rust in the table above.

3.3 Epoxy-based systems tested when applied according to table 1 of this Standard shall satisfy the criteria for epoxy-based systems as indicated in the table above.

3.4 Alternative systems not necessarily epoxy-based and/or not necessarily applied according to table 1 of this Standard shall satisfy the criteria for alternative systems as indicated in the table above.

4 Test report

According to section 4 of appendix 1.

ANNEX 2

EXAMPLE OF DAILY LOG AND NON-CONFORMITY REPORT

DAILY LOG

Sheet No:

Ship:	Tank/Hold No:	Database:							
Part of structure:									
SURFACE PREPARATION									
Method:	Area (m ²):								
Abrasive:	Grain size:								
Surface temperature:	Air temperature:								
Relative humidity (max):	Dew point:								
Standard achieved:									
Rounding of edges:									
Comments:									
Job No.:	Date:	Signature:							
COATING APPLICATION:									
Method:									
Coat No.	System	Batch No.	Date	Air temp.	Surf temp.	RH%	Dew point	DFT* Meas.*	Specified
* Measured minimum and maximum DFT. DFT readings to be attached to daily log									
Comments:									
Job No:	Date:	Signature:							

NON-CONFORMITY REPORT

Sheet No:

Ship:	Tank/Hold No:	Database:
Part of structure:		
DESCRIPTION OF THE INSPECTION FINDINGS TO BE CORRECTED		
Description of findings:		
Reference document (daily log):		
Action taken:		
Job No.:	Date:	Signature:

ANNEX 3

DRY FILM THICKNESS MEASUREMENTS

- 1 The following verification check points of DFT are to be taken:
- .1 one gauge reading per 5 m^2 of flat surface areas;
 - .2 one gauge reading at 2 to 3 m intervals and as close as possible to tank boundaries, but not further than 15 mm from edges of tank boundaries;
 - .3 longitudinal and transverse stiffener members:

One set of gauge readings as shown below, taken at 2 to 3 m run and not less than two sets between primary support members;

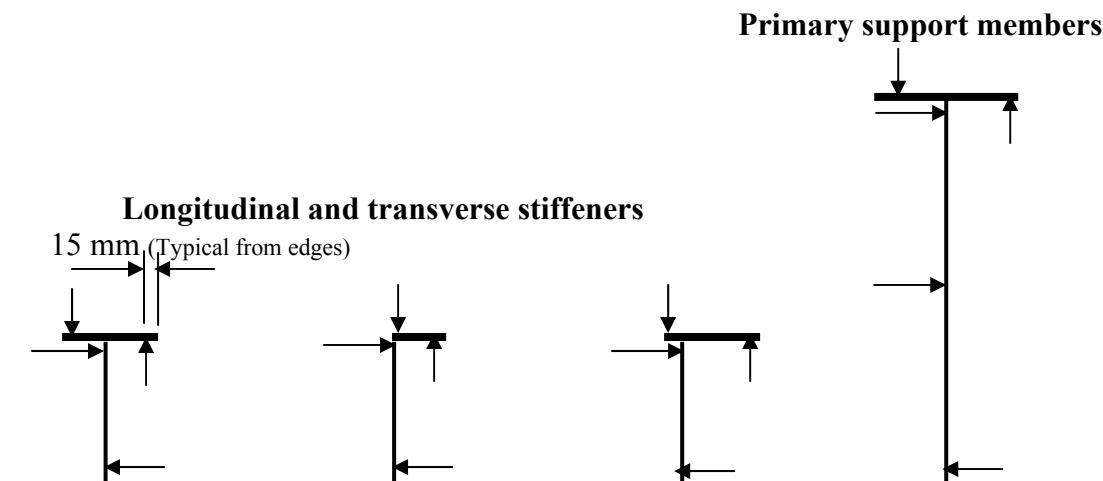


Figure 3

Note: Arrows of diagram indicate critical areas and should be understood to mean indication for both sides.

- .4 3 gauge readings for each set of primary support members and 2 gauge readings for each set of other members as indicated by the arrows in the diagram;
- .5 for primary support members (girders and transverses) one set of gauge readings for 2 to 3 m run as shown in figure 3 above but not less than three sets;
- .6 around openings one gauge reading from each side of the opening;
- .7 five gauge readings per square metre (m^2) but not less than three gauge readings taken at complex areas (i.e., large brackets of primary support members); and
- .8 additional spot checks are to be taken to verify coating thickness for any area considered necessary by the coating inspector.
