



# **FROSIO**

**CERTIFICATION BOOK  
FOR  
SURFACE TREATMENT**

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# About Frosio and Introduction

## Preface

For over 30 years, FROSIO has strived at being a leading certification body of surface treatment and to certify inspectors according to our high quality requirements. Our goal is to contribute to certify best possible inspectors.

Inspectors assure that the surface treatment is according to the specification and contribute to make projects economical, safe and to give long-term corrosion protection. In our effort to continue towards our goal, we have made our FROSIO certification book as a helpful aid for both those to be certified, but also as a reference book for those already certified.

This FROSIO Surface Treatment Book has been developed on the basis of information provided by Jotun.



FROSIO Board  
September 2017

# About Frosio

## Introduction

FROSIO is a member organization established in 1986 by the Norwegian industry to meet a growing demand of qualified and certified personnel on all levels within management, production and inspection of work within corrosion protection and surface treatment. In 2012 FROSIO established a similar system for training and certification of insulation inspectors.

FROSIO acts through formulation of quality requirements for surface treatment and insulation inspectors. FROSIO approval and certification scheme have achieved high international recognition and a FROSIO certified inspector is a specific requirement within different standards and specifications.

Certification is a natural career progression for anyone with a successfully completed apprenticeship or for anyone with long experience in anticorrosion work or insulation work.

Since 2003 FROSIO has been accredited according to ISO 17024. The standard for personnel certification and involves stringent requirements to quality assurance.

### [ISO 17024 certificate](#)

## Objectives

- To elevate the quality level with all aspects of the surface treatment and insulation trades
- To act through formulation of quality requirements and development of education programs for surface treatment and insulation inspectors

## Main tasks

- To prepare and maintain training curriculums for both surface treatment and insulation courses and examinations
- To approve the training bodies
- To conduct examinations
- To assess and approve/reject candidates for certification
- To renew certificates
- To keep records of all certified personnel

## Certification scheme

- Approval and certification of surface treatment inspectors in accordance with FROSIO Scheme - for approval and certification of surface treatment inspectors.

# Requirements for certification

## Introduction

**Certification scheme:** FROSIO Scheme - for approval and certification of surface treatment inspectors.

**Training:** Attend an 80-hours training course, conducted by a FROSIO approved training body

**Knowledge:** Pass theoretical examination

**Skills:** Pass practical examination

**Experience:** Documented relevant experience

## Theoretical examination (4 hours)

### You may bring

- Pencil and/or pen and ruler
- Non-programmable calculator
- Dictionary book (will be checked by the FROSIO representative)

### You may

- Raise your hand to make contact with FROSIO representative
- Relevant questions and answers will be communicated to all candidates
- Have small breaks, one person at a time

### You shall

- Mark all your papers handed out with candidate number only. All papers shall be handed to the FROSIO representative upon completion of the exam
- Sign for handing inn the examination

Maximum score for the theoretical examination is 150 points. To pass you must achieve minimum 100 points (66.6%)

## Practical examination (4 hours)

### What to do

- The candidate starts on the first available station and moves to next station when finished
- Note! Do not move to next station until it is free
- No more than one candidate per station
- No communication with other candidates

### You may

- Raise your hand for contact with the FROSIO representative
- Have short breaks. One at a time.

Maximum score for the practical examination is 48 points. To pass you must obtain minimum 32 points (66.6%)

This is not allowed during any of the examinations

- To communicate with other candidates during the examination (or during lunch break if another group of candidates is alternating examinations on the same day)
- *Bring or use your mobile phone*
- Use programmable aids, e.g. electronic dictionary
- Bring notes or other papers with the intention to cheat

**Breaking these rules may lead to disqualification and you may be asked to leave the room!**

- As a consequence, you will not be able to take an new examination within one year

Relevant experience: Work directly related to

- pre-treatment of metallic surfaces
- application of paint and coatings
- inspection of such work

Experience may be obtained within the fields of Ship building; Marine- and offshore installations; Hydroelectric power plants; Bridges; Industrial plants; Chemical process/industry; Paint and coating industry

Certificate level is based on relevant work experience

The certificates have 3 levels depending on documented experience.

#### **Level I - White certificate**

Candidates who have passed the examination, but do not have any or insufficient relevant work experience. An upgrade to level II or level III has to be done within 5 years of passing the examination.

#### **Level II - Green certificate**

Candidates who have passed the examination, and have minimum 2 years relevant work experience, but none or less than 2 years inspection experience.

#### **Level III - Red certificate**

Those who can document minimum 5 years relevant work experience, where minimum 2 of these years shall be documented inspection experience.

Renewal of Certificate

- The certificate expires after 5 years
- It is the inspectors responsibility to notify the FROSIO Secretariat in due time about renewal
- Renewal can be done directly on your personal page in the web registration system on [www.frosio.no](http://www.frosio.no)
- For level III, minimum 2 years inspection experience must be documented in the 5 year period, preferably by confirmation of employer(s)
- A renewal fee will be required

**FROSIO Secretariat**E-mail: [frosio@frosio.no](mailto:frosio@frosio.no)Web: [www.frosio.no](http://www.frosio.no)

# FROSIO approved training bodies

Approved FROSIO training bodies are listed below. More information and contact details can be found on FROSIO web site [www.frosio.no](http://www.frosio.no).

<b>KIWA Teknologisk Institutt</b>	<a href="#">KIWA TI</a>
<b>Hempel Academy</b>	<a href="mailto:academy@hempel.com">academy@hempel.com</a>
<b>pH VALUE</b>	<a href="mailto:phvalueas@gmail.com">phvalueas@gmail.com</a>
<b>pH VALUE Japan</b>	<a href="mailto:y-yuki@asocentral.co.jp">y-yuki@asocentral.co.jp</a>
<b>Jotun Academy</b>	<a href="mailto:Jotun, stine.floberg@jotun.com">Jotun, stine.floberg@jotun.com</a>
<b>Oceaneering Asset Integrity</b>	<a href="#">Oceaneering</a>
<b>DICCA-University of Genoa</b>	<a href="#">Marina Delucchi</a>
<b>SLV Duisburg</b>	<a href="http://www.slv-duisburg.de">www.slv-duisburg.de</a> , <a href="mailto:czysch@slv-duisburg.de">czysch@slv-duisburg.de</a>
<b>AIMEN Centro Technologico</b>	<a href="mailto:AIMEN;formacion@aimen.es">AIMEN;formacion@aimen.es</a>
<b>Helsinki Metropolia University of Applied Science</b>	<a href="#">Metropolia</a> , <a href="#">Kai Laitinen</a>
<b>Gubkin State University of Oil and Gas</b>	<a href="#">Gubkin</a>
<b>Harvish Technical Services</b>	<a href="http://www.hitschennai.com">www.hitschennai.com</a> , <a href="#">Venkat</a>
<b>PAINT-INSPECTOR.COM</b>	<a href="https://www.frosio-inspector.com/">https://www.frosio-inspector.com/</a> <a href="#">Markéta Součková</a>

# PDF version of FROSIO Surface Treatment Book

Download a PDF version of Frosio Surface Treatment Book.

[SurfaceTreatmentFrosio20.02.2018.pdf](http://www.frosiobook.no/Downloads/SurfaceTreatmentFrosio20.02.2018.pdf)

# Disclaimer and Privacy Policy

## Disclaimer

The user of the app is responsible for, and carries the risk for the correct use of, the content. The user must perform the necessary control, change and adjustment for their use and context. In case of doubt about proper use, we recommend to contact an expert. The training material has been independently developed by Frosio, based on information from Jotun. Frosio is solely responsible and liable for the content of the training material and Jotun cannot not be held liable for any loss or damage whatsoever and howsoever arising in connection with the use of Frosio's material. Sunnsoft Publishing's responsibilities are limited to the technical framework and not the content of the app.

## Privacy Policy

### General

This privacy policy has been compiled to better serve those who are concerned with how their 'Personally Identifiable Information' (PII) is being used online. PII, as described in US privacy law and information security, is information that can be used on its own or with other information to identify, contact, or locate a single person, or to identify an individual in context. Please read our privacy policy carefully to get a clear understanding of how we collect, use, protect or otherwise handle your Personally Identifiable Information in accordance with our website.

### **What personal information do we collect from the people that visit our blog, website or app?**

When ordering or registering on our site, as appropriate, you may be asked to enter your email address or other details to help you with your experience.

### **When do we collect information?**

We collect information from you when you register on our site or enter information on our site.

### **How do we use your information?**

We may use the information we collect from you when you register, make a purchase, sign up for our newsletter, respond to a survey or marketing communication, surf the website, or use certain other site features in the following ways:

- To personalize your experience and to allow us to deliver the type of content and product offerings in which you are most interested.
- To improve our website in order to better serve you.

### **How do we protect your information?**

- We do not use vulnerability scanning and/or scanning to PCI standards.
- We only provide articles and information. We never ask for credit card numbers.
- We use regular Malware Scanning.

Your personal information is contained behind secured networks and is only accessible by a limited number of persons who have special access rights to such systems, and are required to keep the information confidential. In addition, all sensitive/credit information you supply is encrypted via Secure Socket Layer (SSL) technology.

We implement a variety of security measures when a user enters, submits, or accesses their information to maintain the safety of your personal information.

All transactions are processed through a gateway provider and are not stored or processed on our servers.

#### **Do we use 'cookies'?**

Yes. Cookies are small files that a site or its service provider transfers to your computer's hard drive through your Web browser (if you allow) that enables the site's or service provider's systems to recognize your browser and capture and remember certain information. For instance, we use cookies to help us remember and process the items in your shopping cart. They are also used to help us understand your preferences based on previous or current site activity, which enables us to provide you with improved services. We also use cookies to help us compile aggregate data about site traffic and site interaction so that we can offer better site experiences and tools in the future.

#### **We use cookies to:**

Understand and save user's preferences for future visits. You can choose to have your computer warn you each time a cookie is being sent, or you can choose to turn off all cookies. You do this through your browser settings. Since browser is a little different, look at your browser's Help Menu to learn the correct way to modify your cookies.

If you turn cookies off, Some of the features that make your site experience more efficient may not function properly. It won't affect the user's experience that make your site experience more efficient and may not function properly.

#### **Third-party disclosure**

We do not sell, trade, or otherwise transfer to outside parties your Personally Identifiable Information.

#### **Third-party links**

Occasionally, at our discretion, we may include or offer third-party products or services on our website. These third-party sites have separate and independent privacy policies. We therefore have no responsibility or liability for the content and activities of these linked sites. Nonetheless, we seek to protect the integrity of our site and welcome any feedback about these sites.

#### **Google**

Google's advertising requirements can be summed up by Google's Advertising Principles. They are put in place to provide a positive experience for users. <https://support.google.com/adwordspolicy/answer/1316548?hl=en>  
We have not enabled Google AdSense on our site but we may do so in the future.

## **COPPA (Children Online Privacy Protection Act)**

When it comes to the collection of personal information from children under the age of 13 years old, the Children's Online Privacy Protection Act (COPPA) puts parents in control. The Federal Trade Commission, United States' consumer protection agency, enforces the COPPA Rule, which spells out what operators of websites and online services must do to protect children's privacy and safety online.

We do not specifically market to children under the age of 13 years old.

## **Fair Information Practices**

The Fair Information Practices Principles form the backbone of privacy law in the United States and the concepts they include have played a significant role in the development of data protection laws around the globe. Understanding the Fair Information Practice Principles and how they should be implemented is critical to comply with the various privacy laws that protect personal information.

In order to be in line with Fair Information Practices we will take the following responsive action, should a data breach occur:

We will notify you via email

- Within 1 business day We also agree to the Individual Redress Principle which requires that individuals have the right to legally pursue enforceable rights against data collectors and processors who fail to adhere to the law. This principle requires not only that individuals have enforceable rights against data users, but also that individuals have recourse to courts or government agencies to investigate and/or prosecute non-compliance by data processors.

## **CAN SPAM Act**

The CAN-SPAM Act is a law that sets the rules for commercial email, establishes requirements for commercial messages, gives recipients the right to have emails stopped from being sent to them, and spells out tough penalties for violations.

### **We collect your email address in order to:**

To be in accordance with CANSPAM, we agree to the following:

- Not use false or misleading subjects or email addresses.
- Identify the message as an advertisement in some reasonable way.
- Include the physical address of our business or site headquarters.
- Monitor third-party email marketing services for compliance, if one is used.
- Honor opt-out/unsubscribe requests quickly.
- Allow users to unsubscribe by using the link at the bottom of each email. If at any time you would like to unsubscribe from receiving future emails, you can email us at and we will promptly remove you from ALL correspondence.

## **Contacting Us**

If there are any questions regarding this privacy policy, you may contact us using the information below.

[www.qbasepublishing.com](http://www.qbasepublishing.com)

Ovre Tyholmsvei 34  
Arendal, 4836  
Norge  
support@qbasepublishing.com

# The Inspector Role

## Definition and types of inspectors

### **FROSIO's definition of an inspector is:**

*Anyone with responsibility to assure that work is performed according to the specification*

### **A First-Class Professional Inspector will**

- Add value to the contract by positive contributions to a quality outcome
- Be polite and respectful, calm and firm, reliable and honest, and represent employer in a diplomatic way
- Communicate extensively with all parties to a project
- Perform duties in such a way that it contributes to constructive measures to be taken, instead of taking an indifferent (or negative) approach (meaning: seek a solution)
- Whenever circumstances force a compromise to be the only solution, she/he ensures that this is properly authorized, recorded and reported

### **Types of inspectors**

There may be several different reasons for having a surface treatment inspector attached to a project, be it during construction of a new structure or repair / maintenance of an existing structure. Their duties and responsibilities are in most cases determined by who has assigned them to the project (their employer). These are the most common categories of surface treatment inspectors, based on who has employed them:

#### **Quality Controller**

These are typically employed by the yard / contractor carrying out the construction / repair / maintenance work. She/he will check that the work colleagues carry out is in accordance with the specification which the employer has agreed with the customer, so they avoid complaints and stay within the stipulated time and budget. She/he should have the power to stop ongoing work which is not deemed acceptable and must write and keep the necessary quality control records. For coating-related work his title might typically be "Paint Inspector".

#### **Owner's Representative**

The company which will take over a new construction or already owns the object to be repaired and must pay for the work upon completion will usually have a representative present during the work to verify that the quality is as agreed. She/he may not have the official authority to stop ongoing work on new constructions, but if she/he identifies and report items which do not meet the agreed specification, and this is not rectified, the construction company can have serious problems at the time of handing over the structure and being paid. For repair and maintenance projects the Owner's Representative usually is the person in overall charge and can accept and reject the work carried out by the contractors. The owner's representative in charge of coatings will often also deal with other aspects of the work, reflected in the title "Superintendent", although on occasions

they may employ dedicated paint inspectors as well.

### **Technical Service**

As part of a supply contract, the manufacturer (or supplier) may offer to make available a competent person to guide the installation process. The inspector is there to give advice and recommendations, and she/he usually has no official authority to stop, reject or accept the work. The inspector will observe the work and make written reports about the standard of work and prevailing conditions. Both construction company, contractor and Owner will be informed about the findings and recommendations. The reports will contain important information in case of future complaints. Due to their limited authority, coating manufacturers will often give their inspectors the job title "Coating Advisors".

### **Classification / certification inspector**

If a construction needs to be certified by for instance a classification society, this society will send their own inspector to check that the certification criteria are met. She/he may typically focus on structural strength and corrosion protection (and fit for purpose) to ensure that the structure will perform as designed. She/he may only inspect the work at critical points and may not have official power to stop any work, but the possibility of ending up with a structure that cannot be certified is usually enough threat to make all other parties to follow his advice.

### **Independent expert**

An unsatisfactory result may often lead to a complaint and perhaps develop into a claim for compensation and/or rectification. If the involved parties cannot reach a settlement, an outside neutral expert may be invited to give her/his opinion, a "third party inspector". She/he will inspect and test the faulty object, check all available reports and data, perhaps do some research, and use own experience and knowledge to arrive at a conclusion and recommendation. The findings and conclusion may not be binding on the parties, but in situations of arbitration or court cases they may heavily influence the outcome.

## **Duties, roles, responsibilities & tasks**

### **Duties of an inspector**

All surface treatment inspectors are either employed by a company or engaged (appointed) by a client, as indicated above. The inspector's primary duty is to look after his employer's or client's best interests (as long as these are honest, ethical and legal). This usually means to ensure the work and materials conform to the agreed project specification.

### **Definition of an inspector**

Anyone with responsibility to assure that work is performed according to the specification.

### **Roles of an inspector**

For each project, an inspector's specific authority and role shall be defined. Generally, the role is to:

- Observe
- Assess (inspect)/test - what, why and how
- Document/verify - is it in accordance with the specification?
- Report - document facts

## **The inspector's authority / responsibility**

- The inspector shall report non-conformance / deviation from the specification
- Unless he is the owner's representative, he shall not make decisions on behalf of the owner, except when given written authority to do so
- For each project, the authority of the inspector shall be defined in collaboration with his / her contractual partner
- The frequency and the extent of inspection and reporting shall be addressed and agreed at the commencement of the project

## **Inspector's knowledge / tasks / duties**

- Know and understand the project specification, procedures and standards
- Be qualified for the job and work within qualified limits
- Be loyal to requirements
- Theoretical expertise - must acquire knowledge and be updated on developments / newest technology within the field
- Have knowledge of relevant control and test instruments, how they operate, and their limitations
- Write reports
- Handle confidential information correctly

[FROSIO Role of the inspector - ENG Rev02.pdf](#)

## **Ethics**

### **An inspector shall**

- Adhere to ethical guidelines
- Understand cultural differences
- Be dedicated and always quality conscious
- Be responsible and reliable
- Be fair, accurate and correct
- Understand the role and work within own limits of competence and authority
- Provide accurate reporting and documentation
- Refuse any favours or gifts
- Respect confidentiality

See [Frosio-Code-of-Ethics.pdf](#).

## **Inspector's daily work**

- To ensure that the coating specification is met
- To verify the quality of work carried out by the contractor / yard
- To prepare written records for the specified coating work:
  - Approval: meets the specification
  - Not acceptable: non-conformance
  - Punch-list (also called "Snag list"), meaning any incomplete / outstanding issues
- Establish an inspection plan to comply with the coating specification

- Use a daily log book and transfer information into reports as required
- Any changes to the coating specification must be agreed by owner and put in writing and signed
- Maintain contact with the parties as previously agreed

## An inspector needs to know

- All the products that will be used
- All relevant inspection methods and inspection tools (including their calibration)
- Relevant standards
- Relevant Technical Data Sheets, Application Guides and Safety Data Sheets
- Methods used for pre-treatment and paint application
- The equipment used for pre-treatment and application: benefits and limitations

## What needs to be inspected?

- Shop-priming of the steel (if not done by others)
- The steel work (Pre-blasting preparation or steel dressing)
- Cleaning and surface preparation prior to paint application
- Paint mixing and application of coatings
- The applied paint film thickness, visual appearance and cure conditions
- Ambient conditions during all the above stages

## Reporting

Routine reports to be made by the paint inspector:

- Daily reports
- Weekly reports
- Summary and Final reports
- Non-Conformance Reports (NCR):
  - To be signed by the responsible contractor, and brought forward to your employer

# Construction & materials

## Metals for construction

### Introduction

There are many different materials one can use to build structures. The most common are cement-based materials (e.g. concrete), metals (e.g. steel), clay (e.g. bricks), wood, plastics (e.g. PVC), composites (e.g. GRP) and many more.

When an engineer designs a new structure or object, the choice of construction material will be important for a number of reasons. The material's strength-to-weight ratio can for example be crucial when designing an aircraft. The tensile strength of low carbon steel (365 MPa) and of aluminium alloy (310 MPa) may seem reasonably close, but considering that the density of steel (7.87 g/cm<sup>3</sup>) is 2.9 times higher than the density of aluminium (2.70 g/cm<sup>3</sup>), an airplane made of steel would be almost three times as heavy as one made from aluminium.

Typical considerations when selecting a material for construction are:

- Its strength (to carry weight)
- Its flexibility (to handle vibration / movements)
- Its weight (to move / handle the object)
- Its ability to be formed into the required shape
- Its durability (against environmental conditions, e.g. corrosion & weathering)
- Its need for maintenance work
- The cost of the material
- Life Cycle Cost (a combination of many of the above factors)

In this chapter, we will focus on metals used for construction, and in particular:

- Iron and its alloys
- Aluminium and its alloys
- Copper and its alloys
- Zinc
- Titanium

### Iron & Steel

#### General

Iron in its various forms is a very common material on Earth. Pure iron (Fe) is not suitable for constructions, but mixed with carbon it forms steel, which is the second most used construction material in the world (after concrete).

All steel is composed of iron and carbon. It is the amount of carbon, and the additional alloys that determine the properties of each grade. While iron alloyed with carbon is called carbon steel, alloy steel is steel to which other alloying elements have been intentionally added to modify the characteristics of steel. Common alloying

elements include: manganese, nickel, chromium, molybdenum, boron, titanium, vanadium, tungsten, cobalt, and niobium.

According to the American Iron & Steel Institute (AISI), Steel can be categorized into four basic groups based on the chemical compositions:

- Carbon Steel
- Alloy Steel
- Stainless Steel
- Tool Steel

There are many different grades of steel that encompass varied properties. These properties can be physical, chemical and environmental.

## **A. Carbon Steel**

Carbon Steel has a carbon content of up to 2%. The carbon content will influence the properties of the steel, such as:

- Hardness
- Flexibility
- Brittleness
- Welding suitability

Steel can be categorized by its carbon content into four main categories:

- Low less than 0,3% carbon, called **mild steel**
- Medium 0,3 – 0,6% carbon, **increased hardness**
- High 0,6 – 0,99% carbon, **difficult to weld**
- Ultra-high 1 – 2% carbon, **for tools, springs, etc.**

Corrosion resistance will be increased as the carbon content increases. Once the carbon content is more than 2% and less than 4%, the steel is called **cast iron**.

### *Low Carbon Steel (Mild Steel)*

Typically contain 0.04% to 0.30% carbon content. This is one of the largest groups of Carbon Steel. It covers a great diversity of shapes; from Flat Sheet to Structural Beam. Depending on the desired properties needed, other elements are added or increased. For example: Drawing Quality (DQ) – The carbon level is kept low and Aluminium is added, and for Structural Steel the carbon level is higher and the manganese content is increased.

### *Medium Carbon Steel*

Typically has a carbon range of 0.31% to 0.60%, and a manganese content ranging from .060% to 1.65%. This product is stronger than low carbon steel, and it is more difficult to form, weld and cut. Medium carbon steels are quite often hardened and tempered using heat treatment.

### *High & Ultra High Carbon Steel*

Commonly known as “carbon tool steel” it typically has a carbon range between 0.61% and 2%. High carbon

steel is very difficult to cut, bend and weld. Once heat treated it becomes extremely hard and brittle.

## B. Alloy Steel

Alloy steel is steel that has had small amounts of one or more alloying elements (other than carbon) such as manganese, silicon, nickel, titanium, copper, chromium and aluminium added. This produces specific properties that are not found in regular carbon steel. Alloy steels are workhorses of industry because of their economic cost, wide availability, ease of processing, and good mechanical properties. Alloy steels are generally more responsive to heat and mechanical treatments than carbon steels.

### *Low alloy Steels*

Iron with less than 0.25% carbon (often below 0.15%), with alloying elements totalling only 2 – 3%. Typical alloy elements include:

- **Carbon** significantly increases mechanical strength
- **Nickel** increases ductility and toughness, it also reduces the corrosion rate
- **Chromium** gives stainless steels their basic corrosion resistance
- **Molybdenum** significantly increases the resistance to both uniform and localized corrosion. It increases the hardness at higher temperatures
- **Manganese** is generally used to improve the metals ability to be formed when hot
- **Silicone** increases resistance to corrosion and increases strength

The corrosion resistance of carbon steel and low alloy steel is more or less the same. They are used to construct objects such as ship's hulls, buildings, bridges, cars, etc.

### *Weathering steels*

Weathering steel, best-known under the trademark COR-TEN steel (sometimes written without the hyphen as corten steel), is a group of steel alloys which were developed to eliminate the need for painting, and form a stable rust-like appearance if exposed to the weather for several years.

It exhibits increased resistance to atmospheric corrosion when compared to unalloyed steels by forming a firmly adhering protective rust-coloured oxide layer, or patina, on its surface, as can be seen on certain buildings.

Cor-Ten steel is traditionally used in the construction of shipping containers, although usually overcoated by special container paint.

Weathering steel is a special type of low alloy steel:

- Better resistance against atmospheric corrosion than ordinary structural steels
- A result of having been alloyed with slightly higher amounts of chromium, phosphorus and copper
- Will corrode during an initial period of 1,5 – 4 years, like carbon steel
- Will form a dense and dark surface layer (rust coat) called "**PATINA**", which protect material and provide decorative effects
- When used on building facades it is usually not painted and left with its patina, but unforeseen changes in the climatic conditions may cause unexpected severe corrosion

## High alloy Steels

Mostly called stainless steel, with alloying elements totalling 15 – 30%

- **Stainless steel** is defined as a steel alloy with a minimum **11% chromium content by weight**
- Steel is alloyed primarily with **Chromium and Nickel**
- **Molybdenum** may be added for increased corrosion resistance
- A thin protective **chromium-oxide film** is formed on the surface of the metal, preventing rust from appearing
- Stainless steels are **not** immune to **corrosion**, the protective oxide layer may be damaged or attacked by chlorides, the environment, lack of oxygen and other influences which may lead to extensive corrosion / pitting

There are many different stainless steel qualities and naming systems in use globally based on various published standards, such as EN-standard and AISI / ASTM standards. Examples:

- ASTM 304 (18-20% Cr, 8-10,5% Ni) - *plain*
- ASTM 316 (16 – 18,5% Cr, 10 - 14% Ni, 2 -3% Mo) – *more seawater resistant*
- ASTM S31254 (19,5-20,5% Cr, 17,5-18,5 Ni, 6 -6,5% Mo) – *even more seawater resistant*

## Steel production

Modern steelmaking can be broken down into six steps:

1. *Iron-making*: In the first step, the raw materials iron ore, coke and lime are melted in a blast furnace. The resulting molten iron - also referred to as 'hot metal' - still contains 4-4.5% carbon and other impurities that make it brittle.
2. *Primary Steelmaking*: Primary steelmaking methods differ between BOS (basic oxygen steelmaking) and EAF (electric arc furnaces) methods.
  - EAF methods feed recycled steel scrap through high power electric arcs (temperatures up to 1650 °C) to melt the metal and convert it to high-quality steel.
  - BOS methods add recycled scrap steel to the molten iron in a converter. At high temperatures, oxygen is blown through the metal, which reduces the carbon content to between 0 - 1.5%.
3. *Secondary Steelmaking*: Secondary steelmaking involves treating the molten steel produced from both BOS and EAF routes to adjust the steel composition. This is done by adding or removing certain elements and/or manipulating the temperature and production environment. Depending on the types of steel required, the following secondary steelmaking processes can be used:
  - stirring
  - ladle furnace
  - ladle injection
  - degassing
  - CAS-OB (Composition Adjustment by Sealed argon bubbling with Oxygen Blowing)
4. *Continuous Casting*: In this step, the molten steel is cast into a cooled mould causing a thin steel shell to solidify. The shell strand is withdrawn using guided rolls and fully cooled and solidified. The strand is cut into desired lengths depending on application; slabs for flat products (plate and strip), blooms for sections (beams), billets for long products (wires) or thin strips.
5. *Primary Forming*: The steel that is cast is then formed into various shapes, often by hot rolling, a process that eliminates cast defects and achieves the required shape and surface quality.

6. *Manufacturing, Fabrication, and Finishing*: Finally, secondary forming techniques give the steel its final shape and properties. These techniques include:

- shaping (e.g. cold rolling)
- machining (e.g. drilling)
- joining (e.g. welding)
- coating (e.g. galvanizing)
- heat treatment (e.g. tempering)
- surface treatment (e.g. carburizing)

## **Steel rolling**

Rolling is a metal forming process in which metal stock is passed through pairs of rollers in order to re-crystallize, and modify, strengthen or to form an expected shape and thickness

- Hot rolling is rolling that occurs above the re-crystallization temperature of the material (usually above 600°C)
- Cold rolling occurs with the metal is below its re-crystallization temperature (usually at room temperature)

### **Hot Rolling**

- The hot cast steel is forced between rollers under high pressure and thereby given new shapes and dimensions
- By using combinations of multiple rollers in different configurations, hot rolled products are formed into flat products (steel plates), long products, seamless tubes, various profiles (H-beam, I-beam, L-shape, etc.) and specialty products.
- During hot rolling, a special form of iron oxide is formed on the surface of the steel, called Mill Scale
- Mill Scale is cathodic to the base metal (steel)
- Mill scale is bluish-black in colour and forms initially a barrier to corrosion of the steel
- Mill scale is brittle and will eventually crack and flake off, meaning the steel is no longer protected and will suffer from accelerated corrosion due to the remaining noble mill scale fragments

### **Cold Rolling**

- Cold rolled steel does not have mill scale
- Cold rolled steel is thinner than hot rolled steel (usually below 4 mm) and has better strength

## **Aluminium and its alloys**

- Aluminium (Al) is a silvery-white, soft, nonmagnetic, ductile metal. Aluminium is the third most abundant element in the Earth's crust (after oxygen and silicon) and is its most abundant metal.
- Aluminium metal is so chemically reactive that pure metal is very rare to find in the nature. Instead, it is found combined in over 270 different minerals. The chief ore of aluminium is bauxite.
- Aluminium is remarkable for its low density and its ability to resist corrosion through the phenomenon of passivation. Aluminium and its alloys are vital to the aerospace industry and important in transportation and structures, such as building facades and window frames
- Light-weight metal with silver colour
- Typically alloyed with copper, magnesium, manganese, silicon, and zinc
- Active metal, but passive oxide film (0,01 µm) hinders corrosion
- Aluminium alloys are widely used in engineering structures and components where light weight or

corrosion resistance is required

- Aluminium can corrode when the protective oxide layer is damaged by impact, abrasion or chemical attack

## Copper & Alloys

Copper and all its common alloys have good corrosion resistance.

### Copper

Pure copper (Cu) is a reddish-brown metal. It is soft, has good electrical conductivity and ductility.

#### *Typical use*

- Plumbing
- Heat exchangers
- Process equipment
- Roofing
- Electrical wires

#### *Patina on copper*

The surface film which forms on copper during atmospheric exposure contains basic salts and is quite protective. The film has a pleasant green colour and is used for architectural applications, such as decorative details and on roof, gutters and downpipes on prominent buildings.

### Bronze

Bronze is an alloy consisting primarily of **copper**, commonly with about 12% **tin** and often with the addition of other metals (such as aluminium, manganese, nickel or zinc) and sometimes non-metals or metalloids such as arsenic, phosphorus or silicon. These additions produce a range of alloys that may be harder than copper alone, or have other useful properties, such as stiffness, ductility or machinability. **Lead** and **nickel** may be added to achieve different properties.

Other elements such as **phosphorus, aluminium, manganese, and silicon** can be used to alloy with copper, and are also characterised as "bronze" (Nickel bronze, Aluminium bronze, etc.)

The archaeological period where bronze was the hardest metal in widespread use is known as the Bronze Age.

#### *Typical use*

- Engineering parts, such as:
  - Ships' propellers
  - Boat and ship fittings
  - Springs, bearings, bushings, automobile transmission pilot bearings
- Bells (church & ships bells)
- Sculptures / statues
- Ornaments

## Brass

It is an alloy of **copper** and **zinc**, where the zinc content may vary from about 5 to 45%

### **Typical use**

- Brass is used for decoration for its bright gold-like appearance;
- for applications where low friction is required such as locks, gears, bearings, doorknobs, ammunition casings and valves
- for plumbing and electrical applications
- Used extensively in brass musical instruments such as horns and bells where a combination of high workability (historically with hand tools) and durability is desired.
- It is also used in zippers.
- Brass is often used in situations in which it is important that sparks not be struck, such as in fittings and tools used near flammable or explosive materials.
- Coins (most copper coins are actually brass)
- Medals

## Zinc

Zinc is the fourth most common metal in use, trailing only iron, aluminium, and copper. Zinc is a bluish-white, lustrous metal, though most common commercial grades of the metal have a dull finish. The metal is hard and brittle at most temperatures. Zinc is a fair conductor of electricity and has relatively low melting (419.5 °C) and boiling points (907 °C).

It is a moderately reactive metal. The surface of the pure metal tarnishes quickly, eventually forming a protective passivating layer of basic zinc carbonate, by reaction with atmospheric carbon dioxide. This layer helps prevent further reaction with air and water.

Apart from Zinc sheet metal used as roofing and cladding material on buildings, Zinc is not much used as a construction material. The main consumption of zinc within construction industry is used for galvanizing steel.

Galvanizing is the process of applying a protective zinc coating to steel or iron, to prevent corrosion. The most common method is hot-dip galvanizing, in which parts are submerged in a bath of molten zinc. Galvanizing protects in three ways:

- It forms a coating of zinc which, when intact, prevents corrosive substances from reaching the underlying steel or iron.
- The zinc serves as a sacrificial anode so that even if the coating is scratched, the exposed steel will still be protected by the remaining zinc.
- The zinc protects its base metal by corroding before iron.
- For better results, application of chromates over zinc is also seen as an industrial trend.
- Not typically used in Marine Immersion / Splash Zones
- Good corrosion resistance (~50 -100 years inland)

## Titanium

Titanium (Ti) is a lustrous transition metal with a silver colour, low density and high strength. It is highly

resistant to corrosion.

## Properties

- Low density
- Strong
- Metallic sheen
- Corrosion-resistant to sea water, aqua regia (a mixture of nitric acid and hydrochloric acid) and chlorine
- Noble metal, with good passive film to prevent corrosion
- Used in aggressive environments

Because of their high tensile strength to density ratio, high corrosion resistance, fatigue resistance, high crack resistance, and ability to withstand moderately high temperatures without creeping, titanium alloys are used in:

- About two thirds of all titanium metal produced is used in aircraft engines and frames
- Armour plating, naval ships, spacecraft, and missiles
- When alloyed with aluminium, zirconium, nickel, vanadium, and other elements: critical structural parts, fire walls, landing gear, exhaust ducts (helicopters), and hydraulic systems
- In the chemical and petrochemical industries: welded titanium pipe and process equipment (heat exchangers, tanks, process vessels, valves), used primarily for corrosion resistance
- Automotive applications, particularly in automobile and motorcycle racing where low weight and high strength and rigidity are critical
- Sporting goods: tennis rackets, golf clubs, lacrosse stick shafts; cricket, hockey, lacrosse, football helmet grills, and bicycle frames and components
- Jewellery (rings, necklaces, bracelets, etc.)
- Many medical uses, including surgical implements and implants, such as hip balls and sockets (joint replacement) and dental implants

# Concrete

## Composition of concrete

Concrete is a composite material composed of coarse aggregates bonded together with fluid cement which hardens over time. The aggregates are mixed together with the dry cement and water, which form a fluid mass that is easily moulded into shape. The cement reacts chemically with the water and other ingredients to form a hard matrix which binds all the materials together into a durable stone-like material that has many uses.

### Concrete is a mixture of:

#### Cement

- This is the binder in the mixture. It is made from limestone and looks like a grey powder.
- There are a few different types of cement, the one commonly used in concrete is called "Portland Cement".
- It sets and becomes adhesive due to a chemical reaction between the dry ingredients and water. The chemical reaction results in mineral hydrates that are not very water-soluble and so are quite durable in water and safe from chemical attack. This allows setting in wet condition or underwater and further protects the hardened material from chemical attack.

## **Sand**

- Small size hard particles. Size from 0,07 to 5 mm
- Must be free from salt and other impurities

## **Aggregates**

- Big sized hard particles, like pebbles and gravel, from app 5 up to 40 mm, irregular in shape.
- Sand will fill in the voids in-between the aggregates

## **Water**

- Clean, free from salt and organic material

## **Additives**

- Speed up or slow down the curing
- Enable use in cold climates
- Makes the concrete more flexible

# Properties of concrete

## **Typical Properties of Concrete**

### **Benefits**

- High compression strength
- High resistance to water and humidity
- High temperature resistance
- Good impact resistance
- Good non-skid properties

### **Limitations**

- Low elasticity
- Low tensile strength
- Dusty
- May be difficult to keep clean
- Appearance

## **Tensile- and Compressive Strength**

- The compressive strength is good (e.g. columns)
- The Tensile strength is poor (e.g. beams)
- Steel reinforcement bars are necessary for load bearing structures

## **Concrete for construction is never used alone**

Concrete is almost always used together with steel reinforcement bars, more commonly known as rebars. Rebars improves the tensile strength of the structure.

- Rebars are bent and shaped and placed inside the structure mould before the concrete is poured.
- The size and amount of rebars, as well as their placing within the structure is calculated and determined by structural engineers.

## **Concrete is used as a construction material for:**

- Dwelling and commercial buildings
- Public and governmental projects
- Industrial and production facilities
- Water treatment plants
- Offshore installations
- Bridges and highways

- Leisure facilities
- Infrastructure
- Power plants
- Mining
- Etc.

## **Curing of concrete**

After pouring, the concrete must be left in the mould until it has set and become strong enough to carry its own weight.

### *Typical curing time*

- Approximately 30 days at room temperature
- The mould (form) can be removed after 2 days
- Concrete needs moisture during this curing period, so contractor has to provide measures to keep the concrete humid during the curing process
- If allowed to become dry before the estimated full curing time, the curing reaction is stopped permanently

### *Drying time*

- After the full curing, the concrete needs to get through dry. This can take months

## **Testing concrete**

During pouring of important structures, small separate cubes are also poured from the concrete mixture going into the structure.

- Cubes are crushed after 3, 7 and 28 days to measure the compressive strength of the concrete used in the structure
- Concrete compressive strength is generally based on the 28 days' test results. There is a correlation between time and strength:
  - 3 days: 16 N/mm<sup>2</sup>
  - 7 days: 24 N/mm<sup>2</sup>
  - Full cure after 28 days: 30 N/mm<sup>2</sup>

The testing and correlation factor ensures early warning of potentially low strength concrete

## **Concrete quality**

Factors influencing the concrete quality:

- High water content:
  - Gives less compression strength, more porosity, separation
- Low cement content:
  - Less compression strength
- Poor quality sand:
  - Less compression strength
- Poor quality aggregates:
  - Less compression strength

# Concrete corrosion

## Concrete deterioration

Concrete can fail and require repair for many reasons:

- Honeycombing
- Spalling
- Stress cracking (makes access for water and chemicals)
- Shrinkage cracking (makes access for water and chemicals)
- Rebar corrosion
- Erosion
- Impact/abrasion damage (from tires with steel spikes)
- Chemical attack

## High pH of a new fresh concrete

- A bi-product of the curing reaction is Calcium Hydroxide
- Calcium Hydroxide is water soluble and gives very high pH
- As freshly made concrete contain lots of water, the pH in new concrete will be high
- The pH of new / fresh concrete is in the range of 12 - 14
- Steel will not corrode in an a highly alkaline environment, which is why sound concrete protects its own reinforcement bars so well

## What do we mean by concrete corrosion?

Concrete can corrode (deteriorate) like any other type of material

- Mechanism:
  - A change in the chemistry
  - The pH value drops from 12 to 8
  - At this pH the rebars are no longer protected against corrosion
- For submerged conditions in salt water:
  - Aggressive chlorides will increase the corrosion of the rebars

## How rebars are damaged

1. Carbonisation: Carbon dioxide (CO<sub>2</sub>) from the air reacts with Calcium Hydroxide in the concrete, forming Calcium Carbonate
2. pH decreases, the pH will become lower, leading to an increased danger of rebar corrosion
3. Corrosion starts, Sulphur dioxide (SO<sub>2</sub>) from the air will react and convert Calcium Carbonate to gypsum, which is water soluble. This increases the possibilities for further Carbonising
4. The corrosion products are very voluminous. When steel corrodes, its volume increases 4 to 6 times
5. An enormous pressure will be exerted to the surroundings by the corroding rebars
6. The concrete will crack, loosen and fall off

Reinforcing steel (rebars) need to have an adequate covering of concrete:

- Minimum 50 mm for flooring
- Minimum 35 mm for vertical surfaces

# Repairing concrete

## Concrete repair

1. Chip away the damaged concrete (not allowed in some countries)
2. Remove carbonated concrete (test pH with indicator paper strips)
3. Shape the repair area and renew rebar if necessary
4. Preparing the rebar by blast cleaning or other means
5. Add corrosion protection to the rebars (e.g. alkali-resistant anti-corrosive paint, like epoxy primer)
6. Fill in the repair area with new concrete
7. Apply Carbonation-inhibitive paint

# Surface preparation & painting

## Why painting concrete?

- Protect structures against atmospheric impact (CO<sub>2</sub> / SO<sub>2</sub> / pollution)
- Protect concrete against exposure to chemicals (spillage, bund walls, warehouses, garages, etc.)
- Protect concrete subjected to mechanical stresses, such as traffic, high loads, impact and abrasion
- Waterproofing
- Cosmetic

## When can we paint the concrete?

- With physically drying and 2-pack paint systems, the concrete should have below 7% moisture content. For flooring lower than 4%
- The moisture can be measured by using a concrete moisture meter
- A simple test for concrete floors is to take a square piece of clear plastic sheet and tape this thoroughly around the edges to the floor. Leave it in place until the next day and observe whether any moisture has accumulated as condensation under the clear plastic sheet. If paint had been applied, that moisture would accumulate under the paint film and would cause paint failure.
- Remember to determine the relevant climate, with winter conditions we have to be very careful when painting outdoor, due to possibility of freezing temperatures

## Concrete - surface preparation before painting

- The surface preparation is a critical factor to achieve a long lasting performance
- The pre-treatment is often even more important than the application of paint
- Always start the pre-treatment procedure by removing loose contaminants
- Apply a penetrating primer coat, essential for a good result!

## Concrete floors - Laitance

- Laitance is a major cause of failure in floor painting. It consists of a weak, friable layer on the surface of concrete which appears after curing.
- It is made from cement and fine aggregates that rise to the surface when too much water is added. It may also be due to rain damage during placing, or from power floating or over trowelling. Subsequent poor curing of the surface will also contribute towards the formation of laitance.
- Surface preparation is the most important step of painting a concrete floor. Removing surface contaminants, such as laitance, is therefore vital to a long- term successful installation.
- Laitance is always present on new concrete and must be removed. However, surface laitance is not to be confused with a poor quality concrete or screed that needs addressing in other ways.

- Laitance comes in varying degrees of thickness, from a fine dust to several millimetres or more, depending on contributing factors.
- If laitance is left untreated, the application of subsequent materials, (such as paint), will have a high risk of failing.
- Removing any existing laitance is vital to ensure that subsequent treatments can successfully adhere to the concrete substrate. There are several ways to remove laitance and the method chosen should depend on the working environment and purpose of the floor.
  - Shot blasting is the fastest and most efficient form of laitance removal, especially for large areas. Shot blasting machines are available in varying sizes and with vacuum attachments, making them ideal for use on most surfaces, no matter the size. Using a shot blaster will allow up to 1000sq m of flooring to be prepared in just one day and, as shot blasting is a dry process, work may continue in other areas of the room while the surface preparation process is taking place.
  - Using a mechanical planer is often used to remove greater thicknesses of laitance. Also referred to as concrete planing, the machines carry rows of rotating cutters tipped with tungsten to provide an excellent removal of laitance.
  - Scrubbing, grinding and abrading are also recommended for removing laitance. Handheld grinding machines, designed for precision, control and safe operation are recommended for use in smaller areas and edge detail.
  - Low Pressure Water Cleaning (LPWC): <34 MPa (340 bar/5000 p.s.i.) can work well to remove laitance and it makes imperfections in the surface visible. No dust is produced, but the floor needs to dry before paint application can start

Unless it has been removed by previous surface preparation techniques, laitance may still be present on old concrete floors.

# Corrosion

## Corrosion theory, types & protection

### Corrosion theory

When we think of corrosion, we often associate this with a material (usually a metal) which is damaged or degraded when exposed to the weather (or to water). A more precise definition of corrosion could be:

*Corrosion is an electrochemical reaction between a Metal and its Surrounding Environment under the formation of corrosion products.*

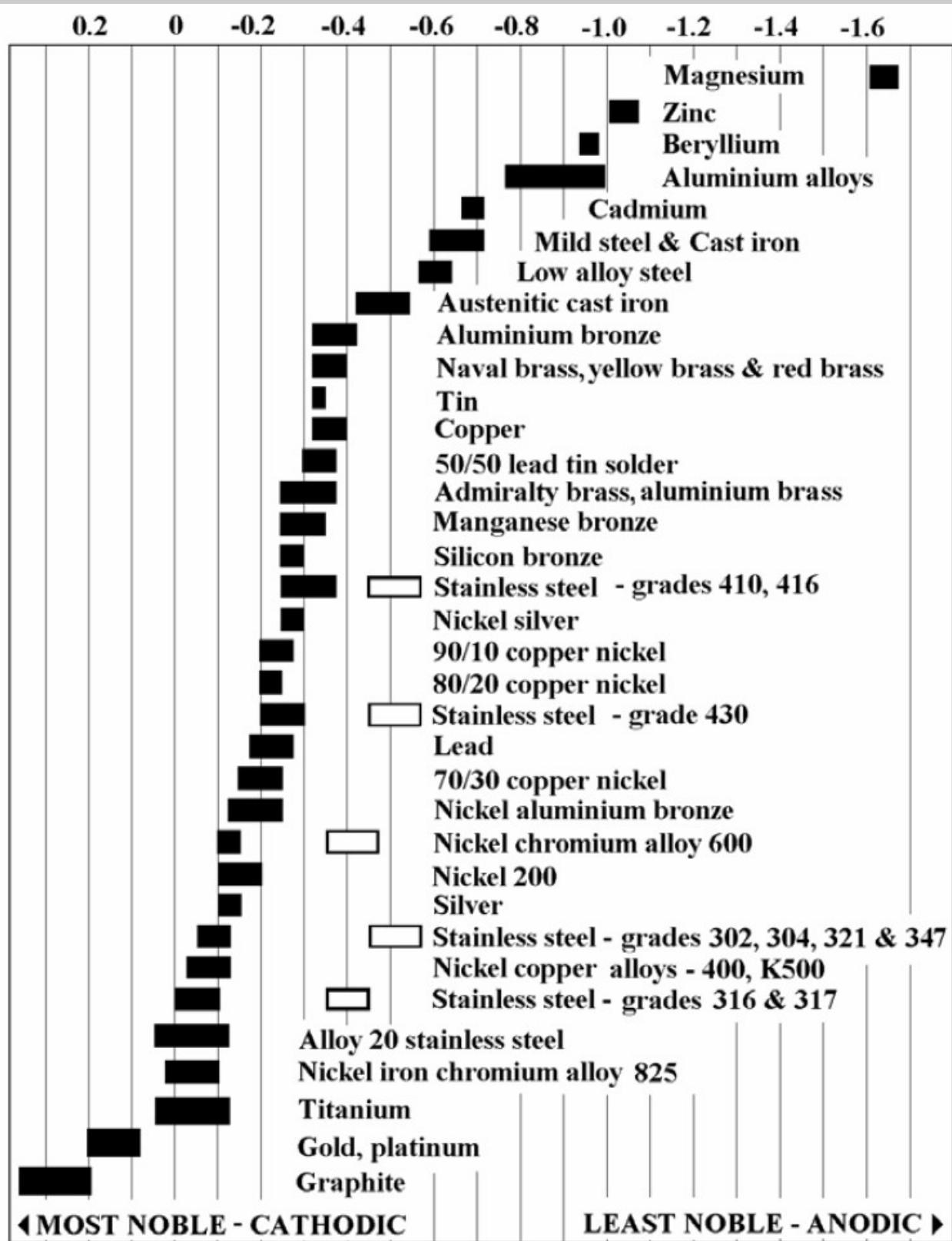
In order to understand why this takes place, we must look a bit closer into the chemistry of metals. Different metals may behave differently, but they all follow the same principles or "Laws of Nature", as we may call these. As the most commonly used metal, we will use iron as an example in the following illustrations, but the same principles apply to all metals.

Iron can exist in many different forms, such as pure metallic iron, iron oxide (rust), iron sulphide, iron carbonate, iron chloride, etc. If iron shall change from one form to another, this will in some cases require use of energy and in other cases release of energy. Iron will always strive to be in the form with the lowest energy level, which is iron oxide (this is a law of nature). This is why almost all naturally occurring iron found in nature is in the form of iron ore, which is basically iron oxide. It is near impossible to find a piece of metallic iron in the landscape. When we convert iron ore to metallic iron we must use a lot of heat and therefore energy (furnace in iron works). Metallic iron will always strive to get rid of this extra energy by converting back to iron oxide (rust), and this can be seen when steel is corroding. So when we are fighting corrosion we are actually fighting one of the laws of nature. We can never eliminate or defeat a law of nature. We can try to neutralise its effect or block its consequences, but the moment our defence is weakened or damaged, corrosion will immediately start up again. This is why even a tiny pinhole in an otherwise perfect protective coating is enough for corrosion to take place.

We take advantage of the law about release of energy when a metal changes form (corrodes) when we make batteries used in torches and pocket lamps and all other portable electrical devices. Batteries typically contain two metals with different electro-potential and an electrolyte (water that can conduct electricity). When one of the metals starts to corrode inside the battery, it will release energy in the form of ions which will move through the electrolyte to the other metal. The result is that a surplus of electrons will accumulate on the non-corroding metal. If these two metals are connected via an external connection, electrons will flow through that connection and we have electricity which can be used to light a torch.

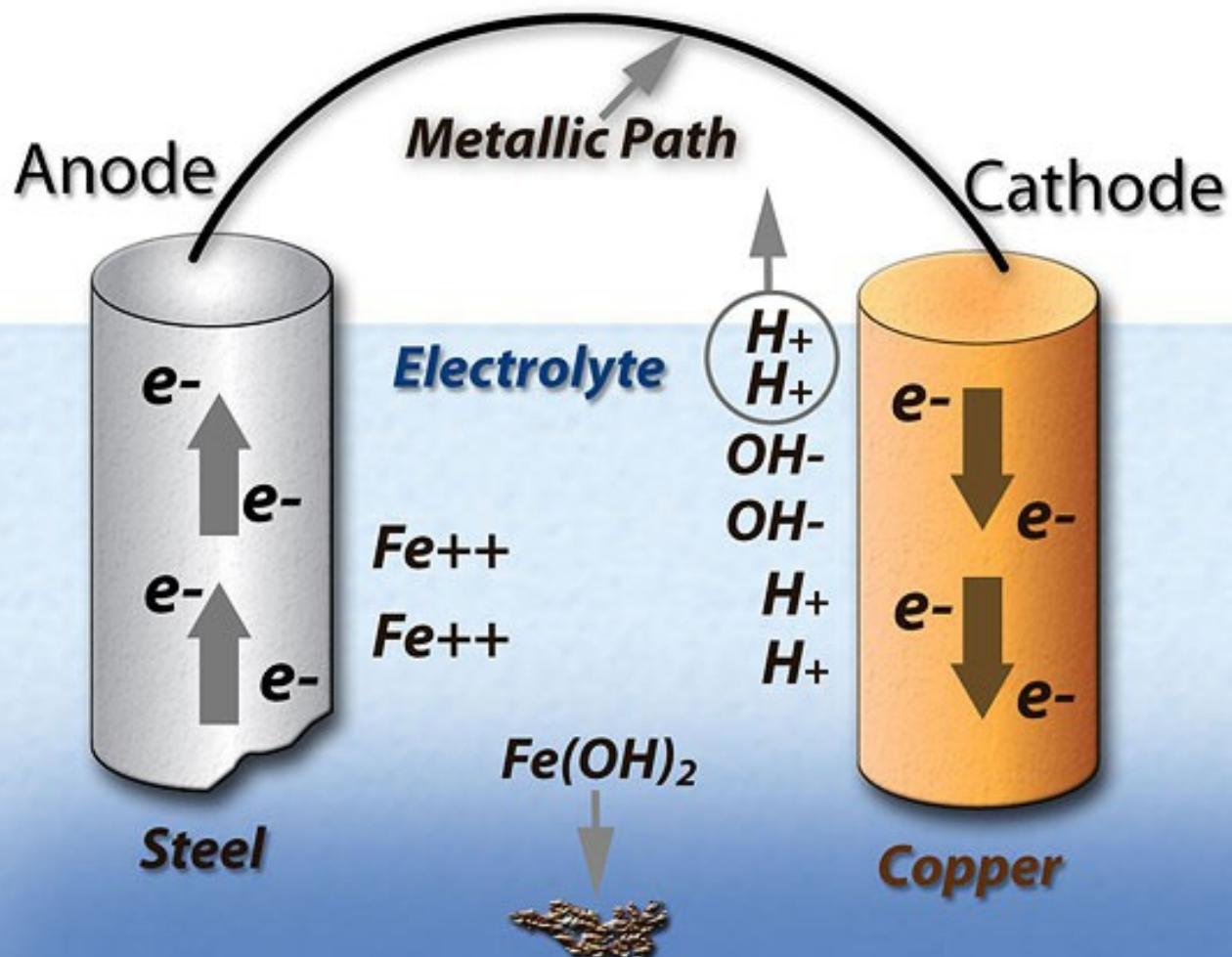
Some metals corrode more willingly and faster than others. Metals which corrode very little are often called noble metals, such as gold and silver, while metals which corrode very easily are less noble. We can rank different metals in accordance with how noble they are, as shown in a galvanic series table (or electro-potential series). The further away from each other the two metals in a battery are in the galvanic table, the "stronger" the battery will be (greater voltage). If two different metals are used in the same structure, we can tell which one will corrode by looking at the galvanic table (the less noble will corrode).

## Galvanic Series



The noble metal in a battery is called the cathode and the less noble metal is called the anode. The anode will slowly dissolve into ions (corrode), while the cathode will be protected from dissolving. When old used batteries start leaking, this is caused by the anode being perforated through corrosion and the electrolyte is escaping.

# The Basic Corrosion Cell



The driving force behind corrosion is the same law of nature that creates electricity in a battery. Whenever we have a corrosion cell we will also have a cathode, an anode and an electrolyte. The anode and cathode may be two different metals in direct contact with each other (bi-metallic corrosion) or two different areas on the same piece of metal, but with slightly different electrochemical potential due to for example impurities or crystalline structure. The electrolyte may be seawater or rain water or simply moisture in the air. This driving force is influenced by a number of factors, such as:

#### Difference in electro-potential between anode and cathode

The greater electro-potential difference, the greater corrosion (greater driving force).

#### Difference in size between anode and cathode

A smaller anode area will corrode more quickly when connected to a larger cathode area, while a larger anode area will corrode more slowly when connected to a smaller cathode.

## Conductivity of electrolyte

Conductivity of the electrolyte relies on the concentration of ions. Sea water has a higher concentration of ions than tap water, which is why corrosion is more rapid in seawater than fresh water.

## Temperature

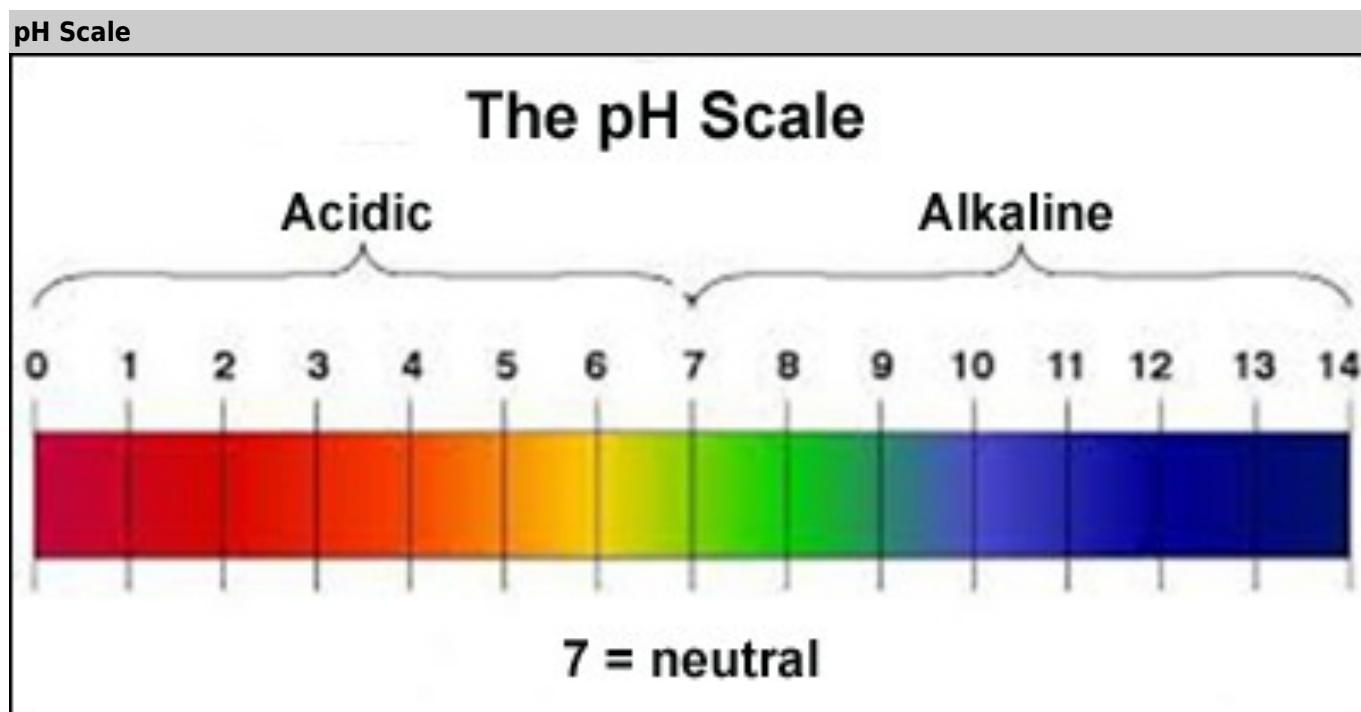
Corrosion is an electro-chemical reaction. As for all chemical reactions, they will go faster at higher temperatures and slower at lower temperatures.

## Conductivity of the external connection

The electrical resistance of some materials makes it difficult for electron flow in the material. The opposite term is electrical conductivity. A material with high electrical resistance can be used to separate dissimilar metals and thereby minimise corrosion. Highly electrical resistant materials such as rubber or PVC are often used as isolation materials.

## pH in the environment

Different metals react differently to the pH in their close environment. Corrosion of steel increases in acidic solutions, while strong alkaline solutions prevent corrosion (passivity). Zinc and Aluminium will show slow corrosion in near neutral solutions, but heavy corrosion in acidic and alkaline solutions.



## Humidity

Atmospheric corrosion is clearly influenced by the relative humidity, typically increasing above and slowing down below 60% RH. In practice, little or no corrosion takes place at RH less than 50%.

## Pollution

Air and water pollution may provide aggressive ions which may accelerate corrosion (including acid rain, soot

and dust particles).

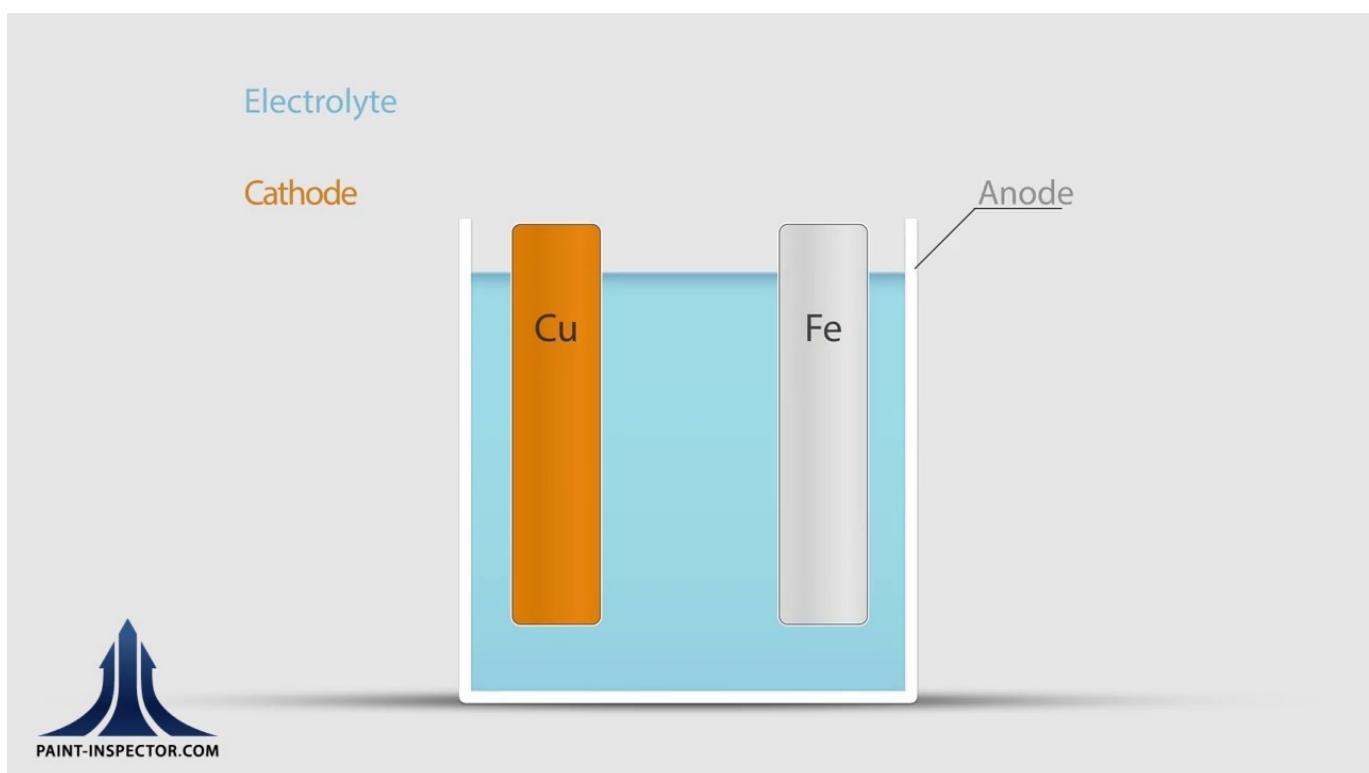
## Passivity

Some metals corrode slowly due to a passive film of oxide forming on their surface, reducing or preventing further corrosion to take place. Examples: Aluminium, Stainless steel and Titanium. However, these passive films may be destroyed by aggressive species in the electrolyte or by mechanical damages, so corrosion may still take place.

## Stress

Stress caused by various factors, such as mechanical, chemical or temperature variations may cause stress corrosion cracking.

## Corrosion mechanism:



## Corrosion types

### General corrosion

General corrosion is uniform by nature and results in a relatively uniform loss of steel thickness. Typically occurs on a piece of steel which may not be in contact with any other metal. Small anodic and cathodic spots are formed on the steel due to slight differences in salt level, oxygen content and steel microstructure (crystalline structure). Can be found both in submerged and atmospheric conditions. Risky if untreated, but less risky than other types of corrosion.

## General corrosion



## Steel with mill scale

Mill scale is more noble than carbon steel and will act as a cathode, making the carbon steel an anode. As long as the mill scale is intact it will protect the steel from corrosion (like a metallic coating). However, the mill scale is brittle and will during exposure crack, allowing water and dissolved salts to penetrate to the carbon steel. Heavy corrosion will develop on the steel, since this is anodic to the mill scale. Rust and mill scale must always be removed prior to paint application. Mill scale is most effectively removed by blast-cleaning.

## Pitting corrosion

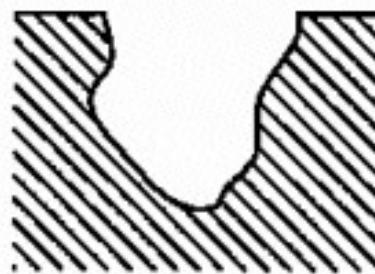
This typically takes place on metals with a natural protective film, such as carbon steel with mill scale, and aluminium, stainless steels and titanium with passivating oxide films. If these protective films have weak points or are damaged by mechanical or chemical exposure (e.g. chlorides), concentrated corrosion will occur on such spots. This can lead to perforation of the metal in a short time.

In pitting corrosion the metal at the top of the pit has access to the oxygen in the air and becomes the cathode. At the bottom of the pit oxygen is depleted and the metal becomes the anode. The deeper the pit is the less the oxygen available at the bottom and the corrosion rate increases. Pitting corrosion can be a very serious form of corrosion since its early stages may easily be overlooked, but may quickly penetrate the metal and cause leakage in for example pipes and tanks.

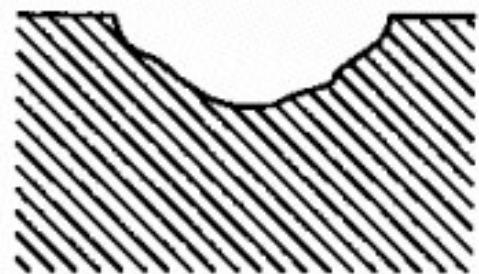
### Examples of shapes from ASTM G-46



Narrow, Deep



Elliptical



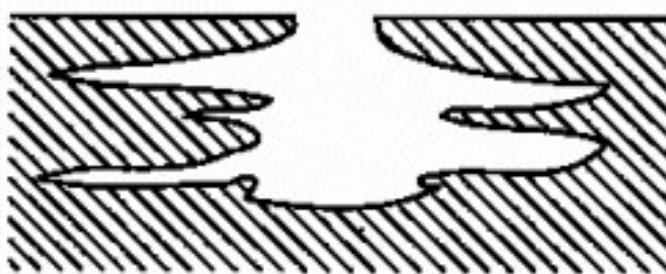
Wide, Shallow



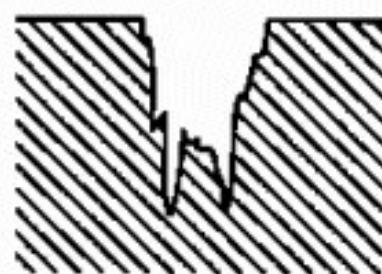
Subsurface



Undercutting



Horizontal



Vertical

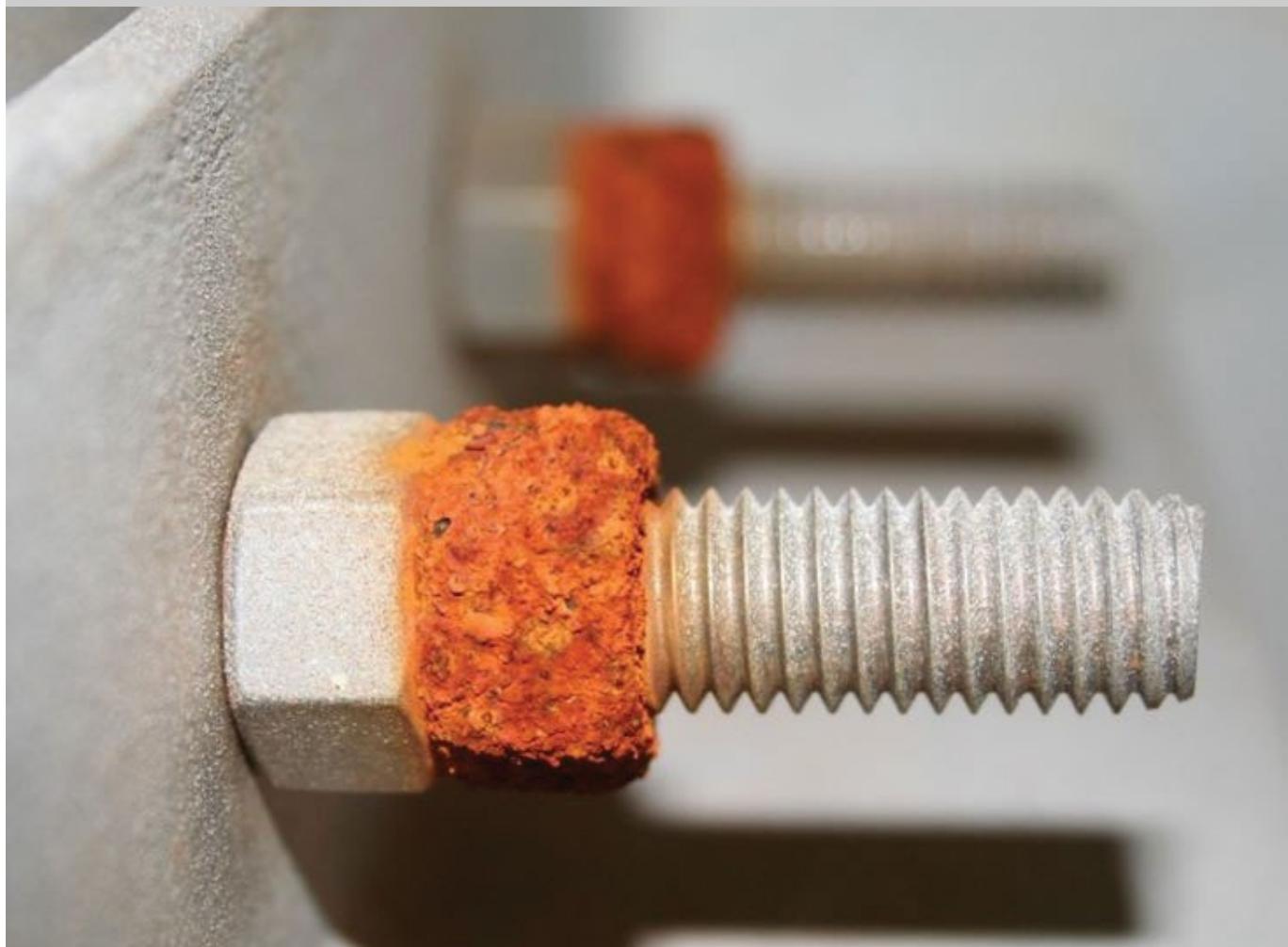
### Galvanic (bi-metallic) corrosion

This is likely to take place when two different metals (or alloys) are connected (electrical contact) to each other in the presence of an electrolyte. This will form a classical battery where the anodic metal will corrode and the cathodic metal will be protected from corrosion. The speed and intensity of galvanic corrosion will depend on things like electro-potential between the two metals, the surface areas of the two metals, the electrolyte composition (conductivity), presence of aggressive ions (e.g. pollutants), etc. Example of galvanic corrosion situations could be carbon steel bolts used on a stainless steel construction, copper wire tied to an aluminium pipe, brass bushings used with a mild steel valve, etc.

## Galvanic corrosion



## Galvanic corrosion



## Crevice Corrosion

A crevice means a tiny gap or opening. Water and dissolved salts can easily penetrate such small spaces through for example capillary action, but may have difficulties leaving the crevice, allowing the water to stagnate. The initial corrosion will reduce the oxygen dissolved in the water inside the crevice compared to water outside the crevice. This will lead to an anodic zone inside the crevice and cathodic outside, thus creating a concentration cell which causes corrosion inside the crevice. Crevices like this may easily be created in connections where two flanges are bolted together (e.g. a valve in a pipe) and on structures which are riveted together. Crevice corrosion does not require the presence of two different metals.

## Crevice corrosion on flange



### Cavitation

Cavitation is the formation of vapour cavities in a liquid – i.e. small liquid-free zones ("bubbles" or "voids") – that are the consequence of forces acting upon the liquid. It usually occurs when a liquid is subjected to rapid changes of pressure that cause the formation of cavities where the pressure is relatively low. When subjected to higher pressure, the voids implode and can generate an intense shock wave.

Cavitation is a significant cause of wear in some engineering contexts. Collapsing voids that implode near to a metal surface cause cyclic stress through repeated implosion. This results in surface fatigue of the metal causing a type of wear also called "cavitation". The most common examples of this kind of wear are to pump impellers, control valves, pumps, propellers and impellers, wear on ships' propellers and rudder, mostly caused by repeated impact on the same spot of air bubbles or vacuum bubbles.





## Erosion

Erosion corrosion arises from a combination of corrosion and the physical abrasion caused by a rapid moving fluid, for example inside a pipe. Virtually all alloys or metals are susceptible to some type of erosion corrosion depending on the moving fluid. The best way to limit erosion-corrosion is to design systems that will maintain a low fluid velocity and to minimize sudden changes in line size or direction (e.g. elbows).

Materials that rely on a passive layer are especially sensitive to erosion corrosion. Once the passive layer has been removed (eroded), the bare metal surface is exposed to the corrosive environment. If the passive layer cannot be regenerated quickly enough, significant damage can occur. Fluids that contain suspended solids are often responsible for erosion corrosion.



## Selective Corrosion (preferential corrosion/de-alloying)

An alloy is a mixture of two or more different metals, for example copper and zinc forming brass. If one of the active alloying elements is more active than the other(s), it will corrode away from the rest of the alloy. In the case of brass, zinc may corrode away so the yellow brass- colour of the object changes towards the red-brown copper colour. After leaching of the zinc has occurred, the mechanical properties of the remaining metal are impaired and the metal may crack.

In cast iron, affected areas change from grey to black by the iron corroding away, leaving behind the more noble ingredient carbon, making the dark colour.

Marine aluminium is commonly alloyed with magnesium. Magnesium is more active than aluminium and corrodes during exposure. Chlorides are highly aggressive to magnesium and to the passive layer of aluminium. Residues of this corrosion are aluminium hydroxide.

## Stress Corrosion Cracking

Stress corrosion is the result of combination of an applied tensile stress and a corrosive environment. Metal under tensile stresses can corrode at higher rates than normally expected. The stressed areas will develop microscopic surface cracks which can accelerate the rate of localised corrosion. Once the stress cracks begin, corrosion can accelerate at these sites and weaken the metal. The metal may ultimately be perforated. The tensile stress is often the result of expansions and contractions that are caused by big temperature changes or thermal cycles. The best defence against stress corrosion is to limit the frequency of the tensile stress.

Stress corrosion cracking of some metals is more prevalent in certain environments:

- *Copper:* In ammonia solutions
- *Stainless steel:* In seawater
- *Carbon steel:* In nitrate solutions

## Stress corrosion



## Microbiological (Bacterial) corrosion

Microbial corrosion (also called microbiologically -influenced corrosion or MIC) is corrosion that is accelerated by the presence of microbes. These may produce aggressive substances / ions, such as sulphuric acid, which will accelerate corrosion and damage metals and coatings. Typical areas with suffering from microbiological (bacteria) corrosion:

- Sewers
- Water ballast tanks
- Oil tanks

This type of corrosion can take many forms and can be controlled by biocides, coatings and CP



### Common corrosion on Steel

Almost any corrosion can occur on steel since it is a widely used construction material in all environments. However, we may observe more often in real life:

- General corrosion
- Pitting corrosion
- Galvanic corrosion
- Stress corrosion cracking

### Common corrosion of Stainless Steel

Stainless steel develops a passive layer in open air. Halogen salts (fluorine, chlorine, bromine, iodine) are aggressive to the passive oxide film. Stainless steel is often used to make pipes, process equipment, fittings, etc. These corrosion types are common for stainless steel:

- Pitting corrosion
- Crevice corrosion
- Stress corrosion cracking

### Common corrosion on Copper and alloys

Copper and its alloys are widely used as heat exchangers, pipes, plumbing, etc. The common alloying elements (zinc, tin) used in copper alloys are more active. In situations where copper and its alloys are commonly used,

the following corrosion types are often seen:

- Erosion corrosion
- Selective (de-alloying) corrosion
- Stress corrosion cracking

### **Common corrosion on Aluminium**

Pure aluminium is rarely used for construction. Construction aluminium is commonly alloyed with magnesium, copper and zinc. Aluminium will react with oxygen to form a passive layer in atmospheric conditions. These corrosion types are commonly found on aluminium

- Pitting corrosion
- Galvanic corrosion

### **Common corrosion on Zinc (Zinc coatings)**

Pure zinc is not a metal that is often used for construction. Zinc is mainly used as corrosion protection coating on steel, so galvanised steel is the most common construction material with zinc. Steel items of limited sizes are often galvanized, such as pipes, handrails, screws, bolts, thin plates. Corrosion of galvanised steel can include:

- General corrosion
- Galvanic corrosion
- Crevice corrosion

### **Check list**

When evaluating possibilities of corrosion, check for:

- Sharp edges & corners
- Rough welding seams / Blow holes / Weld spatter
- Bi-metallic combinations
- Drainage / Stagnant water / Accumulation of water
- Access for paint application and maintenance work: Notch radius / Stitch welds / Crevices / Narrow gaps / Design of structure / etc.
- Flow: Turbulence / Cavitation / Crevices
- Exposure: In-/ Out-doors / Aggressive ions / Chemicals
- Environment: Temperature / Humidity / Stress (applied or residual or Cyclic)

## **Corrosion protection**

### **Possible consequences of corrosion**

#### ***Economic***

- Replacement of corroded equipment
- Overdesign to allow for corrosion
- Preventive maintenance, for example, painting
- Shutdown of equipment due to corrosion failure

#### ***Safety***

Structures may become weak and no longer safe as a consequence of corrosion, creating potential dangerous situations for human life, property and the environment.

## How to prevent corrosion?

Corrosion is an electro chemical process with four basic elements:

- Anode
- Cathode
- Electrical connection
- Electrolyte

Corrosion will stop if one or more of these elements are eliminated

## Structural design

An ideal structure can minimize corrosion risk by:

- Providing enough space for paint application and maintenance
- Minimising steel defects which can cause early breakdown of protective film
- Minimising gaps, crevices or other shapes that can entrap aggressive or corrosive substances
- Allowing free drainage from the surface
- Good design
- Avoiding dissimilar metals connecting or by using sufficient isolation materials to stop galvanic corrosion
- Providing proper planning and methods for handling, transportation, and avoiding construction damage during fabrication

## Proper materials selection

We must find the most suitable material for a given environment. Modern materials technology has developed a number of new materials such as high strength plastic, corrosion resistant steel, chemical resistant concrete.

## Insulation

High temperatures and increased electron transmission will accelerate the corrosion rate. Insulation can be used to:

- Control heat exchange
- Reduce corrosion current transmission

## Environment control

The most practical way to minimize corrosion by environmental control is:

- Removal of moisture in the air by de-humidification using machinery designed for purpose
- Raising the steel temperature in order to avoid condensation

Can only be achieved in confined and enclosed areas.

## Cathodic Protection

Cathodic protection is used as a corrosion preventing back up system in case of coating failure. Based on the principle of the galvanic cell, the more active metal can be used to protect a more noble metal. Another way is to supply electrons to the metal to be protected by impressed current. Cathodic protection is used widely for structures immersed in water or buried in soil.

## **Metallic coatings**

Metallic coatings can protect steel by:

- Forming a dense barrier layer (noble metal) on steel surface, e.g.: Chrome plating
- Cathodic protection, e.g. Hot Dip Galvanising

## **Corrosion inhibitors**

It is always difficult to apply a protective film in a closed system containing corrosive fluids or gases and to find any corrosion and treat it. Corrosion inhibitors are chemical compounds which can react with water and steel to form a passive layer which will protect the steel.

## **Paints and coatings**

This is the most common method to protect substrates from corrosion. Thousands of different paints and coatings are available in the market to protect substrates by:

- Barrier effect
- Inhibitive (passivating) effect
- Cathodic effect

### **Coatings' Barrier Effect**

The coating creates a barrier which prevents seawater or other corrosive agents from coming into contact with the substrate. Example: Epoxy primers

### **Coatings' Inhibitor Effect**

In inhibitive coatings, moisture penetrates to reach the inhibitive primer where the reactive pigment is activated, which in turn passivates the metal substrate at the coating/metal interface. Inhibitive paints are not recommended for immersion service. Example: Zinc phosphate primers

### **Galvanic Effect**

The paint contains metallic zinc powder and acts as a sacrificial anode. Example: Zinc-rich primers

# **Cathodic protection (corrosion)**

## **Introduction**

Cathodic protection can, in principle, be applied to any metallic structure in contact with a bulk electrolyte. In practice its main use is to protect steel structures buried in soil or immersed in water. It cannot be used to prevent atmospheric corrosion.

### **Cathodic protection - An application of a galvanic cell**

In a corrosion cell, steel will corrode when coupled to a more noble material. If however the steel is coupled to a material being more active than steel (less noble), the direction of the current will change. The less noble material will corrode and the steel will be protected from corrosion. The less noble material becomes a sacrificial

anode.

## Principle of Cathodic Protection

The principle is based on “supply of electrons to the base material”. This is done either by:

- connecting the structure to more active material (Sacrificial anode)
- connecting the structure to an external source of electrons (Impressed current)

Both systems supply electrons to the structure. The structure will become more noble, and metal dissolution (corrosion) of the structure will be prevented.

## Sacrificial anodes (SACP)

Sacrificial anodes are made of a metal that is more active (less noble) than the metal it is intended to protect. The anode “sacrifices” itself by corroding when connected to a more noble metal. This provides the noble metal with cathodic protection.

Sacrificial anodes will only function when they and part of the structure are submerged. A calcareous deposit is formed on the steel surface when submerged in seawater.

## Anodes

Many different sizes and shapes are available. Anodes can be welded, clamped or bolted on to the structure. They can be made of:

- Zinc alloy anodes
- Aluminium alloy anodes
- Magnesium

Aluminium is often recommended instead of zinc because aluminium anode weight is approx. 1/3 of zinc. This makes a difference in total price for equal protection with lower installation costs due to the weight difference (and less weight added to the structure).

## Sacrificial anodes on a ship

Sacrificial anodes will protect areas where the protective coating has suffered mechanical damages. Both zinc alloy and aluminium alloy anodes can be used on ships. A sacrificial anode cathodic protection system (SACP) will only work in submerged conditions, such as the submerged part of the ship's hull or in its ballast tanks (but will have no effect when the tank is empty). Sacrificial anodes on the hull of a ship will increase its friction in the water.

## Bracelet sacrificial anodes on rig or pipeline

The anodes are clamped on to the construction like a bracelet. Additional welding to the construction ensures good electrical contact.

## Impressed Current Cathodic Protection (ICCP)

### Impressed Current Cathodic Protection (ICCP)

For larger structures, it is often more cost effective to use impressed current cathodic protection (ICCP) systems

instead of sacrificial anodes to provide corrosion protection. ICCP systems use permanent anodes connected to a power source (e.g. AC rectifier or DC Solar Permanent anodes for ICCP systems are available in a variety of shapes and sizes. Common anodes are tubular and solid rod shapes or continuous ribbons of various noble materials. These are made from high silicon cast iron, graphite, mixed metal oxide (MMO) and platinum.

## **ICCP system**

The ICCP system on ships comprise of these components:

### **Rectifier / Control Panel**

This unit supplies DC electrical current (Direct Current) to the permanent anodes. A rectifier can convert an AC (Alternate Current) power supply to a DC output.

These units are available in many sizes (e.g. 50 amps to 1,200 amps) with instruments showing the output to each anode. They can incorporate over/under protection alarms and be wired to a central monitoring computer, if required.

### **Reference electrodes**

These are flush mounted on the hull and measure the electrical potential at the hull/seawater interface. A signal is fed to the control panel which increases or decreases the anode output, so both under- and over-protection is avoided.

### **Permanent anodes**

These anodes provide the electrical current (electrons) which protect the steel against corrosion. They can be linear anodes which are mounted on the surface of the hull or circular anodes which are flush mounted to minimise drag. These current emitting faces are made from noble materials, mixed metal oxide (MMO), graphite, platinum, etc. A typical installation may be two circular anodes in the bow area (one on each side) and two linear anodes in the stern area (one on each side).

### **Anode Shield**

The current released by the permanent anodes can damage the protective coatings in the surrounding area. A thick, putty like coating is applied around the permanent anodes to reduce the effect of overprotection.

### **Shaft grounding equipment**

This installation will extend cathodic protection to propeller and propeller shaft surfaces. It will reduce spark erosion damage to shaft bearings. It consists of high efficiency silver coated slip rings and silver graphite brushes attached to the propeller shaft. The effectiveness may be monitored by an optional Shaft Condition Monitor. Rudder and stabilizer bonding cables are provided in the same system.

## **ICCP for Buried Pipelines**

Impressed Current Cathodic Protection can also be used for buried pipelines. Hazardous product pipelines are routinely protected by a protective coating supplemented with cathodic protection. An impressed current cathodic protection system (ICCP) for a pipeline consists of a DC power source, often an AC powered transformer rectifier and an anode, or a range of anodes buried in the ground (the anode groundbed).

The strength of the impressed current will depend on several factors, such as the size of the pipeline and the coating quality. The positive DC output terminal would be connected via cables to the anode range, while another cable would connect the negative terminal of the rectifier to the pipeline, preferably through junction boxes to allow measurements to be taken.

Anodes can be installed in a groundbed consisting of a vertical hole backfilled with conductive coke (a material that improves the performance and life of the anodes) or laid in a prepared trench, surrounded by conductive coke and backfilled. The choice of groundbed type and size depends on the application, location and soil resistivity. The DC cathodic protection current is then adjusted to the optimum level after conducting various tests including measurements of pipe-to-soil potentials or electrode potential.

For a pipeline, the environment will consist of the soil and anything in the soil such as other pipelines, buried cable, minerals, and water. Attention must be paid to other current sources. A stray current source can affect the amount of protection a corrosion control system can provide. In an unprotected system, stray currents can increase the rate of corrosion.

## SACP vs. ICCP

ADVANTAGES	
<b>Sacrificial anode systems</b>	<b>Impressed current systems</b>
• Simple, reliable and free from in-service operator surveillance	• Flexibility under widely varying operating conditions
• System installation is simple	• Weight advantage for large capacity, long life systems (reduced sea water drag)
• Low installation cost for short term protection	• Low life cycle cost (LCC)

DISADVANTAGES	
<b>Sacrificial Anode Systems</b>	<b>Impressed Current Systems</b>
• Large weight for large capacity, long life systems	• Relative complexity of system demands high level of design expertise
• Response to varying operating conditions is limited	• In-service operator surveillance required
• Hydrodynamic loadings can be high (Seawater drag)	• Vulnerable to component failure or loss of power

## Electrolytic corrosion and fouling protection

The system consists of Copper and Aluminium (or soft iron) anodes strategically located in sea chests or sometimes in-board, but as close to the sea water intake point as possible. One such set of anodes is recommended for each sea water service. The anodes are connected to a control panel that feeds a current to the anodes. This causes the Copper anodes to release cupric ions and the Aluminium anodes to release aluminium ions that form an aluminium hydroxide. The resultant ions produced by the anodes are carried by the sea water, spreads through the pipe work and creates an environment that is distinctly unfriendly to the marine

life. Thus any marine life larvae that enter the pipeline will not settle but will pass right through to discharge. An added benefit is that the Aluminium hydroxide creates a protective film on the pipe lines thereby significantly reducing pipeline corrosion. If the seawater service pipelines, condensers, etc., are of aluminium brass, cupronickel, etc., the aluminium anodes would generally be replaced or supplemented by soft iron anodes. The design and control panel functioning ensures that just the right concentrations of Cupric ions are introduced to keep the pipelines free but not affect the marine life outside the ship after discharge.

The result is cleaner pipelines with much longer and trouble free life resulting in lower maintenance and running costs achieved in an environmentally acceptable manner.

## CP - back up the paint system

### **CP can be used to back up the paint system**

No paint system is 100 % perfect, weak spots and holidays will exist. For submerged structures a CP system will protect such areas. A calcareous deposit precipitates on the substrate and reduces the corrosion rate.

## Cathodic disbondment

This is a process of adhesion loss of protective coatings from the protected structure due to the formation of hydroxyl (or in extreme cases hydrogen) between the coating and the protected material (cathode)

If a CP system is not managed correctly, excess current flow to the anode (called over-protection) can result in blistering and loss of adhesion of the paint. This effect is known as Cathodic Disbondment. Over protection will result in the formation of Hydrogen ions and Hydroxyl ions.

### *How can overprotection occur?*

- Active corrosion of steel are under 0.80 to - 0.85 Volts
- Critical potential (-0.85 Volts) is set for CP system to deliver electrons to the cathode
- However, there is a risk of increasing polarization as potential rises
- Result of that will generate hydrogen gas around -1.10 Volts.

### *Hydrogen ions induced problems caused by overprotection:*

- Entrapment of hydrogen gas results in blistering between coating and the steel
- Hydrogen embrittlement of steel
- Risk of explosive atmospheres

### *Hydroxyl ions induce problems:*

- Saponification of the coating binder

### *Controlling hydrogen gas formation*

Apart from controlling the current flow between the noble and more active (anode) metal, the choice of anode metal is also important to avoid over protection. Use of a very active metal such as Magnesium is not recommended due to the rapid degradation of the metal and the increased production of hydrogen gas which increases the cathodic disbondment of the coating

## Objects that typically can be protected by Cathodic Protection

- Ships
- Offshore platforms and rigs
- Sub-sea installations
- Sub-sea pipelines
- Harbour facilities
- Storage tanks
- Buried tanks and pipelines (onshore)

# Structural design (corrosion)

## Introduction

The objective of designing a structure is to ensure that the structure is suitable for its function, has adequate stability, strength and durability, is constructed at an acceptable cost and is aesthetically pleasing.

The overall design shall be planned to facilitate surface preparation, painting, inspection and maintenance.

The shape of a structure can influence its susceptibility to corrosion. Therefore structures should be designed such that corrosion cannot easily establish a foothold (a corrosion trap) from which it can spread. It is therefore strongly recommended that the designer consults a corrosion protection expert at a very early stage in the design process. Ideally, the corrosion protection system should be selected at that time, with due consideration to the type of service of the structure, its service life and maintenance requirements.

The shapes of the structural elements and the methods used to join them should be such that fabrication, joining and any subsequent treatment will not promote corrosion. Similarly, consideration should be given to the shape of the structure and its elements with respect to the category of its environment (see ISO 12944-2) when specifying a protective paint system.

Designs should be simple and excessive complexity should be avoided. Where steel components are in contact, embedded or enclosed in other building materials, e.g. brickwork, they are no longer accessible, therefore, the corrosion protection measures shall be effective throughout the service life of the structure.

## Importance of good design of structure

Structural design should incorporate features of the design that minimise the likelihood of corrosion. Poor design of the structure may initiate early breakdown of the coating and corrosion.

### *Design will affect*

- Surface preparation
- Paint application
- Inspection
- Maintenance

*Paint will give the best performance when applied to*

- An even and continuous surface
- Good design should allow for sufficient space for surface preparation, paint application, inspection, maintenance
- Good design avoids water & contamination retention

## ISO 12944-3: Design considerations

This standard addresses the basic criteria for the design of steel structures which are to be coated by protective paint systems, in order to avoid premature corrosion and degradation of the coating or the structure. Basic design criteria included in the standard:

- Accessibility
- Treatment of gaps
- Precautions to prevent retention of deposits and water
- Edges
- Welding surface imperfections
- Bolted connections
- Box chambers and hollow components
- Notches
- Stiffeners
- Prevention of galvanic corrosion
- Handling, transport and erection

Furthermore, ISO standard 8501-3 (Preparation grades of welds, edges and other areas of surface imperfections) describes preparation grades of imperfections.

## Accessibility

The steel structure should be accessible, visible and suitable for:

- Application
- Inspection
- Maintenance

Accessories, such as ladders, walkways and hooks of scaffolding need to be considered in the design. There must be sufficient opening for people to access box chambers and/or confined areas (tanks), narrow spaces should be avoided.

If a component cannot be properly maintained after fabrication, corrosion resistant materials or long lasting protective systems should be considered.

## Treatment of gaps

### ***Notches / rat holes***

Notches should have a radius of not less than 50 mm so they can both be prepared and coated to a good

standard.

### **Spot welds / Stich welding / Intermittent welds**

This type of welding may be quicker, cheaper and weigh less than full welding, but they may end up as corrosion traps. Paint is unable to fill the gaps between the pieces which are spot welded together. These areas will be at risk to corrosion. Spot welding is not recommended for areas exposed to severe / aggressive environments.

Other areas of a structure which may easily trap moisture, dirt, abrasives, etc.:

- Narrow gaps
- Blind crevices
- Lap joints
- Skip welding
- Mating surfaces

### **Accessories – In design**

Future maintenance and repair may require use of scaffolding. By incorporating permanent scaffold supports in the design, damages to the main area may be avoided. Damage to the supports themselves is easily touched up. Material of retainer is commonly made by stainless steel (painted).

### **Edges**

Sharp edges must be rounded or chamfered for the purpose of:

- Apply a uniform coating
- Provide adequate thickness
- Minimize damage of coating
- A minimum radius of 2mm is recommended

### **Stiffeners**

All types of stiffeners should be designed so as to avoid gaps and thereby removing the risk of retention of dirt deposits or water. There must be sufficient space for surface preparation and paint application.

### **Design to prevent retention of water and contaminants**

Accumulation of water, be it rainwater or splashed seawater, as well as air-born pollutants, will provide an excellent electrolyte for corrosion and should be avoided.

- Good drainage will reduce corrosion
- Proper shape to allow easier water run off
- Drainage open in suitable location
- Avoid forming pockets and recesses

## Welding surface imperfections

Many problems are caused by a poor welding job

- Sharp edges
- Narrow gaps
- Weld spatter
- Blow holes

## Bolted Connections

### **Slip-resistant connections with high-tensile bolts**

- Connection surface should be blasted to achieved agreed roughness
- A coating tested and approved for contact surfaces can be used

### **Preloaded Connections**

- Paint system to be used should not decrease preloading force

### **Bolts, Nuts and Washers**

- Bolts, nuts and washers shall be protected against corrosion to the same durability as the corrosion protection of the structure

## Box Chambers and Hollow Components

### **Open box chambers and hollow components**

- Require good drainage and air flow
- Effective protection-envelope barrier coatings

### **Sealed box chambers and hollow components**

- Ensure air/moisture proof, check welds for pinholes
- Avoid water entrapment during fabrication

## Galvanized steel

- The structural design for galvanising should meet relevant regulation and/or standards (e.g. ISO 1461 AND ISO 14713)
- Venting and drainage should be provided on all enclosed structural members that are to be hot dip galvanised to avoid air expansion and explosion in the zinc bath

## Hollow components

A hole in a hollow component will allow moisture, oxygen and other corrosive ingredients to enter the item as a result of temperature changes (e.g. night to day). The ingredients will be trapped inside the hollow component and create corrosion.

## Handling, transport and erection

Ways to avoid damage of the protective coatings at the different stages of construction should be considered at the design stage:

- Handling
- Transportation (lifting)
- Erection
- On site operation (welding, cutting and grinding)

# Surface treatment

## Pre-treatment

### The purpose of surface preparation

We often think of the coating as the most significant factor in the protection of a surface. However, we should also consider the substrate (surface) and its effect on the stability, durability and effectiveness of the coating. The substrate, or surface over which the coating is applied, is the groundwork or foundation of the coating, so its characteristics have a direct influence on the life of the coating.

The construction of a building on sand, clay, or rock shows a similar relationship. The same house could be built on each of these bases, but the one built on clay would have a shorter life and therefore be less satisfactory than the one built on rock. Also, the foundation necessary for a house built on sand would differ from that needed to build on clay.

In the same way, coating systems vary according to the substrate, both the type of substrate material and how it is prepared before being coated. The performance of the paint system is affected by the surface type and its preparation prior to painting. If a coating has been developed to protect a particular type of material, it may not be suitable to use on a different type of material. Likewise, if a coating has been developed to be used on a blast cleaned steel surface, it is not likely to perform well on steel which has only been subjected to wire brushing.

We usually consider the preparation of a substrate before coating to consist of two phases:

1. *Steel dressing*, where the shape of the steel is under scrutiny, for example the presence of sharp edges, delamination in the steel, unsuitable welding seams, etc., and correcting these as necessary
2. *Surface preparation*, where the surface of the steel is scrutinized and improved so it conforms to the requirements of the coating to be applied in terms of cleanliness, roughness, etc.

Important factors to be considered for steel protection are:

- Treatment of steel imperfections (Steel Dressing)
- The presence of rust and mill scale (Surface Treatment or Surface Preparation)
- The presence of surface contaminants, including salts, dust, oils and greases (Surface cleaning or degreasing)
- The surface profile

A clean and dry surface will provide the best adhesion for paint

### Determining methods and procedure

#### **Determining surface preparation methods**

ISO 8504: Preparation of steel substrates before application of paints and related products. Surface preparation methods

Various methods can be used for surface preparation. In order to determine the most appropriate method, the contractor/designer must be aware of:

- Metal condition (e.g. new or previously coated steel)
- Expected surface preparation grades and profiles (if any)
- Available equipment and personnel
- Coating system to be applied
- Regulations / laws
- Cost

Steel substrates may consist of new metal, previously coated metal, or shop primed metal

- *New steel*: must be checked for initial type of steel, initial rust grade, any chemical treatment (chromating, phosphating), presence of chemicals or contaminants
- *Previously coated steel*: existing coating must be checked for genetic type, adhesion, DFT, condition, contaminants, etc.
- *Shop Primed Steel*: type of shop primer must be identified, its condition checked for mechanical and welding damages, contamination, and compatibility to subsequent coating system

### **Surface Preparation prior to Paint Application**

- Assess the initial condition
  - For new steel, the inspector can refer to ISO 8501
  - Four grades of steel surface condition (A, B, C & D) are defined
  - To assess coated steel is more complicated, ISO 4628 is commonly used for assessment
- Steel dressing
- Surface cleaning (degreasing)
- Surface preparation/treatment (abrasive blasting, hand or power tooling, water jetting, etc.): remove rust and mill scale
- De-glossing, and abrading of the surface of the existing coating and feathering edges at damaged areas
- Removing abrading and/or dust residues

### **Steel dressing (pre-preparation)**

#### **Steel defects affect coating performance**

Steel defects can cause three possible coating problems:

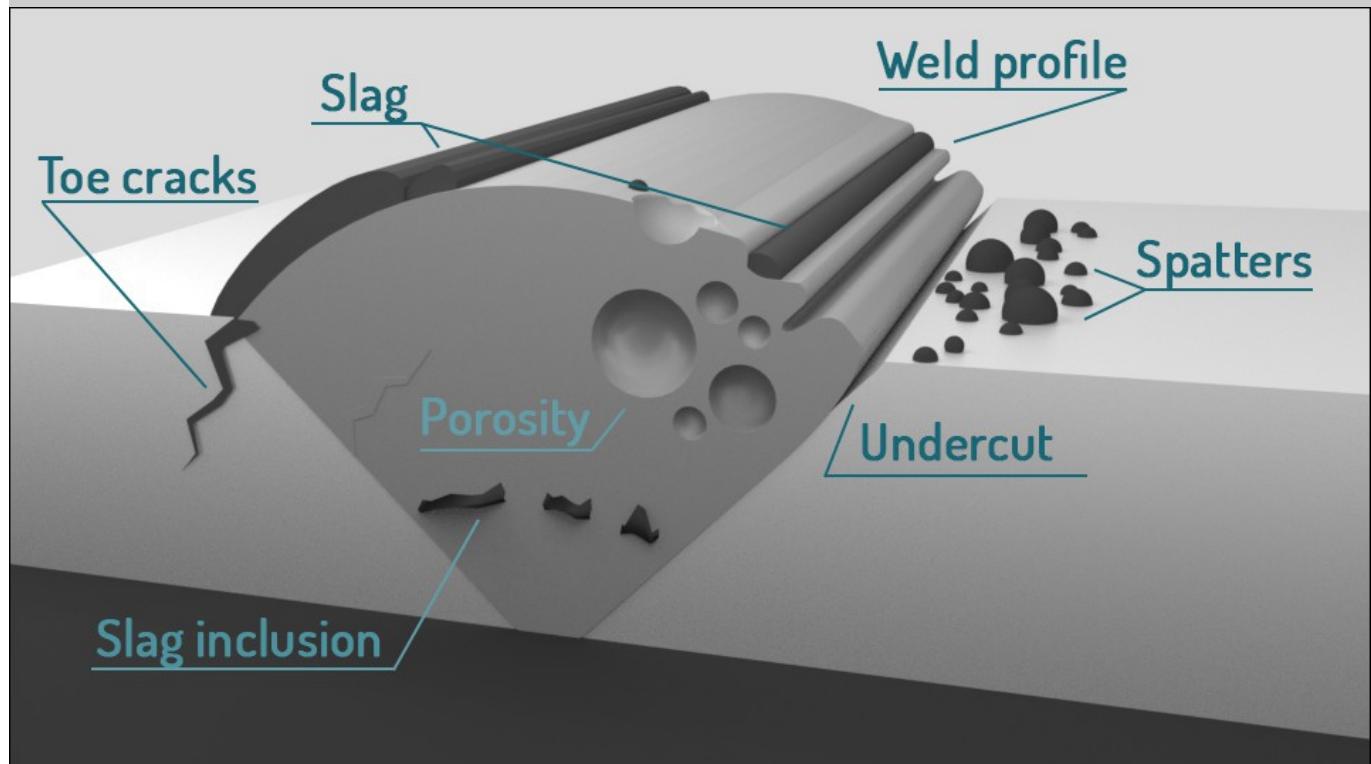
- Adhesion: A sharp edge or weld spatter can result in the coating not covering the sharp edge allowing water penetration under the film which can result in loss of adhesion after corrosion commences
- Wetting properties: Contamination on the surface can hinder or restrict the coating from wetting the surface and developing adhesion
- Coating stress: An uneven surface (peaks and valleys) can result in changes to the surface tension as the coating cures / dries resulting in weak spots or cracking after cure

By Steel Dressing we mean removing steel imperfections (such as welding spatters, sharp edges, blow holes, etc.) through grinding or welding

## Steel Imperfections treated by Grinding

- Lamination, shelling, slivers, hackles: Remove using grinder
- Weld ripple/profile: Sharp profile peaks to be smoothed using grinder
- Weld spatter: Remove by hammer, grinder according to specified grade
- Flame cut: Remove rough edges using grinder to smooth and radius the edge
- Sharp edge: Round to specified radius (e.g. 2mm) by grinder
- Rolled-in extraneous matter: Remove using grinder

Photo from PAINT-INSPECTOR.COM





### Steel imperfection may require welding

- Undercut: Weld undercuts require re-welding and grinding
- Weld porosity: Treat by either welding/grinding or enlarge the pore for paint penetration
- Pits and craters: Either welding/grinding or enlarge for paint penetration



### Grinding a construction

- Mark areas where grinding is required
- Remove weld spatter
- Grind the welds
- Grind the notches
- It is important to carry out grinding to improve the lifetime of the paint system
- Grinding of Sharp Edges
  - Paint will not be able to develop an adequate film thickness over a sharp edge
  - Rounding the edges followed by stripe coating gives an even film thickness and will improve the lifetime of the paint system

Disc grinder:



Pencil type grinder:



Photo from PAINT-INSPECTOR.COM



## Reminders

- Weld beads, spatter and other defects must be ground to form an acceptable substrate for the paint system
- Paint can't fill blow holes
- Blow hole often becomes visible only after paint is applied
  - Will lead to initiation of corrosion by allowing moisture to penetrate
  - Remedial actions: Remove the paint, re-weld and grind
  - Re-Apply the paint

**NOTE:** Small failures like this are difficult to find, but the consequences can become big.

## Surface cleaning (degreasing)

There are two types of Contamination:

- **Visible contamination**, which may include:
  - Condensation
  - Dust
  - Oil/grease
  - Rust and mill scale
  - Marine Fouling

- **Non-visible contamination:**

- Soluble salts

### **Why should contamination be removed?**

- Most contamination lacks adhesion to the substrate
- Some contaminates such as oil/grease have a high surface tension making paint adhesion difficult or impossible
- Soluble salts can absorb water from the environment (hygroscopic action) which can lead to:
  - Rapid surface rusting (steel) on the treated surface
  - Osmotic blistering of the coating if applied over soluble salts
- All contamination will result in poor adhesion of the paint film

### **Dust is a contaminant and may come from scaffolding**

- Spent abrasive which has not been cleaned up after blast cleaning may blow or fall into the wet paint during application, leaving a rough surface which may not be covered by the paint film and can initiate corrosion
- If paint is applied over dust, a weak point is formed in the paint film, air can be trapped, adhesion is reduced and corrosion will develop rapidly

### **Equipment can contaminate the Surface**

- Oil contamination from pneumatic equipment (e.g. air-driven grinder) can take place if oil is leaking out of equipment, the equipment has been stored with oil, or there is a missing oil trap (air from compressor contains oil)
- Must be removed prior to surface preparation

### **Marking Pens & Chalk can contaminate the Surface**

- There are only a few types of Marker Pen recommended for inspection of steel and coatings
- Paint detachment may be caused by using the wrong type of marker pen
- All Chalk marks must be removed from bare steel and coatings before applying new paint

### **Welding smoke is a contaminant**

- Smoke created by welding contains soot, burned material and salts from the flux in the welding rods
- Welding smoke is water soluble and should be removed by water washing
- If not removed, osmotic blistering of the paint may occur
- Solvents will not remove welding smoke sufficiently

### **The coating inspector may cause contamination!**

- Dirty work boots or clothing may cause contamination inside a tank or on a freshly prepared deck or floor
- Human perspiration contains soluble salts
- Even a human fingerprint may in some situations be considered as contamination
- Osmotic blistering occurs (after submerging in water) when paint has been applied on a surface contaminated with Water Soluble Salts

### **Surface cleaning (degreasing)**

Common methods:

- Fresh water cleaning (preferably pressurized water)
- Steam cleaning
- Solvent cleaning
- Other methods agreed upon

### **Cleaning procedure - water soluble degreaser**

1. Apply the cleaner / degreaser from below and upwards
2. Work systematically on all surfaces
3. Let the cleaner react, normally 1-5 minutes
4. Wash off from below and upwards
5. Final rinse from above and down

Degreasing by wiping the surface with thinners and rags is not recommended. This method will spread a thin film of contamination such as oil over a wider area and the solvents increase the risk of fire or explosion.

### **Degreasing with alkaline detergent**

- Should always be carried out before blast-cleaning
- After the detergents have been applied and allowed to work for the recommended time, they must be removed by "Low pressure water cleaning (LPWC)" (around 250 - 300 bar) or higher pressures

### **Removal of marine growth, salts and loose paint**

- It is important to start the washing as soon as the ship is in the dry-dock
- If the growth and contaminants are allowed to dry on the substrate they will be much harder to remove
- Usually pressure of minimum 250 bar at the nozzle
- Some of the antifouling paint on ships' hull may be removed during the cleaning process (e.g. self-polishing antifouling)
- Certain types of marine growth (e.g. barnacles) will often require additional scraping or grinding to be removed

Photo by Leroy Dias



Marine fouling on ship side

### Water Quality: Potential risks from unknown sources

The quality of the water is important for washing and contamination removal, otherwise additional contamination may take place during surface cleaning

- Check the source of the water, where is it coming from (drinking water, lake or river, brackish water, desalination plants, bore-holes, etc.)?
- Addition of inhibitors or other chemicals (chlorine)?
- Re-circulation, re-used water? Cleaning, filtering before re-use?
- Certificates or analysis?

### Potential contents:

- Salts
- Contaminations
- Particles

### Potential paint failures:

- Osmotic blistering
- “Dust” after drying, causing loss of adhesion

# Equipment and abrasives

## Hand & power tooling

### Hand tools

Hand tools are no longer commonly used for professional surface preparation. They require muscle power and plenty of time and patience. In return they do not give a very good standard of preparation. Their main advantages are that they are easy to transport and are not depending on any power supply. Examples of hand tools used for steel preparation:

- Scrapers, used to remove rust and old paint
- Wire brushes, used to remove rust
- Hammers, used to knock off / chip flakes and cakes of rust
- Emery paper and abrasive pads, used to grind rust and old paint

### Power tools

These can either be driven by electricity or by compressed air (pneumatic). They are easier to work with and have a higher production rate than hand tools, but the quality of the output has still some limitations. Most of them are working on a rotating basis or are reciprocating impact tools. Examples of power tools used for steel preparation:

- Rotating wire brush, used to remove rust
- Rigid disc grinder, used to grind away steel defects (faulty welds, spatter, delamination, etc.), sharp edges, and rust and mill scale
- Flexible sanding disc, used to abrade old paint and general rust, feather edges of old paint
- Needle gun, removes rust scale
- Chipping hammer, removes rust scale
- Rotary impact or scarifying tools, such as Roto-Peen and Bristle Blaster, used to remove rust

Most of the power tools are hand-held portable type, but there are some larger versions as well of the "walk-behind" type

### Hand- and power tooling

#### Advantages

- Simple
- Good for poorly accessible areas
- Cheaper

#### Limitations

- Low productivity
- Rotating wire brushes and disc-sanders may give a polished surface
- Needle gun may create indentations and pits - hard to paint
- High labour cost

#### Standard

- ISO 8501-1 St 2 and St 3 surface condition can be achieved

- Manual wire brushing is heavy work and has very low productivity
- Rotating wire brushes and disc grinders speed up the production rate but increase the risk of having a polished surface
- A polished substrate will result in poor adhesion of the paint

## Abrasive blast cleaning

This is the most common surface preparation method for large areas. The surface is cleaned by propelling abrasive particles at high speed towards the surface to be treated. The impact of the abrasive particles will remove rust, mill scale and old coatings.

The abrasive can be propelled by:

- Compressed air
- Centrifugal force
- Water with high velocity
- Combination of Air and Water (slurry blasting / vapour blasting)



## Dry abrasive blasting

### **Compressed air abrasive blasting**

Abrasive is fed into a high-pressure air stream from a pressurized container through a mixing valve to a hose which is used to direct the air/abrasive mixture at high velocity from a special nozzle toward the surface to be cleaned



### **Advantages**

- High productivity
- Creates a surface profile which can be varied
- High degree of surface cleaning at high speed
- The most efficient method of surface preparation
- Surface remains dry
- Good anchor pattern for paint
- Flash rusting avoided

### **Limitations**

- Complex equipment
- May need dehumidification of the blast air
- Pollution (dust, heavy metals, etc.)
- Noise
- High velocity stream of abrasives is a safety risk
- Does not remove salt
- Does not remove oil
- Creates dust

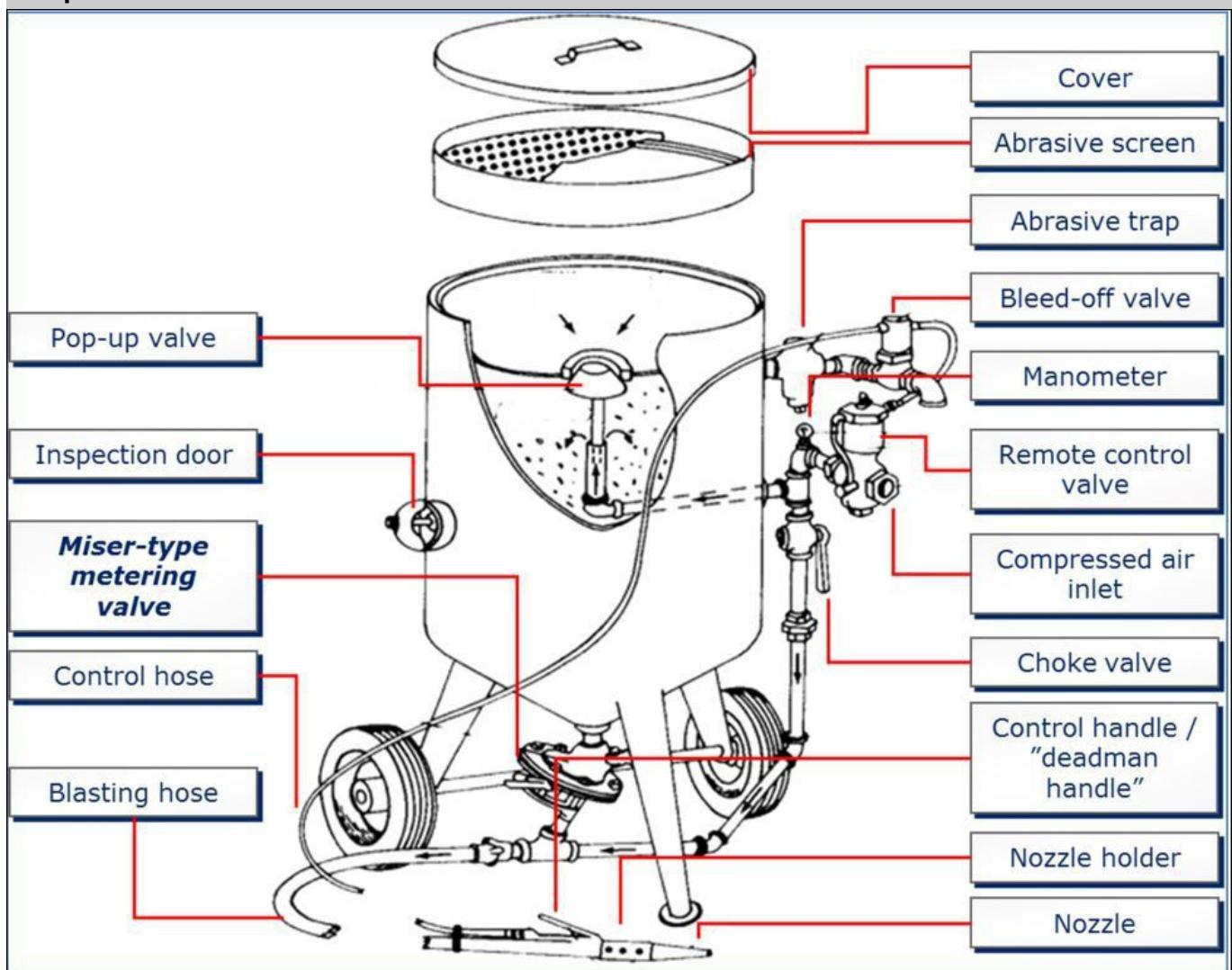
Abrasive blast cleaning produces a good surface profile and several visual blasting standards can be achieved,

but it does not remove soluble salts from the substrate.

## Main components

- Compressed air
- Abrasives
- Blasting pot
- Metering valve
- Blasting hose
- Control hose
- Dead man's switch
- Blasting nozzle

## Components



## Blast pot

The blasting pot is pressurised by the same compressed air which drives the abrasive. A pop-up valve at the top of the pot is opened when more abrasive is added to the pot. The pressure in the pot prevents a "blow-back" when the abrasives are gravity-fed into the airstream through the metering valve.



Workers filling blast pot

## Productivity

In order to achieve the best efficiency, the mixture ratio of abrasive and compressed air is a key factor:

- Too much abrasive: slow efficiency, low profile and waste of abrasive
- Too little abrasive: Slow efficiency as the time to achieve the required result is extended for each m<sup>2</sup> and abrasive can be wasted
- The ratio of abrasive to air is adjusted by the metering valve under the blasting pot

Productivity is directly proportional to the pressure at nozzle:

- Pressure at Nozzle 7 kg/cm<sup>2</sup> = 100% productivity
- Pressure at Nozzle 5,6 kg/cm<sup>2</sup> = 66% productivity
- Pressure at Nozzle 4,2 kg/cm<sup>2</sup> = 50% productivity

## The Blasting Hose & Nozzle

- The blasting hose is made of special pressure and abrasive resistant material and can be tiring to work with due to its weight and stiffness
- When extending the hose, it is important that the couplings are of approved type and without damages
- To minimize loss of pressure, the blasting hose shall have a diameter which is 3-4 times bigger than the diameter of the nozzle

- Blasting efficiency is limited by nozzle size, bigger nozzles consume more air
- Nozzles will be worn with regular use
- Once the nozzle size exceeds the manufacturer's limit (normally 1 - 1.5 times), it should be replaced
- Two main types of blasting nozzles:
  - Standard nozzle abrasive speed: 300 Km/h at 7 bar pressure
  - Venturi nozzle abrasive speed: 700 km/h at 7 bar pressure

### **Spot blasting**

During repair and maintenance work, some owners may specify that only corroded spots and areas shall be blast cleaned, often referred to as spot blasting, and leave intact paint untouched. However, nearby paint and all edges between blast-cleaned spots / areas and remaining paint will be damaged by stray abrasives from the blasting. The edges will be rough and clearly suffering from impact damages (punctures). Additional damages, which are not easy to see, will be small cracks in the remaining paint (micro-cracks).

When the remaining paint is overcoated by new paint, solvents will penetrate these cracks and cause a reduction in adhesion near these edges, sometimes also a slight lifting of the old paint. The result is that after a relatively short time the blasted spots may still look good, but the edges of the spots suffer from new corrosion (and the owner complains about a poor blasting and painting job).

In order to avoid this disappointing result, all edges of blast-cleaned areas must be feathered by grinding equipment before being overcoated. Feathering is both time consuming and costly, so the best solution is to blast-clean larger defined areas instead of many small spots.

### **No feathering of the edges**



## Abrasives

### Abrasive types

There are two main groups of abrasives used for blast cleaning:

- **Metallic abrasives:**

- Chilled iron grit (angular)
- High-carbon cast steel grit and shot (angular or round)
- Low-carbon cast steel shot (round)
- Cut steel wire (cylindrical)

- **Non-metallic abrasives (Mineral and slag abrasives):**

- Natural abrasives: Garnet, Olivine, Staurolite
- Slag: Copper refinery, Nickel refinery, Coal furnace, Fused aluminium oxide, Iron furnace

The shape of abrasive particles influences the surface profile. Three dominant shapes of abrasive:

- Angular (grit)
- Round (shot)
- Cylindrical (wire cut)

Abrasive are selected to achieve the specified roughness and cleanliness:

- Particle size will define the depth of the surface profile
- Distribution of abrasive will define the surface profile and peak density
- Abrasive must be free from contaminants such as oil, salt or other
- The choice of abrasive can also be influenced by:
  - Type of substrate
  - Productivity required
  - National / International laws and regulations

## **Quality control of abrasives**

- ISO 11124 gives specifications for metallic abrasives (Chilled-iron grit; High-carbon cast-steel shot; Low-carbon cast-steel shot; Cut steel wire)
- ISO 11126 gives specifications for non-metallic abrasives (Silica sand; Copper refinery slag; Coal furnace slag; Nickel refinery slag; Iron furnace slag; Fused aluminium oxide; Olivine sand; Staurolite, Garnet)

## **Re-use of abrasives-recycling**

- Metallic abrasives, Carborundum and Aluminium oxide can be recycled and are usually used more than once, particularly for stationary plants
- Mineral and slag abrasives are generally used only once and in open blast-cleaning

## **Centrifugal blasting**

### **Centrifugal (wheel abrader) blast cleaning**

Two types:

- Mobile units
- Fixed installation

Abrasive is fed to rotating wheels or impellers positioned to throw the abrasive evenly and at high velocity on to the surfaces to be cleaned.

### **Mobile units**

Mobile centrifugal blasting units can for example be used on steel deck (ships) and concrete floors (buildings). The equipment is heavy and only suitable for large, flat areas and has a relative high investment cost. It is environmentally friendly since it reclaims abrasive & dust, but the blast profile can become lower due to the recycling of the abrasives.

### **Fixed Installation**

A system typically consists of:

- Abrasive throwing wheel (or impeller), the number of wheels can vary
- Blast cabinet
- Work piece handling equipment
- Abrasive recycling system
- Dust collector
- Abrasives

The wheel or impeller is the most important part of the system. The wheel or impeller can:

- Accelerate the abrasive by centrifugal force to “throw” the abrasive randomly or it can be aimed specifically so that complex shapes can be treated
- Use a mix of grit and shot for greater efficiency and better surface profile
- The more wheels used can allow for high efficiency and a variety of complex shapes to be cleaned continuously

Factors that can influence the end surface cleaning result:

- If set to the wrong angle the abrasive can miss the target
- The higher the rotating speed the higher the throwing speed and impact force of the abrasive
- These machines are subject to high wear and require frequent maintenance
- Abrasive wears during use and needs to be topped up to maintain a constant quality and surface profile

### **Advantages**

- Very high productivity
- Very little dust produced when operating in open air
- As the motor is electric there is no need for a compressor
- Cost saving in the long term

### **Limitations**

- High initial cost
- Complex equipment
- High maintenance – Worn parts
- Number of wheels can limit the size and shape of treated structure

## **Wet blasting and vacuum blasting**

### **Methods of wet blasting**

Classification of wet blasting depends on how the water and abrasive is mixed:

- *Slurry and Vapour blasting:*
  - Abrasive and water mix together in a vessel and spray through a blasting nozzle
- *Abrasive injection blasting:*
  - Water is highly pressurized and sprayed while a separate nozzle is used to inject abrasive into the water stream in front of water nozzle
- *Abrasive blasting with a water shroud:*
  - A water shroud unit is placed at the end of the blast nozzle to form a water mist in front of the abrasive nozzle to wet the abrasive as it leaves the nozzle

### **Wet blasting**

### **Advantages**

- Eliminates most dust
- Removal of soluble salts and other contamination in one process
- Reduces damages to adjacent areas from abrasive rebound

### **Limitations**

- Depending on the method selected, flash rusting can occur rapidly after blasting
- Inhibitor may be required to control flash rusting
- Not as efficient as dry blasting
- May be necessary to remove remaining abrasives by hosing down

## **Vapour Blasting**

- This is the newest method of dust control for abrasive blasting
- Water and abrasive are mixed in the blast pot in precise (computer controlled) ratios so that the water level is only enough to reduce dust and not flood the surface with water
- Nearly the same productivity as dry blasting
- Flash rusting is not an issue – residual water flashes off

## **Vacuum blasting**

- This equipment has a vacuum attachment which collects the spent abrasive as you blast:
- Equipment is usually for small repairs
- Several types of nozzles profiles can be used to make it possible to treat all steel profiles
- All types of abrasives can be used
- Possible to recycle the abrasives
- Handy size
- Slow production rate
- Environmentally friendly

## **Water jetting**

Cleaning with water has the obvious advantage over abrasive blast cleaning that it does not require a large clean-up operation of spent abrasives and has no abrasive cost. It will however make the substrate wet and it will not create any surface profile.

### **Definition of water cleaning & water jetting**

Both standard ISO 8501-4 and NACE NO. 5/SSPC SP-12 give the following definition:

- Below 70 MPa, the techniques are called water cleaning, classified as:
  - Low-pressure water cleaning (LPWC), defined as cleaning performed at pressures less than 34 MPa (5,000 psi)
  - High-pressure water cleaning (HPWC), defined as cleaning performed at pressures from 34 MPa to 70 MPa (5,000 psi to 10,000 psi)
- Above 70 MPa, the process of cleaning is generally described as high-pressure water jetting
- Above 200 MPa (30,000 psi), the term Ultra-High Pressure Water Jetting (UHPWJ) is commonly used

### **Surface preparation results using water**

- Water cleaning may only remove oil/grease, dust and loose contamination
- Water jetting cannot remove mill scale, but it does remove rust, weathered coatings, etc.
- Ultra-high water jetting equipment is now available which can reach nozzle pressures of 600 MPa (90,000 psi). This gives very high productivity and cleaning efficiency, but the process has safety issues that must be recognised and planned around

## **Ultra-High Pressure Water Jetting (UHPWJ) equipment**

- Water jetting use Rotating Nozzles
  - Nozzles can be tailor made to fit the substrate to be cleaned
  - Angle and capacity of the nozzles can be varied
- Manual water jetting gun:
  - Recoil force is quite strong:
  - Shoulder stock and hand grip can help to resist back force
  - It is important to rotate operators to avoid fatigue
- Robotic water jetting can be used on larger flat areas, such as on ships' hull and storage tanks
  - The robotic equipment may operate suspended from a wire, from a mechanical arm or based on a vacuum-held crawler
  - Robotic UHPWJ equipment will usually collect the spent water and debris automatically and may have a processing unit to clean the water before recycling

## **UHPWJ Health & Safety**

- The extreme high pressure of the water at the cleaning nozzle presents a safety hazard for the operator and observer
- Operators need to add special armoured PPE to their normal PPE when operating this equipment

## **Flash rusting**

With UHPWJ leaving the surface very clean and wet, one might expect flash rust to occur quickly. The formation of flash rust is however often less than expected. The high-pressure water jet supplies energy to the substrate, resulting in heating of the surface. The rise of temperature results in quick evaporation of the water, which together with the lack of salts on the surface reduces the tendency for flash rusting to take place. A more prominent risk is posed by droplets flowing from later water jetting onto the already dry areas.



*Flash rust*

## **UHPWJ**

### **Advantages**

- Removes salt and rust in one step
- No dust produced
- No grit cost (water is cheaper in most areas)
- It is a noisy process, but has a lower noise level than grit-blasting
- Other trades can work nearby (in the neighbourhood)

### **Disadvantages**

- Flash Rusting
- Capital cost of equipment
- Less efficient than abrasive blast cleaning
- No additional surface roughness (but will reveal existing anchor pattern)
- Equipment may be “bulky” for narrow spaces (ballast tanks)
- Water quality and availability
- Water freezes below 0°C
- Inhibitor may be necessary

## Rust converters

Do “Rust Converters” work?

- Generally, you end up with a residue on the surface and that residue may itself be hygroscopic (water drawing) and may initiate osmotic blistering when overcoated
- Check with the coating manufacturer before allowing inhibitors to be used

There are several so called “rust converters” available:

- Phosphoric acid based (forms a layer of iron phosphate on the substrate)
- Tannin based (forms a layer of iron tannate on the substrate)
- Penetrating oils
- Systems transforming rust to Magnetite
- Systems incorporating corrosion inhibitors
- Proprietary “undisclosed content” (other types)

The Australian Standard AS 2312.1 2015 states:

*“The use of a ‘rust converter’ with any of coating systems is not recommended, and will detract from their subsequent performance.”*

# Substrate

## Introduction

The purpose of carrying out surface preparation on non-ferrous substrates is more or less the same as for treating carbon steel:

- To remove contamination
- To create a surface profile

A passive layer (oxide film) will develop on non-ferrous alloys and can interfere with adhesion between the paint and the substrate

A wash primer (etch primer) is sometimes used if thorough cleaning and abrasion is not possible

- Control of the DFT of Etch Primers is crucial as excessive thickness could result in adhesion problems of the next coat due to acid residue on the surface of the etch primer

Common non-ferrous metallic substrates:

- Stainless steel
- Aluminium and its alloys
- Copper and its alloys
- Zinc and its alloys (hot dip galvanizing)

Reasons to apply paint:

- Improve corrosion protection
- Decoration

- Signage or Identification

## Aluminium & Stainless Steel surface preparation

Corrosivity of the environment		
Light corrosivity	Moderate corrosivity	Heavy corrosivity
Degreasing with alkaline detergent and fresh water rinsing followed by:	Degreasing with alkaline detergent and fresh water rinsing followed by:	Degreasing with alkaline detergent and fresh water rinsing followed by:
Light abrading	Hand or machine abrading	Hand or machine abrading <b>OR</b> Brush blasting with non-metallic abrasives

## Copper and its alloys surface preparation

Corrosivity of the environment		
Light corrosivity	Moderate corrosivity	Heavy corrosivity
Degreasing with alkaline detergent and fresh water rinsing followed by:	Degreasing with alkaline detergent and fresh water rinsing followed by:	Degreasing with alkaline detergent and fresh water rinsing followed by:
Light abrading	Hand or machine abrading	Hand or machine abrading <b>OR</b> Brush blasting with non-metallic abrasives

## Zinc surface preparation

Corrosivity of the environment		
Light corrosivity	Moderate corrosivity	Heavy corrosivity
Degreasing with alkaline detergent and fresh water rinsing followed by:	Degreasing with alkaline detergent and fresh water rinsing followed by:	Degreasing with alkaline detergent and fresh water rinsing followed by:
Light abrading <b>OR</b> Weathering (for at least 12 months) then degrease, rinse and light abrade	Hand or machine abrading <b>OR</b> Weathering (for at least 12 months) then degrease, rinse and light abrade	Hand or machine abrading <b>OR</b> Brush blasting with non-metallic abrasives <b>OR</b> Weathering (for at least 12 months) then degrease, rinse and hand or machine abrade

# Ambient conditions

## About ambient conditions

### Introduction

When we in surface treatment terms talk about "ambient conditions", we actually refer to the existing climatic conditions at the scene of the job. The reason for this is that these conditions will have a decisive influence on the resulting quality of the surface treatment, both for the surface preparation, the installation (application) and the conditioning (curing) of the treatment.

The climatic (ambient) conditions we are interested in are not only whether the sun was shining, if it was cloudy or if it was raining, but more specifically:

- The temperature of the air at the scene
- The temperature of the surface receiving the treatment
- The relative humidity in the vicinity of the work
- The risk for condensation to take place on the work surface

The reasons for this interest are that many products and procedures used for surface treatment have restrictions regarding their use at different temperatures and may be sensitive to high or low humidity at critical stages, as well as unsuitable if the surface to be treated is moist or wet.

### Humidity

**Actual humidity** is the actual water content in the air, expressed as gram of water per cubic-meter air (g/m<sup>3</sup>).

**Maximum humidity** is the maximum amount of water vapour which can be contained in air. This will be different for different temperatures, since warm air can hold more water vapour than colder air:

- At 10°C, the maximum moisture content in the air is 9.4 g/m<sup>3</sup>
- At 20°C, the maximum moisture content in the air is 17.3 g/m<sup>3</sup>

**Relative humidity** is an expression for how many percent the actual humidity in the air is of the maximum humidity at the given temperature.

- If the relative humidity is 100%, this means that the air contains the maximum water vapours it possibly can have at that temperature (i.e. actual and maximum humidity are the same).
- If the actual humidity is 30 g/m<sup>3</sup> and the maximum humidity at that temperature is 60 g/m<sup>3</sup>, the relative humidity will be 50% (30 is 50% of 60)
- If the temperature of above air with actual humidity of 30 g/m<sup>3</sup> should increase, the actual humidity will remain the same (30 g/m<sup>3</sup>), but the increased temperature means that the maximum humidity will also increase. If the maximum humidity increases from 60 g/m<sup>3</sup> to 75 g/m<sup>3</sup>, the relative humidity will drop from 50% to 40% (30 is 40% of 75).
- If the temperature of the air in the example with 30 g/m<sup>3</sup> should decrease, the actual humidity will remain

the same ( $30 \text{ g/m}^3$ ), but the decreased temperature means that the maximum humidity will also decrease. If the maximum humidity decreases from  $60 \text{ g/m}^3$  to  $50 \text{ g/m}^3$ , the relative humidity will increase from 50% to 60% (30 is 60% of 50).

- If the temperature of above mentioned air drops so low that the maximum humidity at that temperature is only  $20 \text{ g/m}^3$ , we would in theory end up with a relative humidity of 150% (30 as percentage of 20). It is however not possible for the relative humidity to be higher than the maximum humidity. As a consequence, the overload of water vapour (humidity) will be expelled from the air in form of condensation.

## Temperature

**Temperature in the air:** Unless special heating or cooling facilities are used, paint still in its container (tin) will adjust to the air temperature where it is stored. Some paints are required to be at a minimum temperature when being used, such as solvent free paints (for spray application).

**Substrate temperature:** Regardless of the temperature paint in its tin, as soon as it has been applied to a substrate it will very quickly adjust to the temperature of the substrate. Some paints require a minimum temperature in order to cure, such as epoxy paints.

**Drying times** (such as dry-to-touch, dry-to-recoat, dry-to-use, cured, etc.) will always be influenced by the prevailing temperature, and must for this reason always be checked and recorded.

## Dew point

As explained above, if air contains its maximum humidity content, the RH will be 100% and it is on the borderline for condensation to start. Dew point is what we call the temperature at which the RH is 100% and any excess moisture in the air is expelled in the form of condensation (or dew, as sometimes seen on window panes and mirrors).

*Example:*

- On an early morning inspection, we measure the air temperature to be  $8^\circ\text{C}$  and the RH to be 83%
- Due to cold over-night temperatures, the steel temperature of the structure to be painted is measured at  $4^\circ\text{C}$

*This would cause a problem*

- At  $8^\circ\text{C}$  and RH 83%, the moisture content is  $6.9 \text{ g/m}^3$
- Although the general air temperature is  $8^\circ\text{C}$ , the air next to the steel surface will be cooled by the steel and perhaps only be  $4^\circ\text{C}$  as well
- At  $4^\circ\text{C}$  the max moisture content is  $6.4 \text{ g/m}^3$
- This means that although we may not see it clearly, there will be condensation on the steel ( $6.9 \text{ g/m}^3$  actual versus  $6.4 \text{ g/m}^3$  maximum: excess moisture content!)

The danger for condensation is not only present on early mornings. A sudden change in weather can increase the possibility for condensation to take place at any time of day or night. To ensure that there is no condensation on the substrate to be treated, the sensible work practise is to identify what the dew point is under the current conditions and check that the substrate temperature is higher than the dew point. If the substrate temperature is below the dew point, it is almost certain that the substrate is moist or wet from condensation, even if it may not always be easy to see this with the naked eye.

See below for how to carry out these measurements.

## Condensation

Why are we so concerned about condensation?

- Condensation is water from humidity in the air
- Water on a surface prior to application of paint may lead to adhesion failure
- Water on an abrasive blasted steel surface will cause corrosion
- Condensation on the surface of freshly applied paint may lead to a paint failure or loss of aesthetics (blushing or blooming)
- *ISO 8502 Part 4: Guidance on the estimation of the probability of condensation prior to paint application* states that “Unless otherwise agreed, the steel surface temperature generally should be at least 3°C above the dew-point when paints are used.”
- Above RH 85% the risk of developing condensation on the surface to be painted or condensation on the not yet dried paint film is high, so the industry does not recommend application of paints above RH 85%

While assessing the probability of condensation on the outside of larger object, it is important to bear in mind what is hidden behind the surface:

- Cold liquid in a tank behind the surface and warm air outside will cause condensation on the outside surface
- The mass of steel, such as frames and stiffeners inside the structure, can keep the steel cold longer in very localised areas

## Corrosion

Corrosion is clearly influenced by ambient conditions:

- Atmospheric corrosion increases at higher humidity, above RH 60% there is a clear acceleration, but there is very little corrosion taking place in very dry areas (deserts)
- Since corrosion is a chemical reaction, it speeds up at higher temperatures and slows down at lower temperatures (high in the tropics, low at Antarctica)
- Consequently, corrosion should be very high in tropical rainforests

## Restrictions & precautions

### Paint temperature

- Low temperatures will increase the viscosity, making application difficult (poor flow, poor atomization)
- Higher temperatures can lead to a dry-spray finish and shorter pot-life

## **Substrate temperature**

- Needs to be at a temperature that allows the paint to dry / cure
- Needs to be at a temperature that allows the paint to flow and form a continuous film
- For drying/curing the substrate temperature is more important than the paint temperature
- The paint will acquire the temperature of the substrate after application

## **Relative humidity**

- High humidity may interfere with some paints drying and curing, causing blushing and blooming
- Low humidity may prevent some paints from curing (e.g. inorganic ethyl zinc-silicate and cement based paints)

## **Ambient Temperature and Steel Temperature**

### **Air temperature will influence:**

- Shelf life (storage)
- Pot life
- Induction time
- Viscosity/sprayability
- Steel Temperature

### **Steel temperature will affect:**

- Probability for condensation
- Solvent evaporation
- Viscosity
- Recoating interval
- Speed of drying/curing
- Service life of the coating

## **Controlling ambient conditions**

It is not feasible to control ambient conditions in general. It is however possible to influence them in enclosed or confined spaces, such as inside tanks. These are some of the options:

### **Dehumidifier**

Reduces the actual humidity in the area / surroundings (must be enclosed space)

### **Heater**

Increase the temperature of the objects (surfaces) prior to application in order to reduce the danger for condensation

### **Forced ventilation**

Good ventilation is necessary in order to secure sufficient evaporation of the solvents from the paint film. Temperature and humidity of air used for drying must be monitored:

- Supply of heated air immediately after application may lead to skin drying and entrapped solvents
- Cold air will keep the film open longer and ensure proper evaporation

- Avoid high air temperature (especially epoxy)
- High humidity will slow down drying of water based paints
- Exhaust from heating equipment using propane or paraffin oil contains water and carbon dioxide and may cause amine sweating.

Solvent vapours are heavier than air, so suction ventilation should be arranged at the lowest points in enclosed areas.

# Inspection of Ambient Conditions

## Introduction

As stated in [About ambient conditions](#), the purpose of measuring and assessing ambient condition is to make sure the temperature and relative humidity are favourable for surface preparation, paint application and drying and curing, as well to avoid condensation to form on the substrate at critical stages during the surface treatment.

Modern electronic inspection equipment suppliers, such as Elcometer and DeFelsko, offer multi-purpose instruments which can easily and quickly measure air and substrate temperatures, establish relative humidity and calculate dew point. As long as the battery provides sufficient charge and the electronics works as designed, these instruments are very convenient. They are simple to operate, just follow the manufacturer's instruction, and may produce electronic lists of results and even digital reports. However, if batteries dies or the electronics stop working, a professional surface treatment inspector should also be familiar with how older and simpler equipment work, equipment which is not depending on advanced electronics.

## Ambient temperature (Air temperature)

Everybody knows how to read the temperature on a thermometer. This could be a simple thermometer used for reading the temperature in a room or in the garden, or it could be the dry bulb thermometer of a whirling or sling hygrometer. There are two main types of thermometer:

- Spirit thermometer, identified by having a bulb and rising column of coloured spirit (most common red or blue)
  - Mercury thermometer, identified by having a silver-coloured bulb and raising column containing mercury.
- Note: mercury thermometers are not allowed to be transported by air

## Substrate temperature (Steel temperature)

### Magnetic thermometer

This consists of a spring thermometer connected to a graded dial and is contained in a housing which has a magnet at its base. It can be attached to steel substrates in any horizontal or vertical position / orientation. It is cheap and stable, not battery depending, but need some time to adjust to the temperature of the substrate.

### Digital contact thermometer

These come in many different versions. They all have a probe which is put in contact with the substrate and its

temperature can quickly be read in a digital display window. They have a fast response and are accurate. They are more expensive than the magnetic type and is battery depending.

### **Infrared (laser) thermometer**

Just point the laser on the substrate and read the temperature on its digital display. There is no need for contact with the substrate, so it can be useful for areas difficult to reach. It responds very fast and is fairly accurate, although there have been reports of results being influenced by conditions between the instrument and the substrate (for example the presence of smoke). Battery is required.

## **Relative humidity (RH)**

### **Sling / Whirling hygrometer**

Anybody having been involved in washing cloths will have noticed that the time they take to dry will vary from one day to the other. In warm and dry weather the cloths dry quickly, while in wet and misty weather it takes longer time. We are using this principle in order to determine the relative humidity in the air. When water evaporates it requires energy, leading to a lowering of the temperature of the wet cloth. If there is little moisture in the air the wet cloths will dry quickly, meaning their temperature will fall noticeably. With a lot of moisture in the air the cloths will dry slowly, so the cooling effect will be smaller.

A sling or whirling hygrometer contains two thermometers, the bulb of one is covered by a cloth wick and the other is exposed. After we make the cloth wick wet by water, we will see that the thermometer with wet bulb shows a lower temperature than the one with a dry exposed bulb. To speed up the effect we spin (whirl) the two thermometers in the air around an attached handle, ensuring the evaporation and cooling effect takes place. The difference in temperature between the wet and the dry bulb is directly influenced by the existing humidity in the air. A large difference in temperature between the two thermometers indicates a low humidity, while a small difference signifies a high humidity in the air.

### **Procedure**

1. Fill the reservoir with distilled water
2. Check that the wick covers the bulb of the wet thermometer fully and is saturated with water
3. Hold the handle of the hygrometer and whirl it for 20 to 40 seconds away from your body
4. Quickly read the wet thermometer and whirl the hygrometer again
5. Repeat steps 3 and 4 until consecutive readings are the same
6. Immediately read and note the wet & dry thermometers
7. Calculate the wet bulb depression, i.e. the difference between the dry and wet bulb temperatures
8. Use the accompanying table or slide rule to find Relative Humidity (%RH)
9. Alternatively align the dry bulb temperature and dew point temperature in the dew point calculator and read the %RH in the designated window

### **Psychrometric chart**

A number of different charts are available to determine %RH. Identify the relevant data required on the chart's two axes and find the required result at their cross-point.

Example: Locate the dry bulb temperature in the left column and the difference between the wet bulb and dry bulb temperatures in the column header row. The %RH will be found in the intersection between the column and

the row.

Dry-Bulb Temperature (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (C°)														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
-20	100	28													
-18	100	40													
-16	100	48													
-14	100	55	11												
-12	100	61	23												
-10	100	66	33												
-8	100	71	41	13											
-6	100	73	48	20											
-4	100	77	54	32	11										
-2	100	79	58	37	20	1									
0	100	81	63	45	28	11									

## IX Diagram

The IX Diagram is a special form of psychrometric chart. Based on wet and dry bulb measurements, %RH can be determined from an IX Diagram, see separate IX-section.

There are multi-function instruments that can measure dry and wet bulb temperature, wet drop-down (depression), relative humidity, dew point and substrate temperature in one go.

## Dew Point

As stated earlier, dew point is the temperature where the RH is 100%, so any moisture in the air are about to start forming condensation. We are interested in determining the dew point in order to check that the temperature of any surface being involved in our work is minimum 3°C above the dew point. This will ensure that all surfaces being worked on will not suffer from condensation. If such condensation should occur, the quality of any surface preparation would deteriorate and the paint is likely to suffer from weaknesses or complete failure.

Dew point is not measured, it is calculated with basis in wet and dry bulb measurements. There are several tools which can be used for this calculation:

### Sling hydrometer

Sling hydrometer of the Bacharach type (round, black plastic body) has a built in sliding scale where the dew point can be determined, using the wet and dry bulb measurements:

1. After measuring the wet and dry bulb temperatures, slide the body back into the tube (aligning the groove with the arrow) until the wet and dry temperature readings are opposite each other on the top two scales
2. The %RH is shown on the scale below the arrow
3. To find the dew point, note the Wet bulb temperature. Find this figure on the Dry bulb scale. Dew point is the equivalent value on the Wet bulb scale.

## Dew Point Calculator

1. Use sling / whirling hygrometer to measure dry bulb and wet bulb temperature
2. Follow the instruction printed on the face of the circular plastic calculator

## ISO 8502-4

Use Annex A Table for determination of dew-point in this standard:

1. Locate the% RH in the left column (the column extends over two pages)
2. Locate the air temperature in the column header row (the header extends over several pages)
3. The dew point will be found at the intersection between the %RH and air temperature

## Psychrometric chart

A number of different charts are available to determine dew point. Identify the relevant data required on the chart's two axes and find the required result at their cross-point.

Example: Locate the dry bulb temperature in the left column and the difference between the wet bulb and dry bulb temperatures in the column header row. The dew point temperature will be found in the intersection between the column and the row.

## IX Diagram

The IX Diagram is a special form of psychrometric chart. Based on wet and dry bulb measurements, dew point can be determined from an IX Diagram, see separate IX-section.

There are multi-function instruments that can measure dry and wet bulb temperature, wet drop-down (depression), relative humidity, dew point and substrate temperature in one go.

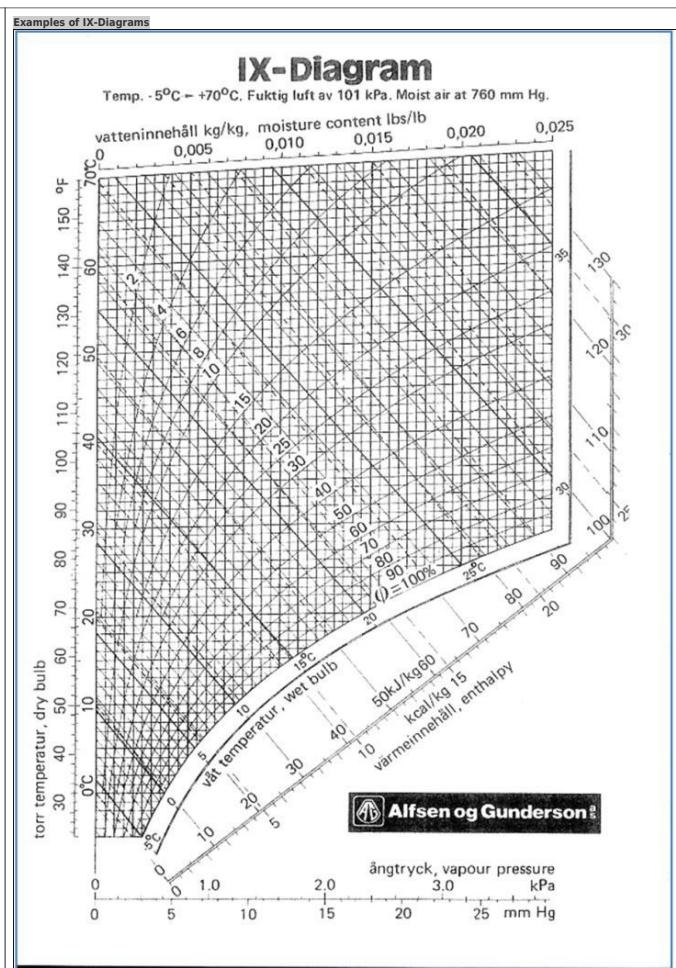
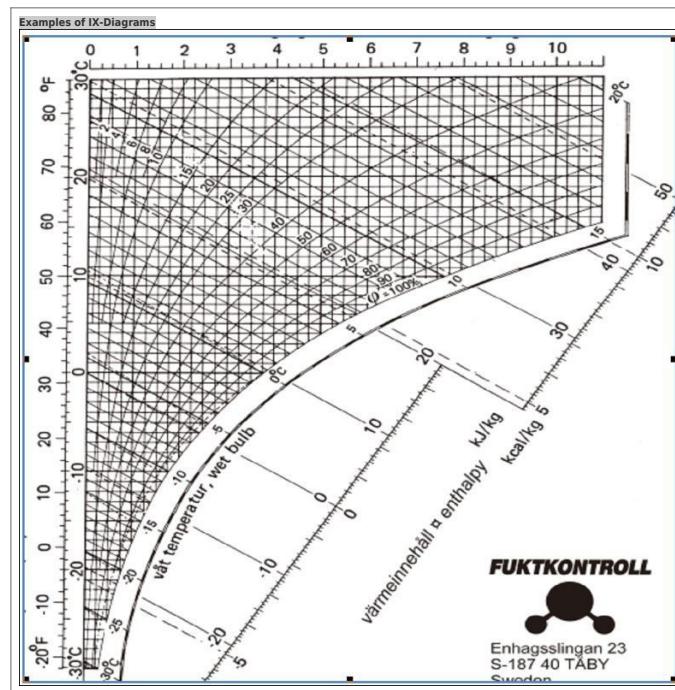
## IX Diagram

The IX Diagram is a special form of psychrometric chart. Based on wet and dry bulb measurements from a sling hydrometer, dew point, %RH and moisture content can be determined from an IX Diagram.

The IX Diagram for air and water vapour mixtures was first published by Richard Mollier, Dresden, in 1927. The diagram has since been extended and updated, and can today be found in a few slightly different versions. The principle for using an IX Diagram is largely the same for all versions:

1. Find the Dry bulb temperature on the left edge scale and draw a horizontal line
2. Find the wet bulb temperature on the diagonal scale and draw a line at 90 degree angle. (NOTE: If the wet bulb scale is split and continues at a different angle, draw the line at 90 degrees to the first part of the scale)
3. Start from cross between the two drawn lines and draw a third line vertically down to 100% RH curved scale
4. From the crossing point on the 100% RH curve, draw a horizontal line back to the dry bulb scale and this cross point will show the Dew Point

## Examples of IX-Diagrams



## Examples of IX-Diagrams

### USING THE IX-DIAGRAM:

Draw a horizontal line from the dry temperature (A)

Draw a line from the wet temperature at 90 degr. angle to the wet temp scale (B)

Determine the crossing point (C) of the dry and wet temp lines

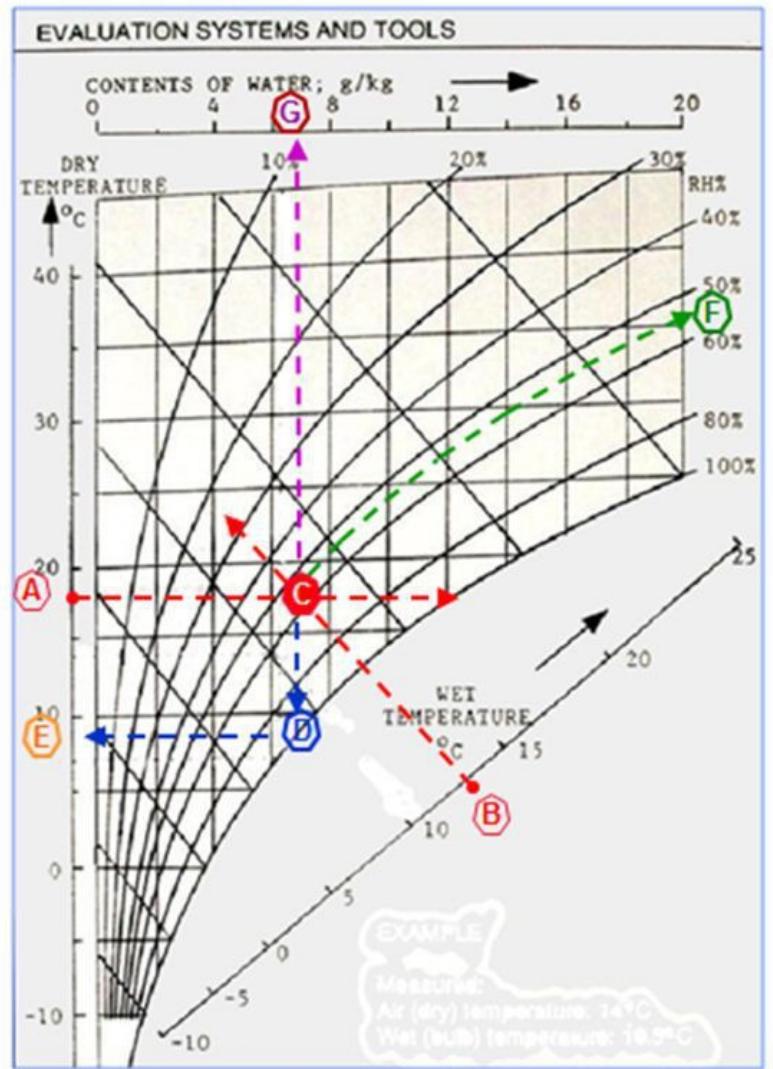
Draw a vertical line from (C) to the 100% RH-line (D)

Draw a horizontal line from (D) to the dry temperature scale

Dew point (E) will be found on the dry temp scale

Estimate RH% from (C) by following the curved lines to the RH scale (F)

Water content in the air can be found by drawing a vertical line from (C) to the scale on top (g/kg or g/m<sup>3</sup>) (G)



## Frequency of measurements

- Within the time of a work shift, ambient measurement should be taken at least before the job starts, at the middle of a job and after the job
- Additionally, more measurements must be taken if weather conditions change

The substrate temperature must be at least 3°C above the substrate temperature.

Commonly, the specification require Relative Humidity should be less than 85%.

# Paint & paint systems

## Paint composition

### Introduction

#### 1. Paint consists of:

<b>A. Liquid: Vehicle / Varnish</b> <ul style="list-style-type: none"><li>Binders</li><li>Solvents</li></ul>	<b>B. Dry: Powders / Pigments</b> <ul style="list-style-type: none"><li>Colour pigments</li><li>Active / Reactive pigments</li><li>Extenders</li><li>Barrier pigments</li></ul>	<b>C. Chemicals: Additives</b> <ul style="list-style-type: none"><li>Production enhancers</li><li>Storage facilitators</li><li>Application aids</li><li>Appearance improvers</li><li>Service life improvers</li></ul>
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(FROSIO's grouping: Binder, Pigments, Extenders, Solvents, and Additives)

#### 2. Composition of paints

<b>A. Binder</b> <i>Natural Resins:</i> <ul style="list-style-type: none"><li>Drying oil</li><li>Bitumen</li><li>Wood Rosin</li></ul> <i>Synthetic Resins:</i> <ul style="list-style-type: none"><li>Alkyd</li><li>Epoxy</li><li>Polyester</li><li>Polyurethane</li><li>Silicate</li><li>Vinyl Ester</li><li>Polysiloxane</li></ul>	<b>B. Pigments</b> <ul style="list-style-type: none"><li>Colouring</li><li>Inhibitive pigment</li><li>Cathodic</li><li>protective</li><li>Biocides</li></ul>	<b>C. Extender</b> <ul style="list-style-type: none"><li>Calcium carbonate/ Chalk</li><li>Barium sulphate/ Barytes</li><li>Mica</li><li>Talc</li><li>Dolomite</li></ul>
<b>D. Solvent</b> <ul style="list-style-type: none"><li>Hydro carbons</li><li>Ketones</li><li>Esters</li><li>Ethers</li><li>Alcohols</li><li>Water</li></ul>	<b>E. Additive</b> <ul style="list-style-type: none"><li>Wetting agent</li><li>Anti-settling</li><li>Drier</li><li>Anti-skinner</li><li>Plasticizer</li></ul>	

### Binders

#### Decides the properties of paint

- Describes the type of paint/coating (generic type)
- Binds pigments and extenders within the solid film
- Provides adhesion to the substrate and cohesion, flexibility in the film
- Provides the water, chemical, solvent and UV resistance

#### Organic vs. Inorganic Coating

The classification organic versus inorganic coating refers to the binder.

### What is an Organic coating?

- Coating based on a binder that is carbon based e.g. made from oil
- For example, epoxy, polyurethane, polyester

### What is an Inorganic coating?

- Coating based on a binder that is not carbon based, typically silicate
- Usually pigmented with metallic zinc
- In general, inorganic binders are electrically conductive
- For example, Zinc alkyl silicate, Zinc alkali silicate

### Types of binders

<b>Synthetic resins:</b> <ul style="list-style-type: none"><li>• Alkyd</li><li>• Acrylic – Solvent borne</li><li>• Acrylic – Water borne</li><li>• Epoxy</li><li>• Polyurethane</li><li>• Silicate</li><li>• Polyester</li><li>• Vinyl ester</li><li>• Polysiloxane</li></ul>	<b>Natural resins:</b> <ul style="list-style-type: none"><li>• Drying oil</li><li>• Wood rosin</li><li>• Bitumen</li></ul>
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### Epoxy resin and hardener



## **Modified binders**

A modified binder may contain more than one binder:

- Epoxy Mastic
- Vinyl Epoxy

A binder may be modified chemically by attaching new molecule groups to their molecules:

- Styrene modified alkyd
- Urethane modified alkyd
- Epoxy ester

## **Solvents**

### **Purpose in the paint**

- Must dissolve the binder
- Gives lower viscosity
- Gives application properties for brush, roller, spray
- Once the paint has been applied, there is no more need for the solvent

### **Solvents - examples**

- White Spirit
- Xylene
- Ketones
- Esters
- Glycol ethers
- Alcohols
- Reactive solvents e.g. styrene

### **Solvent**



## **Solvent vs. Thinner**

### **Solvent**

- Raw material used when making paints and thinners
- Dissolves the binder completely (forms a solution)

### **Thinner**

- Commercial products
- Used to lower the viscosity (and for cleaning the equipment)
- May be made up by a single solvent or of a mixture of solvents

**The paint is supplied with the correct viscosity**

- The paint is supplied at its optimal viscosity for being applied
- Thinning is usually only required to adjust the viscosity to suit application method and temperatures
- Use only the thinner named in TDS
- Excessive thinning should be avoided

## Addition of thinner

Evaporation rate and solubility of a thinner will influence paint's:

- Drying time
- Film-forming properties
- Quality of the film

Most paints are ready to be applied as supplied by the manufacturer.

Never add an unknown thinner to paint, it may cause issues with drying, application and durability

## Volatile / Non-volatile

Paint's "Solid Content" means the ingredients which do not evaporate. Commonly referred to as Solids by Volume (%)

Paint's "VOC" (Volatile Organic Compound) tell us how many grams of volatiles there are in one litre of paint

## Solid content: WFT vs. DFT

When applied in the same WFT, the paint with the higher solids content will give a higher DFT (and thus needs fewer coats or gives better protection)

# Pigments

## Colour Pigments

- Natural or synthetic pigments
- Organic or inorganic pigments
- Give colour to the film
- Hide the substrate / previous coats (opacity)
- Almost all colours consist of a blend of pigments
- A colour can be changed or adjusted by altering the pigment blend

## Decorative pigments



## Active / Reactive Pigments

Takes an active role in ensuring that the paint performs as expected:

- Anticorrosive
  - Zinc-phosphate
  - Zinc-dust
- Antifouling
  - Cuprous oxide

## Barrier pigments

- Flake-shaped pigments
- Tend to align themselves parallel to the substrate
- Reinforces the film
- Increase the pathway between the surface and the substrate (barrier effect)
- Often made from aluminium, glass, mica or micaceous iron oxide (MIO)

## Inhibitive pigments and Cathodic Protective pigments

- Inhibitive pigments:
  - Zinc Phosphate
- Pigments with cathodic protection effect:

- Metallic zinc

## Extender Pigments

Naturally occurring minerals:

- Dolomite
- Talc (Talcum powder)
- Chalk (Calcium Carbonate)
- Clay (China Clay)
- Reinforce and give body to the film
- Improves hardness
- White / grey in colour
- Very little influence on colour of the film (poor opacity)

## Filler



## Pigment Volume Concentration - PVC

An expression of how much of the dry paint film is made up of pigments. This may affect several of the paint's properties, such as abrasion resistance, flexibility, gloss, etc.

# Additives

## Examples

- Wetting agent
- Anti-foam
- Anti-settling
- Anti-skin
- Anti-sagging
- Levelling agent
- Catalysts
- UV-absorbers

## Additives



## Many types

- Production enhancers
  - improve manufacturing
- Storage facilitators
  - storage stability
- Application aids
  - easier application
- Appearance improvers
  - better gloss
- Service life
  - resist fouling

# Generic types of paint

## Drying / curing mechanism

The properties of a paint film are closely related to how the binder dries or cures. The four most common drying / curing mechanisms are:

- *Physical Drying* (solvent evaporation)
- *Oxidative Curing* (reaction with oxygen in the air)
- *Chemical Curing* (chemical reaction between base and hardener)
- *Coalescence* (evaporation of water followed by merging of the paint droplets)

### Physical drying

1. The solvents evaporate
2. Molecules pack and melt together to form a paint film
3. No chemical reactions

### Oxidative curing (drying)

1. The solvents evaporate
2. Oxygen enter the paint and the reaction starts
3. The binder molecules link together through a chemical reaction with oxygen

### Chemical curing

1. The solvents, if present, evaporate
2. After mixing the separate components together the individual reactive ingredients react together
3. A three dimensional network is formed which gives the solid paint film

Proper mixing is a pre-requisite to obtain proper curing. Insufficient mixing makes it impossible for all the reactive ingredients to come in contact in the right proportions with each other and a three dimensional network will not be formed.

### Coalescence (Physical drying waterborne paints)

1. Water evaporate
2. Dispersed droplets melt together
3. Co-solvents evaporate to form a paint film
4. No chemical reactions

### Factors influencing the drying process

- Ventilation
- Temperature
- Film thickness
- Number of coats
- Evaporation rate of the solvents, if present

For water borne paints high relative humidity slows down the drying process

## Curing mechanism of various binders

### ***Physically drying:***

- Vinyl
- Acrylic

### ***Oxidatively curing:***

- Alkyd
- Drying oils
- Epoxy ester

### ***Chemically curing:***

- Epoxy
- Polyurethane
- Polyester
- Vinyl ester
- Silicate
- Polysiloxane

## Generic types of coatings

The generic type refers to the ingredient responsible for the basic properties of the paint. In most cases the binder dictates the properties, and defines the generic type.

### **Common generic types of paint**

- Alkyd
- Vinyl
- Acrylic
- Epoxy
- Zinc rich epoxy
- Polyurethane
- Polysiloxane
- Inorganic zinc silicate
- Polyester
- Vinyl ester
- Silicone

Sometimes paint may be referred to as "modified", e.g. modified epoxy paint. This may involve either a chemical modification of the binder or blending smaller amounts of an additional binder into the paint.

## Typical properties of various generic types of paint

### **A. Alkyd paint**

#### **Advantages**

- Good application properties
- component
- Good weather ability
- Good wetting properties
- Good recoatability
- Good leveling properties
- Good gloss retention
- Heat resistant up to 120 °C

#### ***Limitations***

- Poor chemical resistance (especially against alkalis)
- Never to be used on Zinc
- Limited water resistance (submerged)
- Limited solvent resistance
- Limited film thickness per coat

### **C. Acrylic paint-Solvent borne**

#### ***Advantages***

- Physically drying
- Easy to recoat
- One component
- Good water resistance
- Relatively good chemical resistance
- Good weather resistance

#### ***Limitations***

- High VOC
- Poor solvent resistance
- Low solid content
- Relatively poor wetting properties
- Thermoplastic

### **C. Unmodified epoxy paint**

#### ***Advantages***

- Very good chemical resistance
- High alkali resistance
- Moderate resistance to acids
- Good adhesion
- Very low permeability
- High mechanical strength
- Dry heat resistant up to 120°C

#### ***Limitations***

- Chalking
- Temperature affects cure time

- Over coating time affected by temperature. Some have short maximum overcoat times

#### **D. Epoxy mastic paint (modified epoxy)**

##### **Advantages**

- Surface tolerant
- High solids
- High build

##### **Limitations**

- Not UV - resistant
- Temperature dependent for curing
- Sweating-non reacted cure components

#### **E. Zinc rich epoxy paint**

##### **Advantages**

- Chemically curing
- Good corrosion protection
- Good adhesion
- Requires min. Sa 2½
- Good mechanical strength
- May be recoated with all types of paint, except alkyd based or very high build coatings >500µm
- Dry heat resistant up to 120°C

##### **Limitations**

- Temperature dependent curing
- Film thickness: 25 - 90 um
- Not acid- and alkali resistant
  - (Resistant between pH 5-9)

#### **F. Polyurethane paint**

##### **Advantages**

- Very good weather resistance
- Excellent gloss retention
- Very good chemical resistance
- Very good solvent resistance
- Cures down to 0 °C

##### **Limitations**

- May cause skin irritation
- May create toxic fumes in a fire

#### **G. Zinc ethyl-silicate paint**

##### **Advantages**

- Very good solvent resistance

- Very high heat resistance, up to 400° C (max 540 °C for short periods)
- Very high mechanical strength
- Very good adhesion to blast cleaned steel
- Can be overcoated with a wide range of coatings (not alkyd)

***Limitations:***

- Requires humidity in excess of 50% RH for curing
- DFT: 125 µm
- Mud-cracking or checking at higher DFT

**H. Glass-flake reinforced polyester**

***Advantages***

- Quick curing
- Variable curing time
- Application with airless spray
- Excellent mechanical strength
- Glass-flakes reduce shrinkage, increases mechanical strength and water resistance
- Very good chemical resistance

***Limitations***

- Short pot life
- Limited shelf life
- Recoating interval: 2 to 12 hours
- Should not be applied over zinc primers and galvanized surfaces

**I. Acrylic waterborne paints**

***Advantages***

- Very low VOC
- Water is relatively cheap and readily available
- Quick surface drying
- Simple cleaning of equipment
- Low risk of fire

***Limitations***

- Can not be used below 0°C
- Dries slowly at high relative humidity
- Needs long time to reach full hardness
- Thermoplastic
- Poor solvent resistance

**Common curing agents for Epoxy Paints**

***Polyamide***

- Unmodified & modified epoxy paints

### **Amine and amine adduct**

- Improved chemical resistance
- E.g. Tank coatings

### **Surface tolerance**

- Surface tolerant paints adhere well and offer long term protective properties on substrates where optimum surface preparation is not possible or desired
- The surface tolerance depends largely on the wetting (penetrating) properties of the binder
- Most paints can be applied to steel blast cleaned to Sa 2½
- Not all paints possess the required wetting property for successful application on uneven substrates
- Surface tolerant paints give a longer life time on such substrates

## **Antifouling paints**

Fouling is the settlement and growth of marine plants and animals on surfaces in the sea. There is an estimated 4-5.000 fouling species and these can be classified into:

### **1. Micro-fouling**

- Generally referred to as slime, a complex viscous mixture of bacteria and microscopic organisms

### **2. Macro-fouling**

- Which includes animals and plants

### **Examples of fouling in seawater**

#### ***Micro-fouling***

- Biofilm or slime
- Bacteria
- Blue green algae
- Diatoms
- Protozoa
- Other micro-organisms
- Up to 1 mm thick

#### ***Macro fouling - algae***

- Grass
- Green algae
- Brown algae
- Red algae
- Grow only in presence of light

#### ***Macro fouling - animals***

- Barnacles
- Mussels

- Tubeworms
- Hydroids
- Bryozoa
- Tunicates

### **How does fouling happen?**

- Free floating or free swimming spores and larvae follow the currents, tides and waves
- They look for the opportunity to contact suitable surfaces
- Fouling happens when these larvae or spores settle and develop into an adult, small at first, but steadily growing
- Any man-made structure in the sea will be subjected to fouling (marine growth)
- The challenge is to create a surface which is not attractive or conducive for such growth

### **Fouling on ships' hulls leads to:**

- Increased frictional drag
- Increased fuel consumption
- Increased emissions to air
- Possible transmigration of non-indigenous species
- High cost of removal

### **The purpose of antifouling paints**

- To prevent or reduce growth
- To provide better fuel economy over the sailing period
- To avoid growth penetrating the coating and thereby damage the corrosion protection

### **The composition of antifouling paints**

Antifouling paints contain the same main groups of raw materials as other paints plus additional biocides to prevent or reduce the settlement of marine growth.

- Binder
- Biocide
- Extenders
- Pigments
- Solvents
- Additives

The most common biocide used in antifouling paints is Cuprous oxide

### **Main types of antifouling paints:**

#### ***Conventional antifouling***

- Soluble matrix paints
- Rosin as part of the binder
- Approximately 12 months protection
- Binders dissolve in water and biocide is released

**NOTE:** Danger of cracking and flaking if not quickly immersed in water

### **Long-life antifouling**

- Insoluble matrix paints
- Only the biocides are released
- Effective protection is up to 24 months
- Leaves weak substrate for subsequent coat (leached layer)
- Sealer coat normally required
- Binder: Vinyl, acryl (possible to add small amount of rosin)

### **Self-polishing antifoulings**

- Predictable performance
- Extended dry docking period
- Control of roughness and smoothing
- No “sandwich coatings” problems
- Lifetime directly proportional to dry film thickness

### **Antifouling for aluminium hulls**

- Copper-containing antifouling must not be used directly on an aluminium hull
- Metallic copper in contact with aluminium will cause bi-metallic corrosion
- A full anti corrosive system must be applied on the aluminium hull before the antifouling

## **Shopprimers**

### **Shopprimer definition**

A quick drying paint applied as a thin film to a metal surface after blast cleaning, to give corrosion protection during the period before and during fabrication

**Requirement:** Must not interfere with the speed or quality of cutting and welding of the steel during fabrication, so DFT must be low

### **Shopprimer history**

- In the early days shopprimers were designed for only temporary protection and was removed by blast cleaning before the steel was painted
- Later on, improved quality was developed which required only re-blasting of welds and mechanical / thermal damages before the steel was painted
- Today's technology using only UHPWJ treatment before painting
- Shopprimer may now be a part of the long term protective paint system

### **Shopprimers - types**

While other paints generally are classified according to their type of binder, shopprimers are often classified according to their main pigment content:

1. Iron oxide shopprimers
2. Zinc rich shopprimers

Types / pigments	Binders	Typical DFT (µm)	Corrosion protection, typical (months)
Iron oxide	PVB(*)	15-20 µm	3
	Epoxy	15-20 µm	5
Zinc rich	Ethyl silicate	10-15 µm	10
	Epoxy	15-20 µm	8

(\*) Poly Vinyl Butyral

### Iron oxide shopprimers - characteristics

Types / pigments	Binders	Advantages	Limitation
Iron oxide	PVB(*)	- One component - Quick drying - Flexibility	- Low %-volume solids - Low heat resistance - Not compatible with cathodic protection
	Epoxy	- Adhesion - Chemical resistance - Well suited with cathodic protection	- Short pot life - Low flash point

(\*) Poly Vinyl Butyral

### Zinc rich shopprimers - characteristics

Types / pigments	Binders	Advantages	Limitation
Zinc rich	Ethyl silicate	- Abrasion resistance - Corrosion protection - Allows high welding and burning speed - Few burning damages	- Needs high air humidity for curing - Forms zinc salts on the surface - Zinc fumes from welding and burning may cause zinc fever
	Epoxy	- Adhesion - Ease of over coating	- Forms zinc salts on the surface - Zinc fumes from welding and burning may cause zinc fever

### Activities involved in shop priming

- Cleaning
- Blasting
- Application
- Handling

### Controlling thickness and integrity of the film

- Use glass plates or smooth steel plates only
- Length of test panel must be sufficient to cover overlapping zones
- Glass plate: Hold against a light source to check film integrity (dry spray, pinholes, etc.)
- Steel panel: Thickness measurement (magnetic DFT gauge)
- Repair main steel plate if test panels were fixed to main plate

## **Coating over shop-primed steel**

- Check for cleanliness / intact surface: OK
- If contaminated by zinc salts:
  - Remove by High Pressure Water
  - Cleaning or blast sweeping
- Rust, damage, welds should be treated according to specification
- Heat-affected areas (thermal damages) must receive treatment to specified standard

# Paint systems

## Introduction

### **Can we find a paint for all environments and surfaces?**

Different paints can be used to protect a variety of construction materials. No paint can be used in all environments!

### **Factors influencing the selection of a paint system**

- Customer's expectation (durability)
- Service environment
- Availability of paint and/or other protective materials
- Substrate
- Structure design
- Surface preparation available
- Paint application methods available
- Ease of maintenance
- Cost
- Health, safety and environmental factors

### **Customer Expectations**

- Customers are usually concerned with corrosion and the durability of the asset with aesthetics normally not as important
- To meet their durability requirements coating system durability should be discussed
- According to ISO 12944-1 durability is defined as the expected life of a protective paint system to the first major maintenance painting
- Durability is not the same as a "guarantee" period

### **Corrosivity of the Environment**

- It is important to identify the corrosivity category of an environment since it will relate to:
  - Corrosion rate of the building material
  - Material selection of building products
  - Selection of proper corrosion protection methods for the building materials
- ISO 12944-2 defines the classification of environments by corrosivity category

# Corrosivity Categories of Environment

## Corrosivity Categories of Environment - ISO 12944-2

Atmospheric condition		Immersion	
C1	Very low	Im 1	Fresh water
C2	Low		
C3	Medium	Im 2	Sea or brackish water
C4	High		
C5	Very high	Im 3	Soil
CX	Extreme	Im 4	Sea or brackish water with cathodic protection

### Description of corrosivity categories

#### C1 Very low

- Interior: Heated buildings with clean atmospheres, e.g. offices, shops, schools, hotels

#### C2 Low

- Exterior: Atmospheres with low level of pollution. Mostly rural areas
- Interior: Unheated buildings where condensation may occur, e.g. depots, sports halls

#### C3 Medium

- Exterior: Urban and industrial atmospheres, moderate sulfur dioxide pollution. Coastal areas with low salinity
- Interior: Production rooms with high humidity and some air pollution, e.g. food-processing plants, laundries, breweries, dairies

#### C4 High

- Exterior: Industrial areas and coastal areas with moderate salinity
- Interior: Chemical plants, swimming pools, coastal ship- and boatyards

#### C5- Very high

- Exterior: Industrial areas with high humidity and aggressive atmosphere and coastal areas with high salinity
- Interior: Buildings or areas with almost permanent condensation and with high pollution

#### CX- Extreme

- Exterior: Offshore areas with high salinity and industrial areas with extreme humidity and aggressive atmosphere and subtropical and tropical atmospheres
- Interior: Industrial areas with extreme humidity and aggressive atmosphere

### **Im1 Fresh water**

- River installations, hydro-electric power plants

### **Im2 Sea or brackish water**

- Immersed structures without cathodic protection (e.g. harbor areas with structures like sluice gates, locks, jetties)

### **Im3 Soil**

- Buried tanks, steel piles, steel pipes

### **Im4 Sea and brackish water**

- *Immersed structures with cathodic protection (e.g. offshore structures)*

## **Selecting a paint system according to ISO 12944-5**

ISO 12944-5 is an industrial standard which can be referenced to find a suitable system for new construction. There are lists of typical systems categorized by:

- Substrate (low-alloyed carbon steel, hot-dip galvanized steel and thermally sprayed steel)
- Corrosivity category (C1, C2, C3, C4, C5, CX, Im1, Im2, Im3, Im4)
- Expected durability (low, medium and high)

## **Build-up of a Paint System**

There are no “magic” paints that can do everything, hence, multi-layer systems are normal in most cases:

- Primer / Intermediate coat / Topcoat

However, one coat system may also be specified:

- Paint is specially designed for a single coat
- Constant, mild environment
- Minor job such as maintenance
- Low expected durability

## **Primers**

Primers are universal for most anticorrosive coating systems and are considered the most important component of the system. The most important properties of primers are listed as follows:

- Adhesion (strong bonding to substrate)
- Cohesion (high internal strength in the film)
- Intercoat adhesion (high bonding to intermediate coat)
- Appropriate flexibility

## **Intermediate coats**

The principal purposes of an intermediate coat is to provide:

- Thickness for total coating system
- Strong chemical resistance

- Resistance to moisture vapor transfer
- Increase electrical resistance for the coating system
- Strong cohesion
- Strong bonding to primer and topcoat

## Topcoats

Topcoats also perform several important functions as they:

- Provide a resistant seal for the coating system
- Form the initial barrier towards the environment
- Provide resistance towards chemicals, water, and weather
- Provide a tough and wear-resistant surface
- Provide a pleasant appearance

## General rules – thickness of coating system

Deciding factor is the environment:

An example:

- In a dry inland atmosphere, and indoors 120 µm will be sufficient, while in a coastal environment, 250 - 300 µm may be necessary to achieve the same number of years durability

Number of coats is also of importance

- 100 µm in 2 coats (50 + 50 µm) will give better protection than 100 µm in 1 coat

## Where can we find the properties of a paint?

- It is impossible to know all different paint products
- Technical data sheet (TDS) from supplier is a suitable source
- Information that may be found in a TDS or Application Guide:
  - Product description
  - Recommended use and typical paint system
  - Film thickness and spreading rate
  - Approvals
  - Physical properties
  - Surface preparation (methods and requirements)
  - Application (ambient condition, methods, technical parameters)
  - Drying time
  - Brief HSE requirements (Refer SDS)
  - Packing size

Inspectors need to understand and be familiar with the technical data in TDS

## Environmental factors not covered in ISO 12944-2

- The Corrosivity categories in ISO 12944 do not cover all situations
- Some factors causing increased corrosion:
  - Heat (high)

- Chemicals
- Stray current
- Mechanical stress
- To find proper paint systems for these environments is not easy
- We can always consult paint supplier and also confirm with pre-qualification testing

# Application equipment

## Good practice

If you look up the word “Practice” in a thesaurus, you will find that it can have many meanings, such as Preparation, Training, Habit, Routine, Procedure, to Perform, to Apply, to Follow, to Observe, and TO DO.

“Good Practice” can therefore mean that we must prepare well, have adequate training, get rid of bad habits, follow established routines and procedures, perform to the best of our abilities, follow specifications and observe rules and regulations, simply we DO OUR BEST.

On a practical level, good practice within surface treatment will include:

### Planning & organisation

- Make sure all necessary documentation is up-to-date and available, including copies of specification, relevant standards and data sheets

### Accessibility

- Good access is as important to achieving satisfactory coating application as is the quality of the equipment!
- If a paint applicator cannot reach the areas to be coated in a comfortable and secure way, the quality of the application is bound to suffer

### Personal Protection Equipment (PPE)

- Use correct and adequate protection while using paint

### Proper cleaning of tools after or during application

- Cleanliness and good housekeeping before, during and after application are some of the most important factors toward achieving a good result
- Nothing can stop two-pack paints from curing once they have been mixed, while single pack paints will start to dry when exposed to open air. Application equipment which is not cleaned immediately after use will quickly become useless and completely unsuitable for further application of paint

### Application methods and equipment

There are a number of application methods and equipment available for paint application, such as Painter’s glove (for small pipes & handrails), Electrostatic spray, Pressure-feed brush & roller, Dipping (production line), “Curtain” application (high volume sheet or coil operations), Counter-roller (coil coating), Sponge (decorative)

and Under water application.

Structures requiring heavy duty corrosion protection can be of complex shapes and manufactured from a variety of materials such as carbon steel, aluminium, plastics etc. and can have very large surface areas that need protecting. Some common methods and equipment are:

- Brush application
- Roller application
- Air spray application
- Airless spray application

We will focus on these methods and related equipment in this course. They include both hand tools as well as power-driven application methods.

## Hand Tools

### **Hand-tools for application of paint**

- Stick for stirring paint: Only to be used for small tins, power-mixer must be used for stirring larger tins of protective coatings
- Paint brushes (various sizes and shapes)
- Paint rollers (various sizes and shapes)
- Tape for masking

### **Application by paint brush**

#### **Benefits**

- Good wetting of the substrate
- Forces the paint into the surface
- Better than a roller on the first coat
- Good on areas with poor accessibility

#### **Limitations**

- Gives low film thickness, many coats required
- Creates an uneven film
- Application speed is slow

Good quality paint brushes must be cleaned properly to maintain their properties

### **Application by roller**

#### **Benefits**

- Application speed is faster than with a paint brush
- Good on areas with poor accessibility

#### **Limitations**

- Poor wetting of the substrate
- Never use for the first coat as the roller may trap air and cause pinholes in the paint film

- Gives low film thickness, multiple coats required

Roller application will not force the paint into the profile of the substrate, but rather deposit it over the peaks. Satisfactory result for industrial/marine painting is very dependent on the quality of the surface preparation.

## About spray application equipment

The principle of spray application equipment is that paint is forced through a hose to a spray gun, where it is released through a nozzle with a small opening. Upon leaving the nozzle the paint must be broken down into small droplets and pushed forward at speed. This is achieved in a few different ways depending on the type of spray application equipment.

Below we will present the following:

1. Air Spray
2. HVLP: High Volume Low Pressure
3. Airless Spray
4. Air assist airless spray
5. Plural-component airless spray pump
6. Nomogram

## Air spray

Air spray is often also referred to as “conventional spray”. When the paint exits the air spray nozzle, it immediately enters a crossfire of pressurized air jets which breaks the paint into small droplets and push them forwards. Air spray applied paints thus form a mist of fine droplets.

There are three main principles for making the paint move through and out of the air spray nozzle:

1. Gravity feed: The paint is held in a container which is mounted on top of the spray gun. Gravity will force the paint into the spray gun and nozzle
2. Siphon feed: The paint is held in a container which is attached to the underside of the spray gun. A pipe leads from the paint in the container to the inside of the gun. When compressed air passes through the gun, the paint is siphoned (drawn) from the container to the spray nozzle
3. Pressure pot: The paint is held in a separate closed container which is connected to the spray gun via a hose. The pressure in the closed container is increased by letting in compressed air, causing the paint to be forced through the hose to the spray gun

Air spray application is only suitable for thin paints (low viscosity). Such paints may suffer from pigments settling in the lower part of the containers, particularly if the paint contains heavy metallic pigments (e.g. zinc silicate paint). Many pressure pots have a built-in stirrer, driven by a separate air motor, to prevent such pigment settling.

## Benefits

- Higher productivity than hand tools
- Admirable finish-smooth and glossy
- Lower pressure-safety

- Even film thickness
- Simpler equipment

## Limitations

- May have dry spray (overspray)
- Limited film thickness
- Only for low viscosity paint
- Relies on compressed air

## HVLP: High Volume Low Pressure

Conventional air spray guns operate at a basic, high compressed air pressure. They connect to an air compressor and the finish is "blasted" onto the substrate using this high pressure. Because this high-pressure finely atomizes the spray (produces very fine particles), this gives a very nice smooth application, typically used in the automotive industry. Despite this excellent end result, conventional spray guns are only about 30% effective, meaning as little as 30% of the paint actually ends up where it's supposed to go. The rest is overspray, bouncing off the substrate or simply floating in the air. The high-volume low-pressure spray guns increase transfer efficiency, which means that much more of the paint is actually transferred to the substrate instead of being wasted. With the HVLP system, air is delivered at much higher volume, but with a much lower pressure, so that more paint ends up on the substrate instead of in the air.

There are two different types of high-volume low-pressure spray gun systems on the market. In the first type, the spray gun still runs off an air compressor just as a conventional spray gun does, but it uses much lower pressure. The second type of high-volume low-pressure spray gun is the most efficient. This spray gun uses an air turbine instead of air compressor. This delivers an extremely high volume of air at very low pressure.

## Airless Spray

A special pump will suck the paint out of the tin and deliver it at high pressure through a spray hose to the spray gun. When the spray gun trigger is pulled, the paint will be released at high pressure through the nozzle on the gun. Inside the hose and the gun the paint is kept at this high hydraulic pressure, but when it exits the nozzle there are no boundaries to confine and maintain the pressure. The sudden drop in pressure will rip the paint apart, resulting in a large number of small paint droplets being flung into the air. This is what is called "atomization" among spray painters.

The nozzle in the airless spray gun can be removed and replaced. Many different nozzles are available, each with their own design and properties.

- They are all made with an elliptical opening so the paint will leave the gun in a flat "V"-shape formation, called the spray fan. The fan may be very broad or quite narrow, which is expressed as the "angle" of the nozzle. For large flat areas you may use a large (wide) fan, while areas with a lot of details may be best painted with a narrow fan. The fan is given as the number of degrees the V-shape fan is (e.g. 40°, 60°, 80°, etc.)
- The amount of paint coming out of the nozzle at a given pressure will depend on the opening size, called the "orifice". A high-build, high-solid paint may work well with a reasonably large orifice, while a glossy topcoat would give the nicest result after being applied by a smaller orifice. The size of the nozzle may be

given in the metric system (parts of a millimetre, e.g. 79 mm) or the imperial system (parts of an inch, e.g. 0.031").

- The recommended nozzle to be used for airless spray application of a paint can usually be found in its TDS. Remember that nozzles get worn, particularly when applying paints containing hard pigments, so they must be replaced regularly!
- Using the wrong nozzle may result in poor atomisation (spitting) or blockage of the nozzle. It is now common to mount the nozzle in a cylinder which can be rotated 180°. If a blockage occurs, the cylinder can be rotated and the impurity blown out of the nozzle with a quick squirt and rotated back to the correct position again.

The pump that sucks the paint out of the tin and creates the high pressure in the paint inside the spray hose and spray gun is normally a double-action piston pump. Double-action means it delivers pressure on both the up-stroke and down-stroke of the piston. The pressure is maintained by means of ball-valves seated at the bottom of the pump house (cylinder) and inside the piston. This pump can be driven by an electrical motor, but the most common types for heavy duty application are driven by an air motor. Compressed air is much safer to use near flammable solvents than an electrical motor which creates sparks (unless of an explosion-proof type). The air motor is constructed such that compressed air will push the piston both up and down, directed by a slide valve. The air motor piston and the pump piston are permanently connected by a common piston rod.

All airless spray pumps that are driven by an air motor will have a "ratio". This ratio refers to the size of the piston in the air motor versus the size of the piston in the paint pump. If the ratio is for example 48:1, it means that the surface area of the air piston is 48 times as big as the surface area of the paint piston. The consequence of this is that if the compressed air which drives the air motor is 5 kg/cm<sup>2</sup> (0.5 MPa), the pressure of the paint leaving the pump will be 48 times as large, i.e. 240 kg/cm<sup>2</sup> (24 MPa). In addition to the recommended size of the nozzle, paint manufacturers will also recommend what pressure the paint should have at the nozzle in order to obtain the most suitable atomization. It is worth to remember that the paint pressure will drop due to friction in the paint hose. This can have some influence on the result if the paint line consists of several lengths of hose connected together, and particularly so if the pump is situated at ground level and the spray painter is working high up in a scaffolding (pressure is lost while pushing the paint in the hose against gravity up the difference in height, particularly for heavy paints containing metallic pigments).

The hose connecting the spray gun and the spray pump must be of an approved type, including the couplings used to connect to the pump and the gun (and to any extension hose). It is important that there is a continuous conductive connection between the gun and the pump in order to avoid electrostatic build-up and possible sparks. The hose must therefore have a functioning earth lead built into its wall.

## **Application by airless spray**

### **Benefits**

- Very high productivity:
  - Applicator saves time: Up to 50 - 75% compared to other methods
  - With paint brush: Application takes four times longer
  - With roller: Application takes twice as long
- Can apply high viscosity paint
- Higher thickness in a single coat
- Even film thickness

## **Limitations**

- Dry spray (overspray)
- Safety-high pressures
- Higher loss for smaller sized objects
- Complicated and expensive equipment
- Skilled applicator required

## **How to get the most out of your airless spray tip / nozzles**

- Use the lowest amount of air pressure required to atomise the material and to provide a satisfactory spray fan
- Sieve all material
- Use filters (unless manufacturer advises to remove them)
- Remove the spray tip before cleaning spray gun
- Clean spray tip with brush
- The equipment must be cleaned after use
- Two component paints will continue to cure / harden in pumps, lines and gun and must be removed before they become solvent resistant

## **Air assist airless spray**

Both airless and air assist airless spray guns use high fluid pressure to atomize. Paint is forced through an elliptical shaped orifice. This high pressure allows the coating to be forced through the entire fluid tip, including the narrow edges of the elliptical shape. Such high pressure, while allowing complete atomization, will cause an increase in material flow, an increase in material bounce-back and increased fluid tip wear. The appearance of the applied film may be influenced by the high pressure as well, often resulting in a slightly "textured" finish (e.g. "orange peel"). One solution to avoid this is to lower the paint pressure. However, as the paint pressure goes lower, it will have difficulties exiting the sharp corners of the orifice. The result is what is commonly called tails (rat tails) or fingers in the spray pattern.

The solution to the "texture" and "tails" is to add an air cap to the spray gun. A properly designed air assist air cap will provide the necessary air in the proper direction to eliminate the tails in the spray pattern and reduce the texture in the finished film. These benefits all add up to the ultimate finishing tool for all applications where a superior finish is required together with high output, such as for example in the furniture industry. The amount of air assist will vary with the tip shape and size, paint pressure and paint viscosity. Exceeding the minimum amount of air required will increase bounce-back or overspray of the coating.

If the air pressure is kept to 10 psi or less as measured at the air cap, the gun may be classified as high volume low pressure (HVLP) in some environmental regulations.

## **Plural-component airless spray pump**

Airless spray application of two-pack paints can raise a few challenges. Once the two components are mixed, the curing reaction will start immediately. For some paints, the mixture can be used for a few hours (pot life), but for other paints it may be only a matter of 30 minutes (or less in warm weather) before the mixture has cured so much that it cannot be applied any more. But it is not only a matter of having sufficient time available for application, it is also a matter of emptying the airless spray equipment and clean its interior before the mixture hardens and destroys the equipment. Any paint which has been mixed but not applied within its pot life

will of course be a complete loss.

Plural component airless spray equipment is a device with two separate pumping systems to supply the base and curing agent. There are two types available: fixed mixing ratio and variable mixing ratio. The two components may be mixed as they leave their respective pumps or transported in separate spray hoses and only mixed just before they reach the spray gun (in-line mixer). They are particularly suitable for:

- High viscosity paint
- High volume solids paint
- Paint with short pot life

The equipment can be fitted with heating systems to lower the viscosity of thick, solvent-free coatings and for other coatings in cold weather.

# Application techniques

## Mixing & thinning

Paint tins and cans kept on a construction site will eventually become dirty, particularly on top of the lid. It is important to remove such dirt before opening the lid, and to lift the lid **away** from the opening of the tin. If any dirt or contaminants fall into the paint, this may cause blockage of spray nozzles and/or degrade the dry paint film.

Low viscosity (thin) paints may suffer from some pigment settling at the bottom of the tin and need to be stirred before application starts.

Two-pack paints will always need to be mixed thoroughly before application starts. If the two components are not sufficiently blended, there will be areas in the mixture which will have the wrong proportion of base and curing agent. This will lead to incorrect drying / curing and weaknesses in the dry protective film.

Stirring paint by hand, using a wooden stick, will not give a satisfactory result, unless we are stirring a small tin (1 litre or less). Larger tins or cans must be stirred mechanically, using a power-mixer driven by compressed air or by an electric motor (electric motor is NOT recommended for solvent-containing paints). Ensure that whatever tool you use for stirring is clean, so it does not introduce impurities to the paint.

For two-pack paints, each pack should be stirred separately before the smallest pack is slowly added to the larger pack during additional stirring. Make sure all the content in the small pack is added, otherwise the mixing ratio will not be correct.

Paints are ready to be applied directly from the tin, the manufacturer has adjusted the viscosity to be at the optimum level, so no additional thinning is necessary. If thinner is added, this may lead to sagging during application, reduced hiding power, reduced dry film thickness, solvent entrapment in the film and longer drying time. In general, there are only three situations where addition of thinner should take place:

- The paint (and ambient conditions) is very cold, so the paint becomes too thick

- The ambient conditions (and substrate) is very warm, additional thinner will reduce dry-spray and keep the film open longer to ensure a continuous film
- If paint is applied on a very porous substrate, additional thinner for tie coat or mist coat application technique will aid penetration into the porous substrate

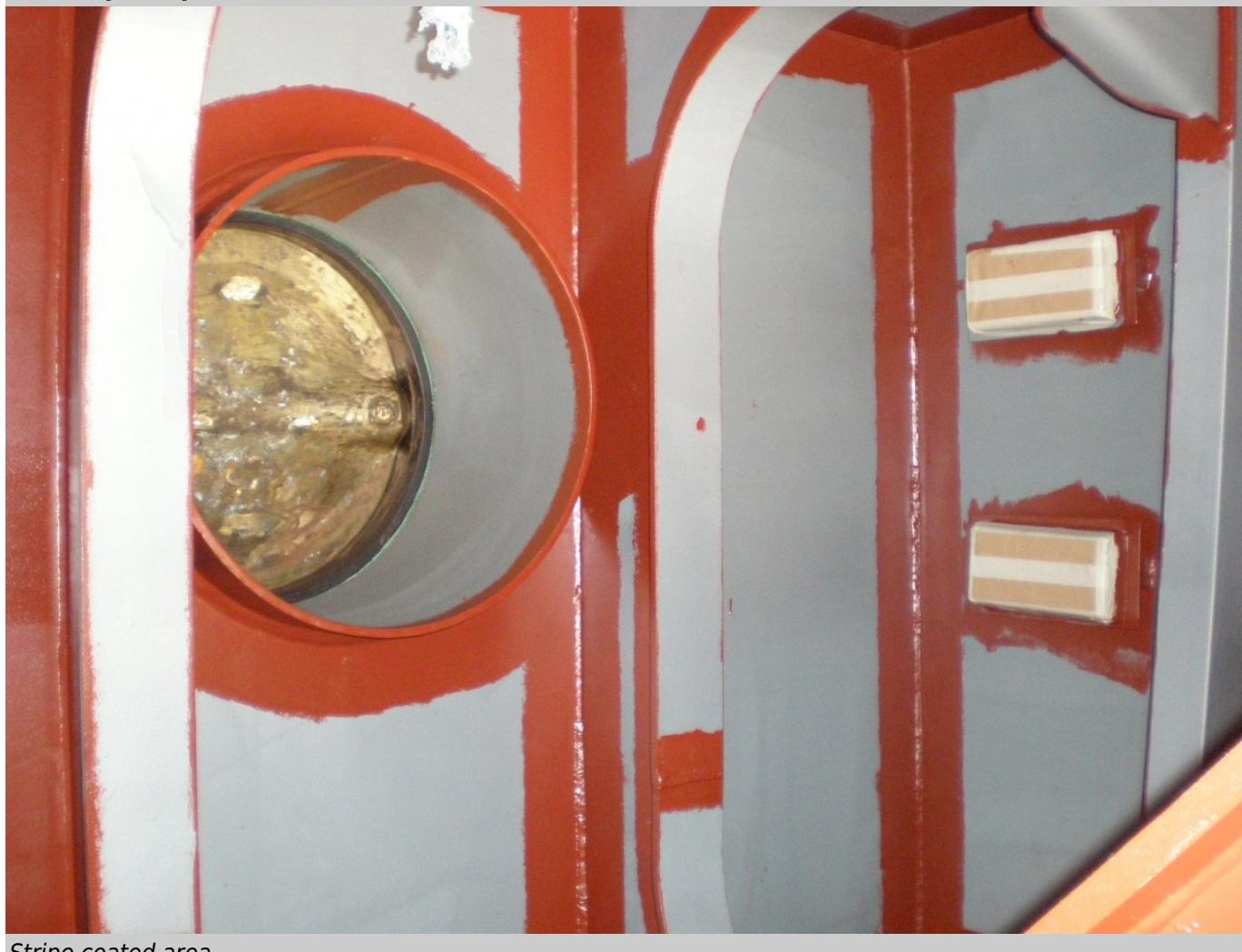
Never add an unspecified or unknown thinner to a paint. In addition to the above listed possible negative consequences, you will introduce an even worse possibility: the unspecified thinner may not be compatible with the binder in the paint. The result could be that the paint starts gelling (which is easy to see), or some physical properties are changed (e.g. much longer drying time), or the resulting dry film is weakened (softer, less chemical resistance, etc.).

## Stripe Coating

Corrosion can take place on any part of a steel structure, particularly in places where the corrosion protection is weak or damaged. During spray application of corrosion protective coatings, certain areas and positions may be difficult to reach or access with a spray gun, or the coating may tend to pull away from edges or refrain from entering tiny gaps, such as:

- Profiles
- Inside edges
- Holes, notches
- Corners, angles
- Sharp edges
- Pits (pitting)
- Manual welding seams
- Behind flanges

Photo by Leroy Dias



*Stripe coated area*

By applying one or two coats by brush before (or after) the spray application takes place, we will increase the thickness of the protective paint film in those vulnerable areas and thereby reduce the danger for corrosion. This is called "stripe coat", since it predominantly ends up being paint applied in stripes on all the edges, welding seams, angles, etc.

A paint brush is an excellent tool for stripe coating, the brush wets the substrate properly and works the paint well into the substrate. Use a good quality paint brush. Stripe coating will improve the life time of the paint system. Contrasting colours between the stripe coat and the full coat will make it easier for the painter to see where it has been applied and easier to inspect as well.



*Importance of stripe coating welds*

## Application by brush

Paint application by brush can give quite good results provided a good quality brush is used and the correct technique is employed. The main advantage by brush application is the ability of the bristles to work the paint into any irregularities (profile) in the substrate. The disadvantages are that it is time consuming and the thickness of the film you can apply is limited.

### Application technique - brush

- Wash a new brush with thinner
- Dry in a cool area
- Don't dip the whole length of the bristle into the paint
- Move brush over the surface evenly
- Cross application method can form a uniform film thickness
- Push the brush to force paint to penetrate into voids or gaps
- Finish off by brushing in one direction to produce a more even film, colour and finish

Poor brush application can cause early breakdown of the paint. Brush marks (stripes) are a common problem and will lead to poor appearance and lower film thickness in the stripes.

## Application by roller

Paint application by roller can be very useful and there are many different sizes available as well as the type and length of the "fur" (pile or nap) on the roller. In some situations only a roller will be able to deposit paint on the substrate, such as behind the flanges of a beam.

### Application technique - roller

- Wash new roller with water or thinner prior to application
- Dry the roller in cool area
- Use a paint roller tray to load the roller fabric with paint
- Roll out the cover in the tray to remove excessive paint from the cover
- Cross application will result in a more even film thickness
- Finish off by rolling in one direction to produce an even film, colour and finish

Roller application will not ensure good wetting of the substrate or work the paint into the surface profile. Use of a roller for application onto bare steel is therefore not recommended, unless this is the only means of reaching the bare steel.

**Photo by Akzo Nobel**



*Roller Application*

## Application by airless spray

Airless spray application is the preferred method for most construction and maintenance industry. It is quick and cost efficient, can build up a high film thickness in individual coats and usually gives an attractive finish. The force of the airless spray will ensure a good wetting and penetration into the surface profile.

### Application technique - airless spray

1. Setting up an airless spray pump:
2. Release the air pressure and trigger the gun to release any hose pressure then put the suction hose into the paint or fill a gravity hopper with paint
3. Force any residual thinner / cleaner out of the system at a pressure in the range of 1-2 kg/cm<sup>2</sup> until the loaded paint comes out of the hose
4. Mount the correct type of spray tip / nozzle to the airless gun, check all gun and hose connections are tight
5. Adjust the inbound air pressure until a correct spray pattern is achieved

**Photo by Akzo Nobel**



*Airless spray pattern*

### Rules when spraying

- Correct distance and angle from the gun to substrate to avoid dry spray (overspray). Dry-spray will develop at the edges of a wide spray fan. This may give a rough film and pinholes
- Seek to keep the gun at a right angle to the substrate. The distance should be between 30 and 60 cm.

The optimal distance will vary, among other things with wind, temperature, pressure at the nozzle and viscosity of the paint

- Keep correct overlapping between strokes to ensure an even film thickness
- The film thickness is affected by the distance between the gun tip and the surface, the speed of the gun stroke, and the pump pressure and nozzle size

### **Distance between gun and structure**

- Keep the spray gun at a correct distance from the object
- A correct distance ensures a good, uniform paint film
- Too great a distance gives poor float and an uneven surface
- Trying to reach areas far away will give an uneven film thickness
- Shadows are created behind welds
- Waving the gun results in an unacceptable spray pattern

### **Longer distance between gun and substrate gives an increased surface roughness**

- Increased risk of leaving dry spray on the surface
- Increased roughness of the inside of pipe walls will reduce the flow velocity
- A rough surface of the ship's bottom will result in an increase in fuel consumption

### **Rules for application**

- Start moving the spray gun before pulling the trigger
- Release the trigger before stopping the gun stroke
- Use smooth and even gun strokes
- Use as low air pressure as possible to obtain a uniform spray fan

When spray applying positions containing a hollow, such as an inside corner or into deep pits, a cushion of compressed air may form inside the hollow. This may prevent a sufficient amount of paint to be deposited at the bottom of the hollow area (inside corner / pit). Proper stripe coating in such areas is the best solution for this potential problem.



Airless spraying

#### **Incorrect use of airless spray equipment will result in:**

- Too much paint dust
- A rough surface
- Pinholes in the paint film
- Entrapped air
- Entrapped solvents
- High paint consumption

#### **Time aspects**

##### **Time Aspects affecting paint**

- *Shelf Life*: Acceptable storage time “on the shelf” in the paint store
- *Pot Life*: How long you can continue to apply a two-pack paint after the two components have been mixed
- *Induction Time*: Pre-reaction of the two components in the tin prior to application
- *Drying Times*: Time required from application until the paint becomes Surface dry/ Hard dry / Fully Cured
- *Re-coating Interval*: Minimum / maximum time after application before applying a subsequent coat

# Paint defects

## About paint defects

### Introduction

It is not unusual to hear that anywhere from 75% to 95% of all coating failures are caused by surface preparation and application errors. One might suspect that these percentages are influenced by for example *who* made the statistic (paint manufacturer, contractor, owner, etc.), *where* the failures were observed (climatic conditions, expectations, etc.), any *industry* association (offshore, marine, architectural, construction / production, etc.), and *when* the data were collected (technology and standards are developing).

A study of paint failures carried out over many years in Australia in 1993 and updated in 2000 after additional investigations concluded that:

Paint failures	1993	2000
Failures caused by faulty paint	2%	2%
Failures caused by incorrect specification	19%	41%
Failures caused by change in environment from original design criteria	11%	11%
Failures caused by application error	68%	46%

Paint failures can be classified in various ways, for example stages: 1) in tin, 2) during application, 3) during curing, 4) during service life.

They can also be divided into failures caused by weather and corrosion, mechanically induced failures, adhesion and blistering failures, chemically induced failures, light and radiation failures, heat induced failures, and biologically induced degradation and failures.

In this course we will restrict ourselves to the most common types of paint and coating failures:

#### Wet film failures

- Sagging, curtain, runs
- Dry spray/over spray
- Fish eyes

#### Dry film failures

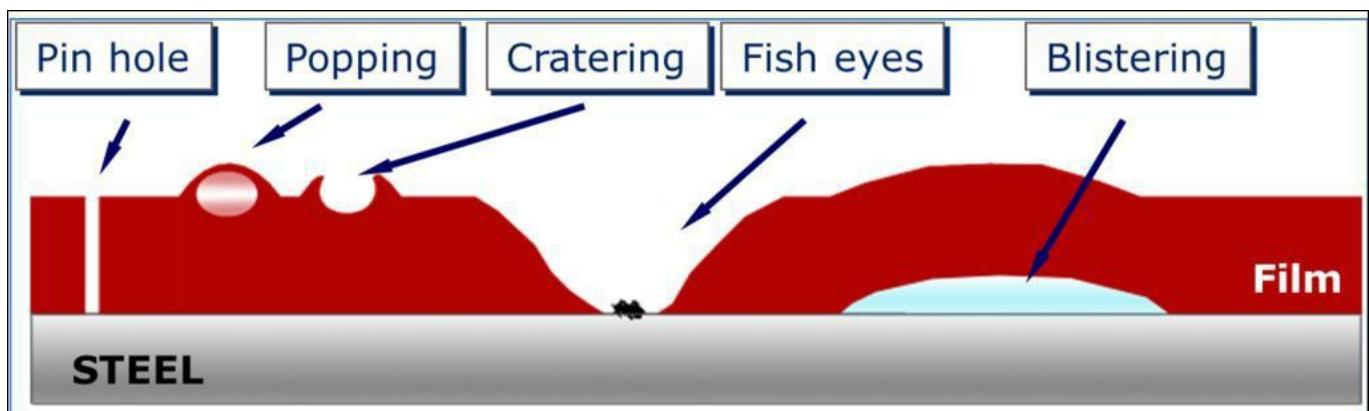
- Holiday, low film thickness
- Orange peel
- Pin hole
- Popping

- Wrinkle/lifting
- Sweating and carbonation
- Blooming/blushing
- Osmotic blistering
- Pin point rust
- Cracking
- Delamination
- Chalking
- Bleeding
- Vacuoles

Predict risk through observation

#### How to describe difference of various defects?

Identification of a defect can be based on cause, appearance and stage of service life. However, a drawing can be an easier way:



#### When do paint defects occur?

- Paint defects can occur at any time when paint is used
- Defects usually occur during one of two stages
  - During application (incl. curing/drying)
  - During service
- Some defects may only occur during application, such as sagging and fish eyes
- Some defects are prone to appear during exposure, such as cracking, delamination and blistering

#### What will cause paint defects?

- Inadequate (blast) cleaning and surface profile is a frequent cause of paint defects
- Poorly operated and maintained equipment, wrong application technique and poor planning will all increase the risk of paint defects
- All paint and coating systems are designed for specific use and exposure. Wrong specification may cause paint defects
- Sometimes paint defects are due to a combination of unfortunate circumstances related to surface preparation, application and exposure

# Wet film failures

## Sagging

### Description

Sags are the downward movement of a coat of paint which appear soon after application and before setting, which results in an uneven area with a thick lower edge. They are usually apparent on local areas of a vertical surface and in severe situations may be described as curtains.

**Photo by permission from Fitz Atlas**





### Probable causes

Over-application of paint, excessive use of thinners, incorrect (lack of) curing agent or poor workmanship. Could in extreme circumstances be a formulation problem.

### Consequences

Poor appearance, possible cracking

### Repair

While the paint is still wet, brush out runs and sags, although this may not result in an acceptable appearance. When the paint has dried, abrade and clean defective areas and apply overall coat or spot repair as necessary.

### Prevention

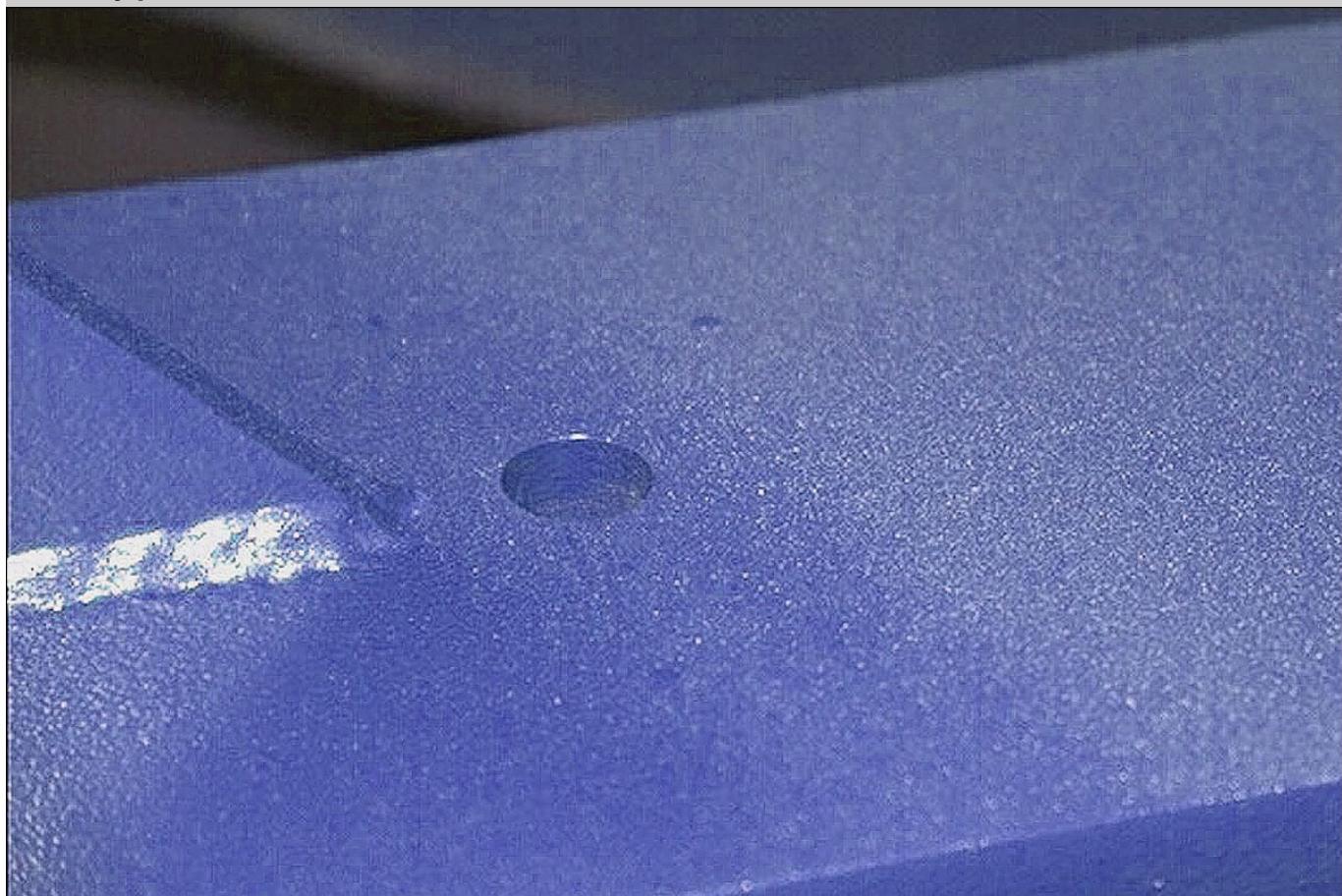
Use correct application technique with suitably formulated products.

### Dry spray

#### Description

Rough and uneven finish to the surface of the paint film where the particles are insufficiently fluid to flow together and are often poorly adhered.

**Photo by permission from Fitz Atlas**



### **Probable causes**

Incorrect spray application, i.e. gun distance. Also associated with fast drying products and too high application temperature.

### **Consequences**

Poor appearance, poor adhesion, loss of gloss

### **Repair**

Abrade and remove any loose dry spray and reapply paint.

### **Prevention**

Use correct application equipment and techniques. Use a slower drying solvent or solvent blend. Follow recommended application procedures.

# Fish eye

## Description

Small circular areas of substrate that are exposed through the applied coating immediately after application and which have at their centre a source of contamination.

**Photo by permission from Fitz Atlas**



## Probable causes

Surface contamination in the form of small spots of wax, silicone, grease or particles from contaminated compressed air.

## Consequences

Poor appearance

## Repair

Abrade the affected area, degrease and reapply the coating system. Can be difficult to repair.

## Prevention

Thoroughly degrease the surface and maintain equipment.

# Dry film failures

## Holidays

### Description

Smaller areas / spots missed out during application. The applied coat does not hide the previous coat or the substrate, uneven colour/ appearance.

**Photo by permission from Fitz Atlas**



### Probable causes

Poor application workmanship and / or the poor application technique

### Consequences

Poor appearance, poor corrosion protection

### Repair

Apply another coat

### Prevention

Improve application technique, frequent WFT measurements.

## Orange peel

### Description

The surface of the paint film resembles the skin of an orange

**Photo by permission from Fitz Atlas**



### Probable causes

Poor levelling of the paint due to high viscosity, fast evaporation of solvent, inadequate atomization. Spray nozzle is too close to surface.

### Consequences

Poor appearance, uneven film thickness

### Repair

Where aesthetics are of concern, abrade overall, clean and recoat.

### Prevention

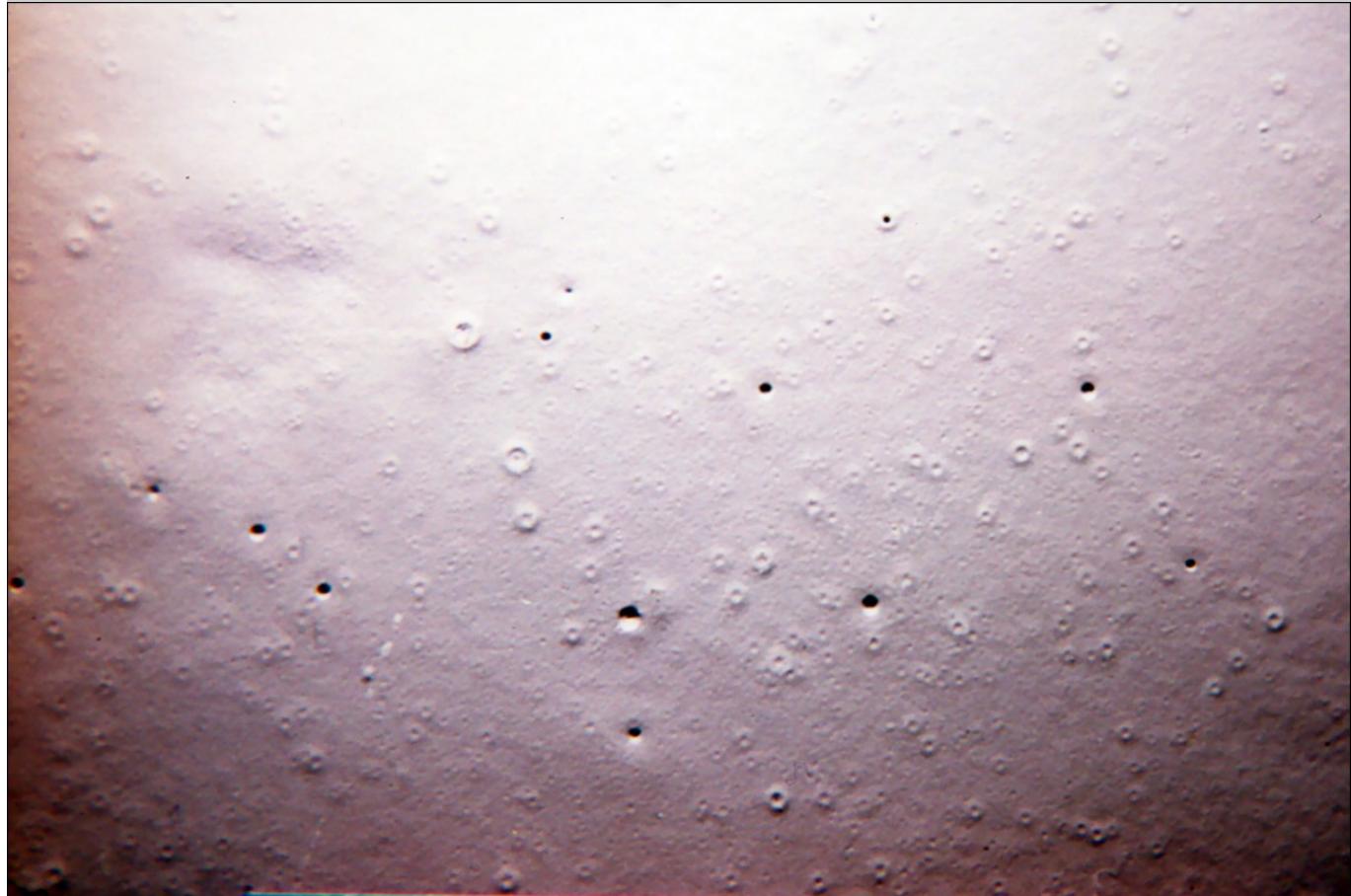
Proper thinning or heating paint. Use correct thinner. Use correct application techniques.

## Pin holes

### Description

The formation of minute holes in the wet paint film during application and drying, like holes made by a needle.

**Photo by permission from Fitz Atlas**



### Probable causes

Solvent or air trapped within the paint film rising to the paint surface, creating small tubes of air which fail to fill in before the film has set. This is a common problem when coating very porous substrates such as zinc silicates and thermally sprayed metal coatings.

### Consequences

Poor appearance, poor corrosion protection, uncertain condition inside the pin hole. Difficult to inspect and repair.

### Repair

Abrade, clean overall and apply suitable tie coat as necessary. Simply applying a new coat without any preparation will not solve the problem, the pin holes will re-appear.

### Prevention

Ensure proper viscosity, choose thinner with low evaporation rate. Sealer coat or mist coat on porous surfaces.

Improve application techniques.

## Popping

### Description

Small translucent or transparent blisters or bubbles on the coating surface. Often the bubbles burst, leaving a crater which does not fill in.

Phot by permission from Fitz Atlas



### Probable causes

Air or solvents trapped in the film and prevented to escape due to surface drying of the film, foaming during roller application.

### Consequences

Poor appearance, poor protection due to low DFT in the popping

### Repair

Abrade, clean and recoat

### Prevention

Use sealer coat or mist coat on porous surfaces, proper thinning ratio, correct application technique. Avoid application at high temperatures.

## Wrinkle/lifting

### Description

Formation of wrinkles on the surface during drying/ curing, often combined with loss of adhesion. Paint removers use this effect.

**Photo by permission from Fitz**



### Probable causes

Paint film is exposed during cleaning or overcoating to solvents which it is not resistant to. Tension created in the surface layer of a film while the underlaying part is still fluid (as in too high alkyd paint film).

### Consequences

Poor appearance, useless film.

### Repair

Remove defective coating, abrade, clean and recoat

## **Prevention**

Use compatible paints within the system. Use correct wet film thickness. Avoid spillage of strong solvents/thinners. Ensure adequate drying and curing.

## Amine sweating & carbonation

### **Description**

After an amine-cured epoxy coating becomes hard and completely dry, there is a sticky substance on the surface.

### **Probable causes**

Incorrect drying conditions, such as: air temperature and substrate temperature are too low; high relative humidity; poor ventilation; direct heating with gas burners (releasing water vapour and CO<sub>2</sub>).

### **Consequences**

Very poor adhesion for subsequent coats

### **Repair**

If not to be overcoated and appearance is not important: leave as is. Otherwise use warm water and detergent to remove the amine sweating, test for free amines before overcoating (e.g. Elcometer 139 Amine Blush test)

### **Prevention**

Follow the induction time instructions. Application under correct climatic conditions. Keep correct thinning ratio.

## Blooming/blushing

### **Description**

After drying the coating has a milky surface with low gloss.



### Probable causes

Coating surface is exposed to water/moisture before the coating is dry: Fog, rain or during the drying period, condensation. Fast evaporation of a thinner can cause condensation.

### Consequences

Poor appearance

### Repair

Abrade, clean and recoat

### Prevention

Monitor ambient conditions and adjust application schedule. Dehumidification in enclosed spaces. Correct thinner to be used.

## Osmotic blistering

### Description

Blisters appearing in the film, normally with liquid inside the blisters.

Photo by permission from Fitz Atlas



### Probable causes

Soluble salts on the substrate under the film (or retained solvents) attract water from the environment and the resulting osmotic pressure inflate the blisters.

### Consequences

Poor appearance, loss of adhesion, loss of corrosion protection

### Repair

Remove blistered areas or entire coating system, fresh water wash and repair or fully recoat.

### Prevention

Ensure correct and sufficient surface preparation, test substrate for presence of soluble salts (Bresle).

## Pin point rust

### Description

Small point corrosion observed on the steel surface, like pin (needle) points



### Probable causes

Low film thickness; Excessive surface profile; Poor wetting of the substrate; High evaporation rate of solvent/thinner; Dry spray; Poor atomization; Pinhole and/or holiday

### Consequences

Poor corrosion protection, poor appearance

### Repair

Remove paint and recoat

### Prevention

Correct surface preparation, correct application technique, correct film thickness.

## Cracking

### Description

Paint film is splitting. The splits may be just on surface, through a coat or through the whole coating system down to substrate. The name of this defect varies according to the depth of the cracks and pattern of cracking, e.g. checking, alligatoring, mud cracking, etc.



### Probable causes

Cracking is a stress related failure and can be caused by substrate movements, ageing, lack of flexibility in the coating, swelling and drying due to moisture, thick layers consisting of many coats of different hardness (sandwich coats).

### Consequences

Poor appearance, lack of corrosion protection

### Repair

Remove the cracked coating by grinding and repair the coating system as per specification. For mud cracking of inorganic zinc coatings, sand-blasting to the substrate and re-paint.

### Prevention

Avoid too high film thickness. Ensure proper drying / curing and that the coatings in the system are compatible. Alternatively use a more flexible coating system.

## Delamination

### Description

Film has lost its adhesion and separates from the surface. The separation may be just the last coat or the whole coating system down to the substrate.

**Photo by permission from Fitz Atlas**



Photo by Linda carlsen



Flaking/delamination of a tank

### Probable causes

Poor surface preparation; contamination on the substrate; hard and very glossy substrate, paint defects such as: chalking, flooding, amine sweating; excessive film thickness; exceeded max over coating interval; solvent and/or air entrapment; weathered coating.

### Consequences

Poor appearance, poor protection against the environment and corrosion

### Repair

Remove the coating with poor adhesion. Prepare the substrate and paint it again as per specification.

### Prevention

Proper surface preparation and cleaning before overcoating. Apply subsequent coats before max. overcoating interval is reached.

Avoid high film thickness. Abrade and clean glossy surfaces between coats.

## Chalking

### Description

A grey / white dusty material appears on the surface after the coating has been exposed to sun light for some time.

#### Photo by permission from Fitz Atlas



### Probable causes

Degradation of paint binder (resin) in the coating by ultraviolet light from the sun; weathering; poor mixing

### Consequences

Poor appearance, poor adhesion for subsequent coats

### Repair

Remove the chalking by cleaning with a detergent and overcoat with a UV resistant coating.

### Prevention

Select suitable topcoat for prevailing climatic conditions.

# Bleeding

## Description

Discolouration of the paint film due to migration of coloured substances from the underlying paint, typically seen when tar or bitumen containing coatings are overcoated.

**Photo by permission from Fitz Atlas**



## Probable causes

Coloured substances in under laying coat are re-dissolved by solvents in the new coat. Can also be caused by unsuitable marker pens used by inspectors.

## Consequences

Poor appearance

## Repair

Remove the whole coating system and apply a non-bleeding coating. Use a paint with flake pigments such as aluminium or glass flake as a sealer coat to reduce the bleeding.

## Prevention

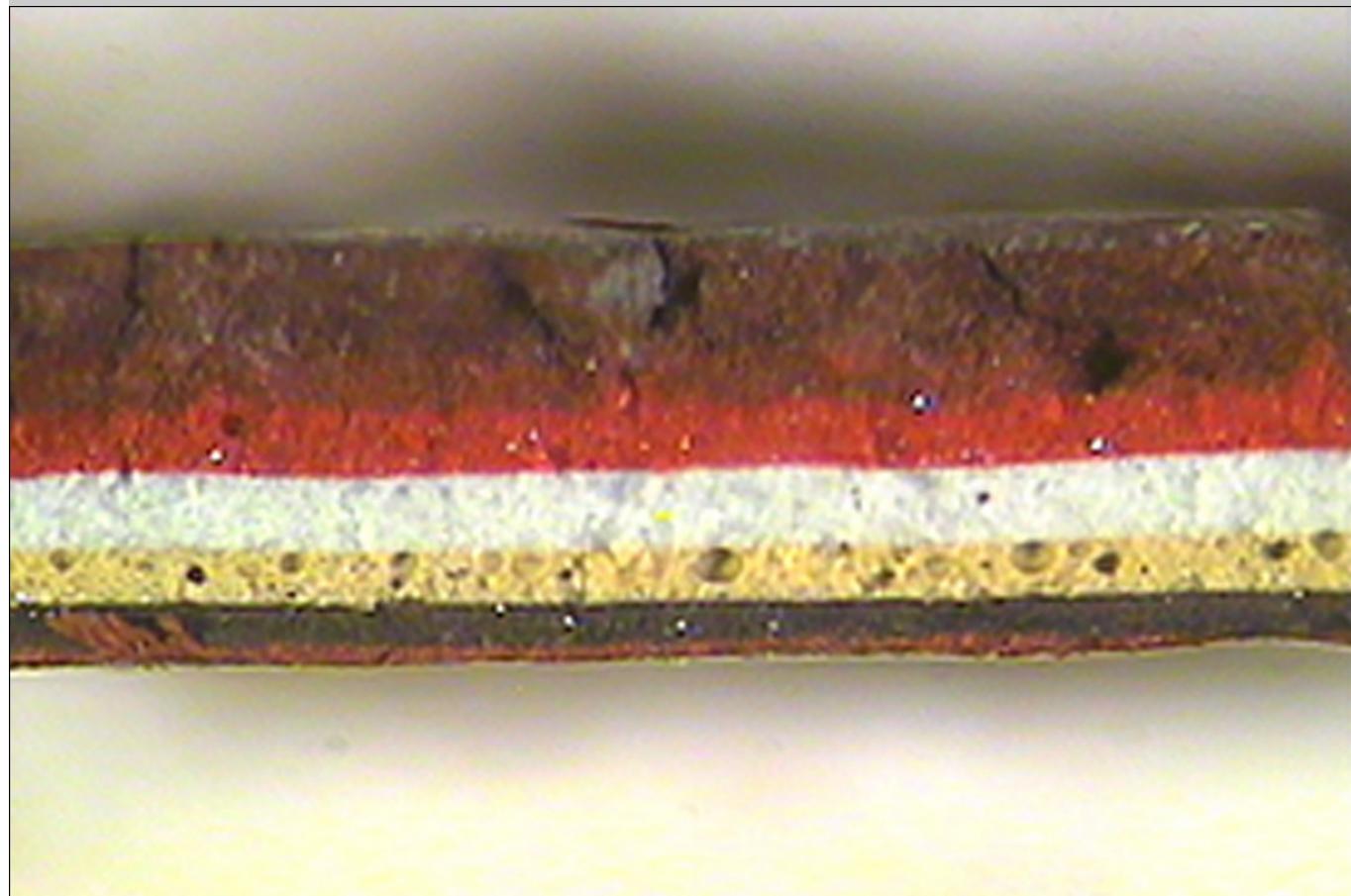
Avoid the use of coatings containing tar and bitumen, only use approved marker pens during inspection.

# Vacuoles

## Description

Voids in the paint film, cross section looks like a Swiss cheese.

**Photo by permission from Fitz Atlas**



## Probable causes

Air and/or solvent trapped within the film during drying, often related to accelerated surface drying (skin drying) during high temperature and strong wind/ventilation.

## Consequences

Early corrosion, may develop into blisters

## Repair

Remove the porous coating and apply a new coat.

## Prevention:

Monitor wind and temperature during open air application and control ventilation in confined spaces, to avoid skin drying.

# Calculations

## Introduction

### Which calculations need to be done?

A certified coating advisor is expected to carry out simple calculations related to the coating operation, like:

- WFT vs. DFT and vice versa
- Solid content after thinning
- Volumes required for specific jobs
- Spreading rates
- Consumptions
- Simple cost calculations

### Calculations during exam

- Formulas required for calculation will be handed out
- Formulas may have to be rearranged for a particular calculation
- Other data required will be given, or must be found by the candidate in technical information provided
- Basic formulas for area calculation will not be given

### Technical data

- Most of the product data needed for carrying out inspections and for necessary calculations are found in Technical Data Sheets (TDS)
- Some data may also be found in Safety Data Sheets (SDS)

### TDS data used for inspections & calculations

#### Corresponding DFT & WFT

- Minimum
- Maximum

#### Physical properties

- % Volume solids
- Flash point
- VOC

#### Surface preparation

- On various substrates

#### Application requirements

- Ambient conditions
- Methods

#### Application Data

- Mixing ratio

- Induction time
- Pot life
- Thinner No.
- Airless spray data
- Thinning restrictions

### **Drying times**

- At various temperatures

### **Typical system**

- coats
- DFT

### **Pack size**

### **Abbreviations used in formulas**

*WFT* = Wet Film Thickness

*DFT* = Dry Film Thickness

*% VS* = Percent Volume Solids

*LF* = Loss Factor

*DV* = Dead Volume

### Formulas to be used during exam

Formulas

$$WFT = \frac{100 \times DFT}{\text{Vol. \% solids}}$$

$$DFT = \frac{WFT \times \text{vol. \% solids}}{100}$$

$$\text{Loss factor} = \frac{100 - \text{loss in \%}}{100}$$

$$\text{Consumption (litres) theoretical} = \frac{DFT \times \text{area (m}^2\text{)}}{10 \times \% \text{ VS}}$$

$$\text{Consumption (litres) practical} = \frac{\text{Consumption (litres) theoretical}}{\text{Loss factor}}$$

**Additional paint consumption due to dead volume:**

$$\text{Theoretical paint volume in litres} = \frac{\text{Dead vol. (litre/m}^2\text{)} \times \text{area (m}^2\text{)} \times 100}{\% \text{ VS}}$$

$$1000 \text{ cm}^3 = 1 \text{ litre}$$

Simple practical formula

**1 : 1 : 1000** paint quantity (ltr) : Area (m<sup>2</sup>) : WFT (micr.)

#### Meaning

1 ltr paint cover 1 m<sup>2</sup> in 1.000 µm WFT

1 ltr paint cover 10 m<sup>2</sup> in 100 µm WFT

**Meaning:**  $\frac{\text{Area (m}^2\text{)}}{\text{Consumption (ltr)}} \times \text{WFT} = 1.000$

Formula for determining the DFT

WTF	<input type="text"/>
% VS	<input type="text"/>
DFT	<input type="text"/>

$$\mathbf{DFT} = \frac{\mathbf{WFT} \times \% \mathbf{VS}}{100}$$

Formula for determining the WFT

DFT	<input type="text"/>
% VS	<input type="text"/>
<b>WFT</b>	<input type="text"/>

$$\mathbf{WFT} = \frac{\mathbf{DFT} \times 100 \%}{\% \mathbf{VS}}$$

Formula for determining the WFT after thinning

DFT	<input type="text"/>
% thinner	<input type="text"/>
% VS	<input type="text"/>
<b>WFT</b>	<input type="text"/>

$$WFT = \frac{DFT \times (100 \% + \% \text{ thinner})}{\% \text{ VS}}$$

Theoretical spreading rate

% VS	
DFT	
$\text{m}^2/\text{litre}$	

$$\frac{\text{m}^2}{\text{litre}} = \frac{\% \text{ VS} \times 10}{DFT}$$

Consumption of paint, no loss (theoretical)

Area ( $\text{m}^2$ )	
DFT	
% VS	
Consumption	

$$\text{Consumption} = \frac{\text{Area} (\text{m}^2) \times \text{DFT}}{10 \times \% \text{ VS}}$$

## Consumption of paint, with loss (practical)

Area (m <sup>2</sup> )	
DFT	
% VS	
Loss Factor	
<b>Consumption</b>	

$$\text{Consumption} = \frac{\text{Area (m}^2\text{)} \times \text{DFT}}{10 \times \% \text{ VS} \times \text{loss factor}}$$

## Dead volume paint consumption

### **Dead Volume: increases paint consumption**

Smooth steel surface: Even film thickness, No dead volume

Uneven steel surface: Paint will fill the valleys in the profile, called "Dead Volume"

### **Dead volume and surface profile**

- Higher surface profile increases dead volume
- The dead volume will be filled, and will increase the consumption of primer
- The dead volume consumption of primer comes in addition to the consumption for the primer coat in the specification
- The other coats will not be influenced by dead volume
- DV will on exam be given as ml/m<sup>2</sup> or as l/m<sup>2</sup>

### **Dead volume paint consumption**

Area (m <sup>2</sup> )	
DV	
% VS	
Loss Factor	
<b>Dead volume paint consumption</b>	

$$\text{Dead volume paint consumption} = \frac{\text{Area (m}^2\text{)} \times \text{DV} \times 100}{\% \text{ VS} \times \text{loss factor}}$$

Stepwise explanation:

**Area (m<sup>2</sup>) x DV:** The total volume (litres) to be filled with dry paint

**Area (m<sup>2</sup>) x DV x 100** : Theoretical wet paint consumption  
 $\% \text{ VS}$

**Area (m<sup>2</sup>) x DV x 100** : Practical wet paint consumption to fill the dead  
 $\% \text{ VS} \times \text{loss factor}$

## Technical data sheet

### Technical Data - Frosio Topcoat

Click here: [TDS Frosio Topcoat 2017.pdf](#)

## Metallic coating-thermal spray

### Electrolytic applied coatings

#### Electrolytic applied coatings (electro-plating)

Electroplating is a process that uses electric current to reduce dissolved metal cations so that they form a thin coherent metal coating on an electrode. Electroplating is primarily used to change the surface properties of an object (e.g. abrasion and wear resistance, corrosion protection, lubricity, aesthetic qualities, etc.), but may also be used to build up thickness on undersized parts.

The process used in electroplating is called electrodeposition. It is similar to a galvanic cell acting in reverse. The part to be plated is the cathode of the circuit. In one technique, the anode is made of the metal to be plated on the part. Both components are immersed in a solution called an electrolyte containing one or more dissolved metal salts as well as other ions that permit the flow of electricity. A power supply supplies a direct current to the anode, allowing them to dissolve in the solution. At the cathode, the dissolved metal ions in the electrolyte solution are reduced at the interface between the solution and the cathode, such that they "plate out" onto the cathode. The rate at which the anode is dissolved is equal to the rate at which the cathode is plated, vis-a-vis the current through the circuit. In this manner, the ions in the electrolyte bath are continuously replenished by the anode.

Electroplating increases life of metal and prevents corrosion. Cleanliness is essential to successful electroplating, since molecular layers of oil can prevent adhesion of the coating.

Electroplating is widely used in various industries for coating metal objects with a thin layer of a different metal. The layer of metal deposited has some desired property, which the metal of the object lacks. For example, chromium plating is done on many objects such as car parts, bath taps, kitchen gas burners, wheel rims and many others for the fact that chromium is very corrosion resistant, and thus prolongs the life of the parts. Electroplating has wide usage in industries. It is also used in making inexpensive jewellery, such as silver-plated and gold-plated necklaces, bracelets and rings.

## Thermal metal spray

Thermally sprayed metal coatings are deposits of metal which has been melted immediately prior to projection onto the substrate. Zinc and aluminium are by far the most widely used for protecting steel against corrosion. Zinc may be used in thickness as low as 25 µm, while aluminium should be 75 µm or above. Pre-treatment should be blast cleaning to Sa 3.

Thermal metal spray requires high attention to personal safety:

- Protect the eyes from the intense light created while melting the metal
- Protect from inhaling metal gases (example zinc-fever)
- Protect against high level of noise
- Protect the entire body against hot melted metal

Thermal metal spray operator must be specially trained, both for quality and for safety reasons.

Three main stages of the thermal metal spraying process:

- The metal (zinc or aluminium) is melted at high temperature at the tip of the spray gun
- A jet of air or gas will break up the molten metal to small droplets and propel them forwards towards the prepared substrate
- The molten metal particles will hit the prepared substrate and form a metallic film

The metal droplets will cool quickly in the air, so the distance between the spray nozzle and the substrate will usually be kept smaller than what is the case for airless spraying. Even so, the molten droplets will not flow entirely together to form a continuous film over the substrate. A thermal metal spray film will end up having a lot of voids and pores, and will be more porous than for example a zinc-rich silicate primer. If overcoated, a mist coat is a necessity.

The metal which shall be sprayed is supplied as either a fine powder or as a continuous wire. If powder is used, this will be kept in a powder cup mounted on top of the spray gun and gravity-fed into the gun just behind the nozzle (a bit like a hopper-gun), where it is melted. If metal wire is used, this will be supplied in large coils which is fed continuously from the back of the gun and into the nozzle where it is melted.

The all-important heat to melt the metal which is sprayed is created in a few different ways, and the most common and important ones are:

- Flame spraying (also called gas spray)
- Arc spraying

- Plasma spraying

## Flame (Gas) spray

The heat is created by burning a mixture of oxygen and a flammable fuel gas at the tip of the spray gun. The flame spray gun thus needs a constant supply of oxygen, fuel gas and metal to be sprayed:

- A single continuously moving wire is passed through the spray gun and melted by a conical jet of burning oxy-fuel gas
- The wire tip enters the cone, melts, atomizes and is propelled onto the substrate
- Alternatively, metal powder is fed into the flame from a powder cup or hopper
- Flame temperature usually 2,700 – 3,100 °C.

General purpose oxy-fuel wire spray guns are capable of spraying all available metallic wires like zinc, aluminium, steel, stainless steel, copper, molybdenum and various alloys.

## Arc spray

The heat is created by an electric arc between two electrodes at the tip of the spray gun. This is the same principle used during electric welding, the arc melts the welding electrode and bonds the two surfaces together. The arc spray gun thus needs a supply of high voltage DC electrical current, the metal to be sprayed and the highly pressurized air which propels the molten metal forward.

What is an arc?

- A pair of metal wires are electrically energized so an arc is struck across the tips when brought close together in the spray gun
- The arc melts the wire ends
- Compressed air is blown across the arc to atomize and propel the auto-fed metal wire particles onto the prepared work piece
- Temperature in the electric arc is approx. 5,500 °C.

## Thermally sprayed abrasion resistant coatings

- Abrasion resistant coatings are used to improve or modify the surface hardness of a component and hence improve its performance and lifespan. The most commonly applied coatings are Tungsten Carbide and ceramic coatings. Depending on the application and the part, machining is often carried out after the coating has been applied. The application of a fluoropolymer with the abrasion resistant plasma coating can be used to give a hard wearing coating with release properties.
- Thermal-spray technology is commonly used for structural components by building up a protective coating layer on their surfaces. Choosing a suitable sprayed metal can improve corrosion resistance, oxidation resistance, wear resistance and/or heat insulation, and thus extend the life of protected components
- These coatings are typically applied using plasma spraying

## Plasma spraying

- An electric arc is formed between a water-cooled anode and cathode

- A gas is fed into the electric arc (e.g. helium gas, argon, hydrogen, nitrogen, or mixtures of these)
- The gas is heated in the arc and forms a mixture of ions and electrons, called plasma
- Metal powder is transported into the plasma stream by a carrier gas
- The powder melts and is propelled at great velocity towards the substrate
- There is an intense generation of heat in the plasma, typically 10,000 – 25,000 °C

## Overcoating sprayed metal coatings

- “Normal” flame and arc-sprayed metal coatings are usually very porous, perhaps even more porous than zinc-silicate primers, and must be treated in the same way when over-coated
- Popping is very much a real problem, so a tie-coat or a mist-coat technique must be involved
- Sometimes the metallic coating is left with only a tie-coat or mist-coat (“sealer”). This will penetrate the pores, reduce the total area of exposed metal and smoothen the surface texture
- In other situations, a full paint system is used on top of metallic coatings

### **Sealing only:**

- Polyamide cured epoxy

### **Full paint system, use a system suitable for zinc-silicate primers, such as:**

1. Polyamide cured epoxy as mist coat
2. Polyamide cured epoxy
3. Suitable topcoat (Polyurethane)

# Metallic coating-hot dip galvanizing

## Introduction

Hot-dip galvanization is the process of coating iron and steel with a layer of zinc by immersing the metal in a bath of molten zinc at a temperature of 815-850 F (435-455 C). When exposed to the atmosphere, the pure zinc (Zn) reacts with oxygen (O<sub>2</sub>) to form zinc oxide (ZnO), which further reacts with carbon dioxide (CO<sub>2</sub>) to form zinc carbonate (ZnCO<sub>3</sub>), a usually dull grey, fairly strong material that protects the steel underneath from further corrosion in many circumstances.

Galvanized steel is widely used in applications where corrosion resistance is needed without the cost of stainless steel, and can be identified by the crystallization patterning on the surface (often called a "spangle"). Like other corrosion protection systems, galvanizing protects steel by acting as a barrier between steel and the atmosphere. However, zinc is a more electronegative metal in comparison to steel. This is a unique characteristic for galvanizing, which means that when a galvanized coating is damaged and steel is exposed to the atmosphere, zinc can continue to protect steel through galvanic corrosion.

## Process of Hot Dip Galvanizing

### **A. Surface preparation**

Surface preparation is a critical step in the application of any coating. In most instances where a coating fails

before the end of its expected service life, it is because of incorrect or inadequate surface preparation. The galvanizing process has its own built-in means of quality control because zinc will not react with an unclean steel surface. Any failures or inadequacies in surface preparation will be immediately apparent when the steel is withdrawn from the zinc bath because the unclean areas will remain uncoated, and immediate corrective action can be taken.

#### **1. *Caustic cleaning***

- A hot alkali solution, mild acidic bath, or biological cleaning bath removes organic contaminants such as dirt, paint markings, grease, and oil from the metal surface. Epoxies, vinyls, asphalt, or welding slag, which cannot be removed by degreasing, must be removed before galvanizing by grit-blasting, sand-blasting, or other mechanical means.

#### **2. *Rinsing to remove the caustic***

#### **3. *Acid pickling (alternatively abrasive blasting)***

- A dilute solution of heated sulfuric acid or ambient hydrochloric acid removes mill scale and iron oxides (rust) from the steel surface. As an alternative to or in conjunction with pickling, this step can also be accomplished using abrasive cleaning or air blasting sand, metallic shot, or grit onto the steel.

#### **4. *Rinsing to remove the pickling acid***

#### **5. *Fluxing***

- The final surface preparation step in the galvanizing process, a zinc ammonium chloride solution, serves two purposes. It removes any remaining oxides and deposits a protective layer on the steel to prevent any further oxides from forming on the surface prior to immersion in the molten zinc. The flux is allowed to dry on the steel and aids in the process of the liquid zinc wetting and adhering to the steel.

### **B. Application**

#### **1. *Dipping in molten zinc bed***

- During the galvanizing step of the process, the material is completely immersed in a bath of molten zinc. The bath chemistry requires at least 98% pure zinc maintained at 815-850 °F (435-455 °C).
- While immersed in the galvanizing kettle, the zinc reacts with the iron in the steel to form a series of metallurgically bonded zinc-iron intermetallic alloy layers, commonly topped by a layer of impact-resistant pure zinc.
- The steel is held in the molten zinc bath and until the temperature of the steel equilibrates with that of the bath.
- Once the fabricated items' coating growth is complete, it is withdrawn slowly from the galvanizing bath, and the excess zinc is removed by draining, vibrating, and/or centrifuging.
- The metallurgical reaction will continue after the materials are withdrawn from the bath, as long as it remains near bath temperature.

#### **2. *Cooling***

- Galvanized articles are cooled in a quench tank with a passivation solution to reduce its temperature and inhibit undesirable reactions of the newly formed coating with the atmosphere.

#### **3. *Inspection***

- Inspection of hot-dip galvanized steel is simple, because zinc will not react with unclean steel. Therefore, visual inspections are very accurate and easy to perform. Coating thickness is an important requirement as it directly relates to the effectiveness of hot-dip galvanizing as a corrosion protection system because zinc thickness is linear to the life of the coating. However,

measuring coating thickness is only one of the requirements in the inspection process, other key items include adhesion, appearance, and finish.

## C. Post treatment

### 1. **Chromate solution**

- Uses a chromic acid (more commonly hexavalent chromium). Will passivate zinc to form pleasant sheen with improved corrosion resistance performance.

### 2. **Phosphating**

- Uses a dilute solution of phosphoric acid and phosphate salts. Will form a layer of insoluble, crystalline phosphates on zinc surface. Improve corrosion resistance, lubricity.

### 3. **Light rolling**

- Use centrifugal force to distribute wet zinc evenly on surface. Roll the article when it is taken away from zinc clave.

### 4. **Roller levelling**

- Use a metal roller to level excessive molten zinc on surface.

## Measure thickness

Service life of zinc layer is directly linked to its thickness, so measuring the thickness of HDG can be critical. There are various ways to measure single spot reading and average DFT, such as:

- Magnetic gauge (single spot measurement)
- Weight by mass (average thickness):
  - Clean, weigh and dip a test piece in the molten zinc, let it cool and weigh again. Convert the increase in weight to grams zinc per square metre surface ( $\text{g}/\text{m}^2$ ). 1  $\text{g}/\text{m}^2$  equals a zinc thickness of 0.14 micr, so if the weight increase was 750  $\text{g}/\text{m}^2$ , the hot dipped zinc thickness will be 105 micr. ( $750 \times 0.14$ ).

# Fire protective coatings

## The purpose of PFP

Passive Fire Protection measures are intended to contain a fire in the fire compartment of origin, thus limiting the spread of fire and smoke for a limited period of time, as determined by the relevant fire code. Contrary to active fire protection measures, Passive Fire Protection installations do not require electric or electronic activation or a degree of motion, so the risk for malfunction is virtually eliminated.

### The purpose of Passive Fire Protection:

1. To protect human lives
2. To protect assets

When materials burn, they give off energy in the form of heat. The time that a material takes to burn and either become consumed or change its physical shape or properties can vary, depending on the material. The one common factor is time – it takes a very short time for fire to destroy or heat materials to a point where they change their physical properties. When petrochemical materials such as oil and gas burn, the increase in temperature is rapid which can cause structural materials to degrade and then collapse before people have time

to leave the fire zone.

### **Protect human lives**

To protect human lives, the structural strength of steel must be kept below the core temperature for a certain length of time, as specified for each of the different fire classes. Core temperature is the temperature when the structural properties change and become weaker leading to material distortion and collapse.

Design should allow to keep flames and smoke away from a designated area for the specified time. It is smoke and flames that kill first, but structural breakdown, preventing escape is just as serious. The figures given for the different Fire Classes are the time that the material must insulate under fire conditions:

- Class H: 2 hours
- Class A: 1 hour
- Class B:  $\frac{1}{2}$  hour

Fire cells are made up of classified fire divisions with a purpose to keep flames and smoke away from a designated area and prevent fire from spreading outside the fire cell within a given time period.

### **Protect assets**

The PFP should insulate the exposed walls, ceiling, floors and structural members of an asset to keep the substrate temperature under certain specific values for a specified time. The time gained by using PFP is used to allow personnel to escape the fire zone and for firefighting personnel to access the fire without having to deal with structural collapse.

## Design considerations

### **Two types of fire**

- **Cellulosic Fires**
  - Fires that involve burning of materials such as wood/timber, fabrics and textiles
  - PFP for Cellulosic fires are not suitable for Oil and Gas fires
- **Hydrocarbon Fires**
  - Fires that involve the burning of Hydrocarbon based materials such as oil and gas
  - Example: fires that could occur in offshore and onshore petroleum and chemical installations

### **Fire temperatures**

#### **Cellulosic fire (wood, paper):**

- Temperature after 5 minutes: 556 °C
- Temperature after 1 hour: 945 °C

#### **Hydrocarbon fire (oil, paint, solvents):**

- Temperature after 5 minutes: 926 °C
- Temperature after 1 hour: 1145 °C

## Considerations

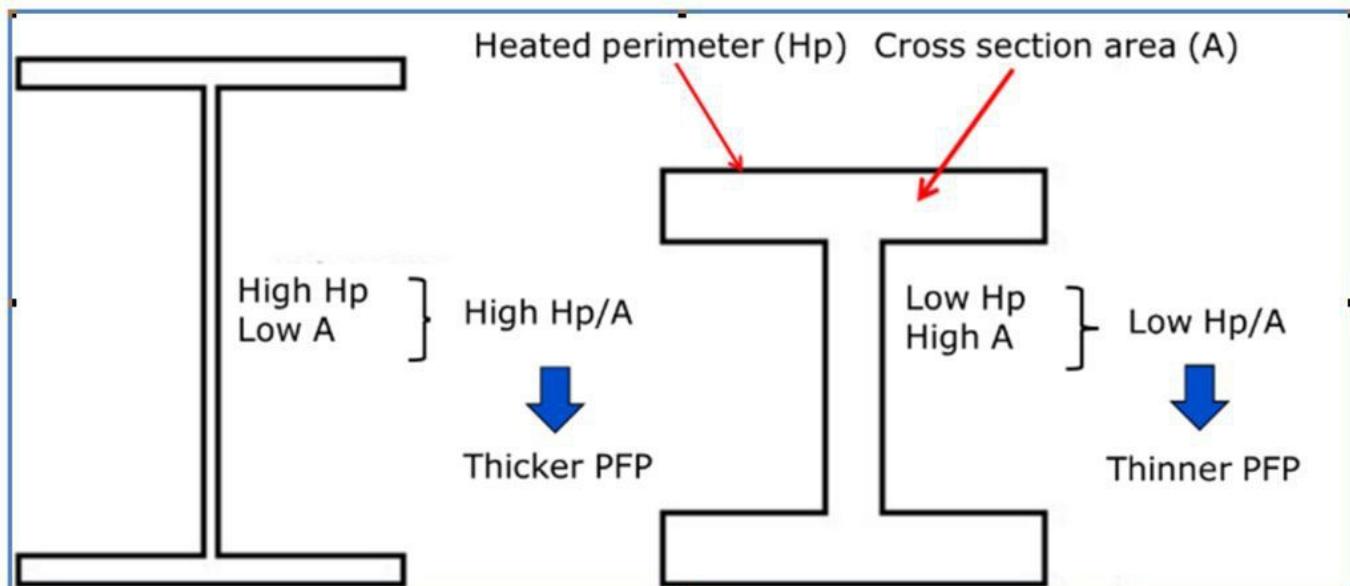
- Section Factor (A/V)
- Shape of section (e.g. I-section, rectangular hollow section)
- Size of section
- Fire resistance period
- Temperatures attained by steel sections
- Critical temperature
- Orientation of section
- Thickness and density of applied protection
- Surface preparation of steel
- Reinforcement (if any)
- Primer compatibility
- Manner of application (brush/spray)
- Effects of over-coating
- Number of coats
- Physical performance and retention of protection material

## Hp/A

The mass of the material will determine how slowly or quickly the material gains and loses heat. When exposed to the same temperature and for the same time, a steel column with a thinner cross section will heat up faster than a column with a thicker cross section.

The ratio between the size of the area receiving the heat (heated perimeter) and the mass that needs to be heated (cross section area) is used to determine the amount of passive fire protection (DFT) that is needed for each steel member. This can be written as:

**“Heated perimeter / Cross section area” or simply: “Hp/A”**



## Types of PFP

**Two types of thick film PFP coatings**

#### **A. Organic coatings**

- Epoxy coatings
- Thickness 3-30 mm
- Swells and creates an insulating layer (intumescent)

#### **B. Inorganic coatings**

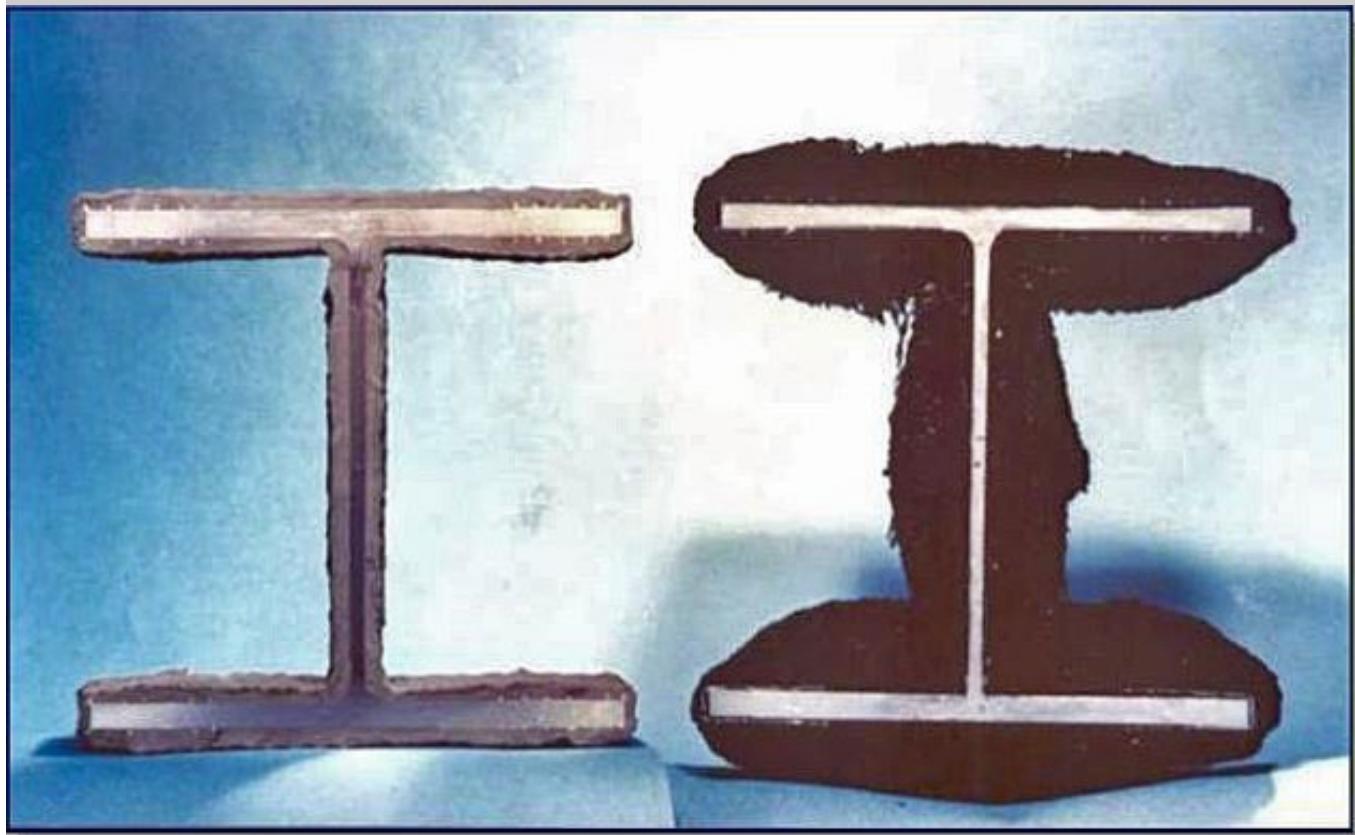
- Cementitious coatings
- Thickness 20-40 mm
- Liberates water which cools the substrate

#### **Intumescent**

Intumescent coatings are paint-like materials which are inert at low temperatures but which provide insulation as a result of a complex chemical reaction at temperatures typically of about 200-250°C. At these temperatures, the properties of steel will not be affected. Because of this reaction the coating swell and provide an expanded layer of low conductivity char. When exposed to fire, an intumescent coating generally expands in thickness by 15 to 30 times in a standard test, but there can be great variations from one product to another.

Intumescent coatings can be divided into two broad families: thin film and thick film. Thin film materials are either solvent based or water based and are mainly used for buildings (cellulosic fires). Thick film intumescent coatings were originally developed for the off-shore and hydrocarbon industries but have been modified for use in buildings as well. The following applies to thick film PFP.

## Swelling of epoxy coating to create char



Epoxy PFP char

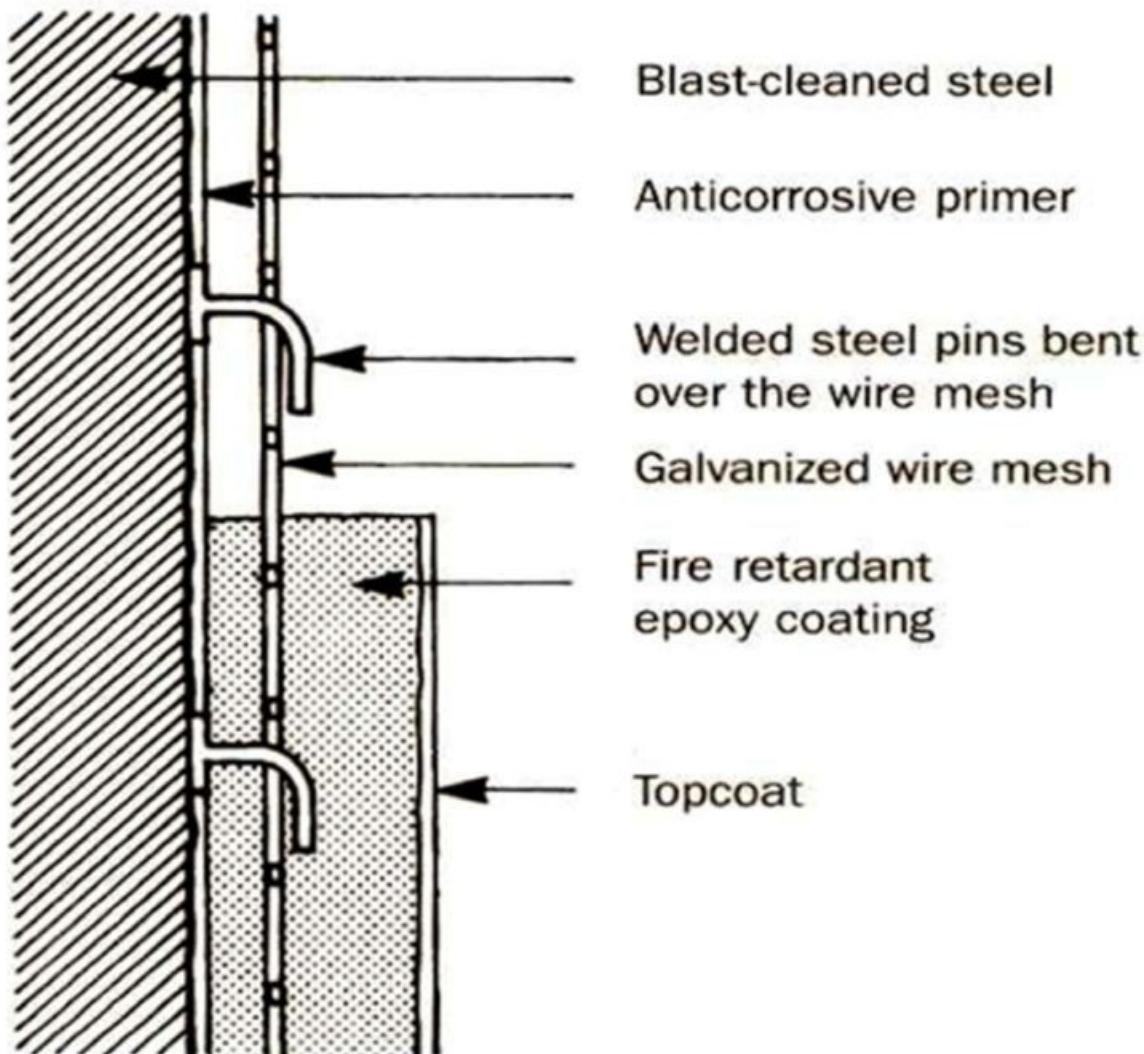
### 1. Organic epoxy based PFP

Organic PFP coatings are intumescent and based on epoxy binders. Intumescent means that it swells as a result of heat exposure, thus increasing in volume and decreasing in density. Intumescent material thus produce a char, which is a poor conductor of heat, thus retarding heat transfer to the substrate (provides insulation).

#### **A typical epoxy-based PFP system**

Steel pins are welded to the substrate. After blast cleaning and application of an anticorrosive primer, wire mesh is mounted on the pins. The epoxy PFP is spray applied in the specified film thickness over the wire mesh in one or two coats, so the mesh forms a reinforcement inside the completed film. Finally, a suitable topcoat may be applied.

Modern PFP systems do not require pins and the fiber reinforced mesh is wrapped into the PFP material.



### **New developments in Epoxy PFP**

Product development of Epoxy based PFP has led to new materials that do not require placement of any reinforcing mesh or fibre material between coats. This development, with no loss of fire endurance properties, has resulted in a product system that is approximately 40% quicker to apply.

### **2. Inorganic cement based PFP**

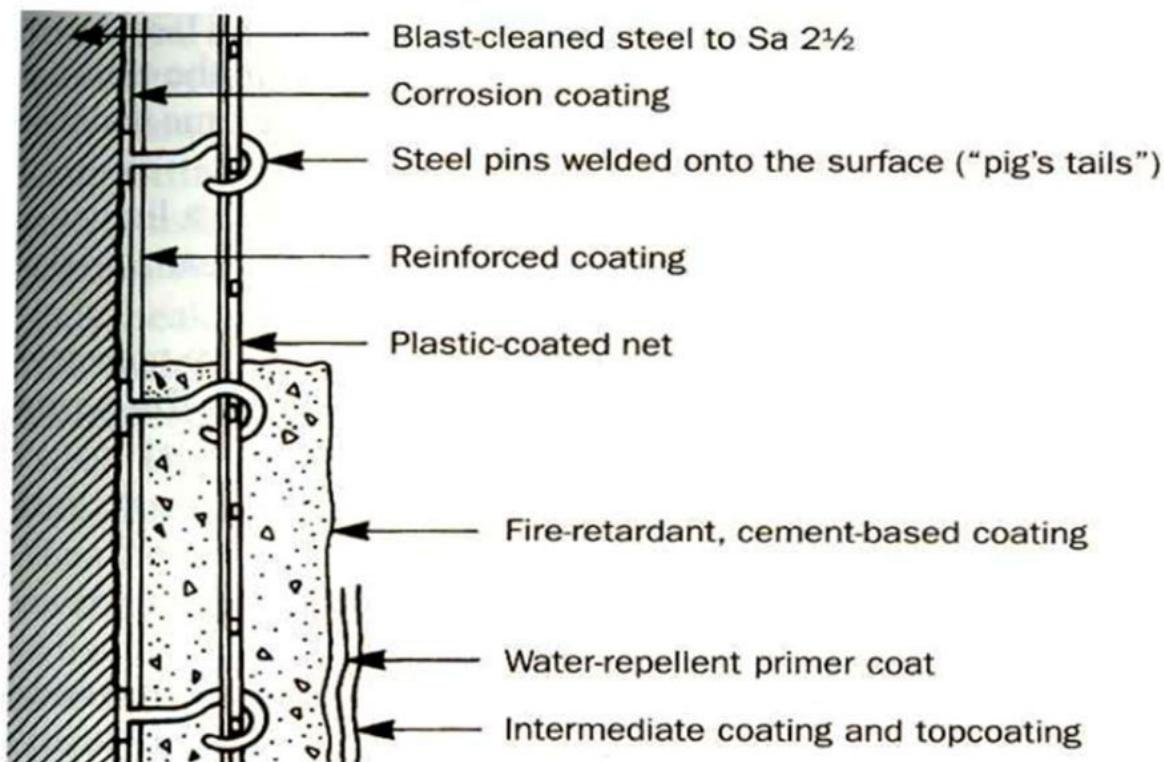
As the name indicates, these materials are cement based and generally contain exfoliated (fired at very high heat) MICA which when it is added to the cement provides reinforcement and it traps water which is very important for fire endurance properties of this type of PFP. Cement based PFP materials are applied thicker than Epoxy PFP but the weight on the steel is usually the same as the Epoxy PFP due to epoxy having a higher specific gravity.

- Cured cement coatings retain water; even if you measure water the content to be less than 4%, which is very dry!
- Heat will force the retained water to evaporate

- The evaporation of the water reduces the heat take up by the PFP material and the steel substrate
- This action delays the temperature increase to the substrate giving time for evacuation and fire fighting
- Adding water during the fire can extend the duration of the PFP past tested fire duration

### **Application of inorganic (cement based) products**

- Pins to support reinforcing mesh have to be stud welded to the steel which requires grinding before welding of pins
- Blast cleaning to SA 2½ of all surfaces after pins are installed
- Application of qualified corrosion protective primer. Normal DFT 200-300 µm
- Fastening of wire mesh (plastic coated) to the pins
- Application of passive fire protection materials to specified thickness (normally 20-40 mm)
- Application of qualified topcoat (if specified, not needed for performance)



### **Measuring PFP film thickness**

The often high film thickness may cause some problem when trying to use "standard" WFT and DFT thickness gauges. The embedded wire mesh will cause additional problem for magnetic or electronic gauges. These are some possible solutions to the problem:

#### **WFT**

- Insert a spike (caliper), take it out, measure
- Make a comb with two teeth with the desired WFT
- Make sure the comb does not hit the mesh
- Application often done in two steps, first application to the mesh, the second after the mesh

## DFT

- Drill a tiny hole, measure the DFT with a spike (caliper). Note! Must repair hole.
- Ultrasonic equipment

## Fire classes

### Fire Cell definition

A segregated part of an installation where a fire may develop without spreading to other areas within a given time.

### Fire Class A

Class A fires consist of ordinary combustibles such as wood, paper, fabric, and most kinds of trash

- Requires divisions made of non-combustible materials and insulating materials, sufficiently reinforced
- Divisions **shall prevent propagation of flames and smoke for a minimum of one (1) hour in a standardized fire test**
- The divisions shall be insulated so that the average temperature on the unexposed side does not exceed 140 °C above the initial temperature
- Furthermore the temperature at any single point shall not exceed 180°C above the initial temperature within the time limits given below:
  - Class A-60: 60 minutes
  - Class A-30: 30 minutes
  - Class A-15: 15 minutes
  - Class A- 0: 0 minutes

### Fire Class B

Class B Fires are fuelled by flammable or combustible liquids, which include oil, gasoline, and other similar materials

- The divisions shall be made of non-combustible materials and **shall prevent the propagation of flames for at least 30 minutes of standardized fire test**
- The divisions shall be insulated so that the average temperature on the unexposed side does not exceed 140°C above the initial temperature
- Furthermore, the temperature at any single point shall not exceed 225°C above the initial temperature within the time limits given below:
  - Class B-30: 30 minutes
  - Class B-15: 15 minutes
  - Class B- 0: 0 minutes

### Fire Class H

Class H fire divisions are fueled by hydrocarbons.

- The divisions shall be made of non-combustible materials, and insulation materials
- The divisions shall be sufficiently braced/reinforced and **shall prevent the propagation of flames and**

### **smoke for a minimum of two (2) hours of the standardized fire test for a hydrocarbon fire**

- The divisions shall be insulated so that the average temperature on the unexposed side does not exceed 140 °C above the initial temperature
- Furthermore, the temperature at any single point shall not exceed 180°C above the initial temperature within the time limits given below:
  - Class H-120: 120 minutes
  - Class H- 60: 60 minutes
  - Class H- 0: 0 minutes

### **Comparing fire classes**

- Class A - Cellulose fire, i.e. a fire burning on materials made of paper, wood, fabrics
- Class H - Hydrocarbon fire, a fire burning on materials such as oil, solvent and paint,- i.e. oil related products
- The time that the divisions shall prevent the propagation of flame and smoke:
  - Divisions in class B - ½ hour
  - Divisions in class A - 1 hour
  - Divisions in class H - 2 hours

## **Special coatings**

### **Powder coating**

#### **What is powder coating?**

- “Paint in dry powder form”
- Mostly epoxy and polyester resins, or combinations of these
- The powder contains resin, curing agent, pigments and additives, all in solid form
- No solvents used in production or in application

#### **Powder coating - production process**

1. All the dry raw materials (in dry powder form) are pre-mixed
2. The mixture is fed into an extruder where some of the raw materials (binder) melt and all the ingredients are force-mixed further under high temperature and pressure
3. The mixture comes out of the extruder as a hot paste which is rolled flat, cooled and chopped into flakes
4. The flakes are fed into a mill and ground to a powder
5. The powder goes through a sieve to ensure the final powder coating matches the specified particle size before it is packed

Quality control, including colour matching, can only be carried out on the extruded product, but any adjustments / additions must be made before extruding.

#### **Surface preparation**

Objects to be powder coated must first receive surface preparation. Common methods are:

- Abrasive blasting
- Alkaline degreasing
- Iron phosphating or zinc phosphating

- Chromating

### **Application by electrostatic spray**

Most often the objects are at ambient temperature when coated electrostatically, and baked in an oven at 160–220°C for 5–20 minutes, where the powder changes:

- melting and flowing to a continuous film
- wetting the substrate
- gelling/ chemical curing

*Objects can also be pre-heated prior to application by:*

- convection oven
- electro induction coil
- infrared

The powder is blown softly from a high voltage powder gun (60 – 100kV) towards the object which is grounded (connected to earth). The powder will stick electrostatically to the object, which is moved to the oven. Typical material loss in an automatic plant:  $\approx 5\%$

### **Application by fluidized bed (FBE)**

#### **Fluidized bed**

A fluidized bed is a container that holds the powder material with an air chamber at the bottom referred to as an inlet plenum.

The container and the plenum are separated by a membrane that is porous enough for air to pass through but not porous enough for solids to pass through. Compressed air is introduced into the plenum and up through the fluidizing membrane.

As the compressed air passes up through the container, the powder particles are suspended in the airstream. In this suspended state, referred to as fluidization, the powder/air mixture behaves somewhat like a liquid.

#### **Application**

- The object is pre-heated to 220-240°C
- Dipped in the fluidized powder for a certain time
- The film is formed while dipping
- Curing takes place by residual heat in the object

#### **Advantages**

- Simple process
- High DFT (400-500  $\mu\text{m}$ ) possible in one operation
- Complete coverage of complex geometries

*Suitable items must have high mass relative to size*

- In order to retain temperature long enough to build coating thickness

- To facilitate complete curing after withdrawal from the fluidized bed

## A typical powder coating application plant

Typically used as part of production line (conveyor belt):

- Cladding, sheets and aluminium profiles
- Domestic appliances
- Steel pipes
- Reinforcing bars for concrete (fusion bonded epoxy, FBE)

## Tank lining

- Tank lining is one of the most critical coating application jobs in the coating industry and needs a lot of attention during application in order to minimize future claims
- A general definition for tank lining is a material (coating, glass fibre lining, rubber lining, etc.) which is applied to interior surfaces of tanks that require protection from exposure to strong chemicals / products contained in the tank
- Purpose of tank lining:
  - Protect the tank content from contamination
  - Protect the tank against corrosion and undesirable effects from the content
  - Provide easy cleaning of the tank

## Common generic types of tank coatings

- Epoxy (pure)
- Phenolic epoxy
- Inorganic zinc silicate
- Vinyl-ester

Both surface preparation (min. Sa 2.5) and application must be of highest quality. Inspection must be thorough and detailed, with particular attention to ambient conditions, DFT, pin-hole detection, drying & curing conditions, etc.

The liquid tank-content will always penetrate the tank coating to a larger or lesser degree, and some swelling of the film may take place. This is normal and it will not cause any problem for a suitable and good tank coating. Once the tank is empty and ventilated, the liquid will leave the coating film and it will be reconstituted. If the liquid content is not volatile, cleaning of the tank will be necessary before the tank is filled again with a different liquid content. Insufficient cleaning will not only result in contamination of the next tank-content, it may cause coating failure if the new tank-content is not compatible with (or cause a reaction with) remains of the previous tank-content which still is embedded in the coating film.

## Two different tank scenarios

- **Storage tanks**
  - The content type is predominantly the same all the time
  - The coating must be resistant to long-term exposure to the particular content
- **Cargo (transport) tanks**

- The content may often differ from one transport to another
- Cleaning between different cargo types may be crucial
- Sequencing (order) of different cargoes is important, since cargo-remains in the film must be compatible with the following cargo

## Glass fibre lining

- Types of glass:
  - Flakes
  - Woven mats
  - Non-woven mats
  - Chop-strand from chopper gun
- Can be combined with both epoxy, polyester and vinyl-ester resins
- Used inside tanks, usually at the bottom / lower sides
- Requires Sa 2½ steel preparation

### Glass fibre lining - application

- Resin is usually applied directly on the prepared steel surface, the glass fibre mat is pressed into the wet film and more resin applied on top
- Chop-strand application may also be used
- System may be built up of several coats
- High labour cost
- High material cost

Instead of using mats of glass fibres, a Chopper Gun can be used to automatically chop and deposit fiberglass filaments. The Chopper Gun makes it easy to quickly cover large surfaces with fiberglass. Strings of fiberglass are fed through the back of the gun in a long continuous piece. An adjustable blade assembly controls the size of the fiberglass strands it cuts, and the trigger controls the speed at which these strands are ejected from the gun and onto the surface. This chopper gun is used together with an airless spray gun, so both fibre glass and resin are applied simultaneously.

## Rubber lining

- Used for tanks, pipe sections, vales and chutes etc.
- Some grades used for abrasion resistance
- Natural rubber lining is typically used in storage tanks for concentrated hydrochloric acid (HCl)
- Film thickness up to several centimetres
- System consists of primer, adhesive and rubber sheets
- Made from different types of rubber such as Hypalon, Neoprene, Natural rubber

### Rubber lining - application

- All steel defects should be remove thoroughly, and surface must be smooth
- Abrasive blasting to Sa 2½
- Apply a system:
  - Primer
  - Adhesive
  - Rubber sheet

- Cure by vulcanization

Vulcanization: a physiochemical reaction to form cross linking of the rubber with sulphur and heat.

## Anti-corrosion tapes & foils

- Limited size and shape of items to be coated
- Mostly used on pipes
- No solvents
- Long runs can require special application equipment
- Applied by wrapping over a primer
- Thickness from 1 mm upwards
- No curing

A number of different types of tapes is available, each designed for their particle use:

- Polyethylene tapes
- Petrolatum (greasy) tapes
- Elastomerised Bitumen tapes
- PE-Butyl Rubber tapes
- High temperature tapes

## Soft coatings

- Coatings that do not dry or cure, but stay soft all the time
- Protect against corrosion by forming a barrier
  - Wax (warm applied)
  - Grease (Lanolin / Wool fat / Sheep grease), very messy!
  - Bitumen (hot applied)
- Usually very good penetrating properties
- Applied by spraying or brush
- Very difficult to change to a drying type of coating (very difficult to clean/remove, causing adhesion challenges for drying type coatings)
- Used in cofferdams, void spaces, ballast tanks, under-carriage of cars & trucks

Flow coats were used some time ago: The oil-like coating was poured into the bottom of a water ballast tank and water was carefully filled into the tank. The coating would float on top of the water and a layer of the flow coat would be deposited on the tank walls as the water level in the tank raised. It provided a limited protection against corrosion and had to be repeated after a few ballast sequences. It is no longer in use due to poor performance and high sea-pollution consequences.

## Glass flake reinforced paints

A number of different special coatings contain glass flakes as reinforcement. The two main reasons would be to increase the coating's abrasion resistance (e.g. for use on the hull of ice-breaking vessels) or its chemical resistance (e.g. for tank coating). Typical binders used for glass flakes containing coatings are epoxies, polyesters, vinyl esters, etc.

## **Glass flake vinyl ester paint**

### **Advantages**

- Very fast curing
- Very good adhesion
- Very good abrasion resistance
- Very good chemical resistance
- Very good solvent resistance
- Can be applied by normal airless spray
- Glassflakes improve abrasion resistance

### **Limitations**

- Short pot life (approx. 45 min.)
- Overcoating interval: Min. 2 hours, max. 24 hours
- Limited shelf-life: 6 months at 23°C
- Dependent on temperature during application
- Only to be applied on blast-cleaned steel (Sa 2½ )

*Note:* the peroxide catalyst has high risk of self-ignition

## **Heat resistant paints**

Most organic binders start breaking down at temperatures above 250°C. Special heat resistant paints will have inorganic binders which can tolerate temperatures above 250°C over longer periods.

The main purpose of heat resistant paints is to protect heated surfaces against corrosion (as well as giving some visual benefits).

Most heat resistant paints shall be applied at ambient temperature, but some allow maintenance painting without shut-down of hot processes.

Common types of heat resistance paints are:

- Aluminium silicone
- Zinc silicone
- Inorganic zinc

### **Temperature limit**

Heat resistance is dependent on choice of binder, and the metal contained. Typical acceptable limits:

- Aluminium silicone: 600°C
- Zinc ethyl silicate: 400°C
- Silicone acrylic: 250°C

### **Heat resistant paints - application**

- To be applied only on Sa 2½

- To be applied in multiple thin coats, typical DFT 20 µm, heavier coats may give blistering
- Zinc ethyl silicate must be fully cured before over coating

# IOGP Definitions of Paint and Surface Treatment

## Introduction

IOGP, the International Association of Oil and Gas producers have created an pamphlet defining common definitions of Paint and Surface Treatment definitions for the oils and gas industry. The complete pdf file can be viewed below.

[589 Paint and surface treatment definitions.pdf](#)

# Requirements for execution of works

## Quality conception

### Introduction

The final quality depends on many factors during the entire process from making the original specification until the project is handed over?

- That our work as inspectors or coating advisors is part of the quality concept?
- That communication between all involved parties is part of the quality?

### Definitions

#### **Quality Policy**

The organization's intentions and principles regarding quality

#### **Operational Control**

Ensure that operations and activities which have impact on significant quality and environmental aspects are carried out in a specified way

#### **Non-conformance**

Not in conformance with the specification (something undesirable has occurred)

#### **Corrective action**

Action taken to correct a detected non-conformance or other undesirable happenings

#### **Preventive action**

Action to eliminate the cause / prevent a recurrence of a non-conformance

### ISO 9001

ISO 9001 is a quality management system (QMS) for companies who want to prove their ability to consistently provide products and services that meet the needs of their customers and other relevant stakeholders. An independent and qualified external body may be invited to inspect all aspects of the company to check that it satisfies all the requirements of ISO 9001. If this is found to be correct, the company will become certified as complying with ISO 9001.

An ISO 9001 certified company will have implemented Quality Management System requirements for all areas of the business, including:

- Facilities
- People
- Training
- Services

- Equipment

The first stage towards certification will be to check that the written Quality Management Systems (QA Manual) meet the requirements of the ISO 9001 Standard and match what is actually done and highlight any areas of deficiency and potential improvement of the system.

In stage two of the certification, an external assessor/auditor will check that the entire company is working to the requirements of its Quality Management Systems and the ISO 9001 Standard. The Quality Management Systems must be incorporated into every area of the business. All staff must be aware of what is expected of them and where their areas of responsibility lie, in order to achieve ISO 9001 Certification.

The documented Quality Management System must define:

- Organisation structure
- Who should record information and what information is recorded
- Responsibilities of employees
- Lines of communication throughout the company
- What actions are required
- How continuity will be maintained as staff change

Defining the Quality Management System will require input from all the departments in the organisation. It needs to:

- Define who the customers are for each department, for example:
  - For the sales and marketing department it will be the end users
  - For the IT department, it will be internal departments
- Document the activities in each area.
- Review the ISO 9001 Standard to ensure the requirements have been met.
- Identify any problem areas and rectify them

## **Management of Documentation**

- The importance of keeping records and using the correct documentation must be communicated to all employees
- *The use of documents must be controlled to ensure the latest version is being used, this is an important part of ISO 9001. It must be ensured that old versions are removed and new versions distributed to the various internal departments, together with a system for version control.*
- It must be identified which records are to be kept to comply with the requirements of the ISO 9001 system and which are needed to successfully run the business.

## **Corrective and preventive measures**

- Inevitably, processes can go wrong and one will need to have a defined process for fixing the problem and identifying where it went wrong, before making changes to prevent it from happening again.
- One must keep a record of any actions that have been taken to rectify a problem. Where possible one should identify potential problem areas and set up a system to prevent or minimise their effect before it happens.

## **On-going support and training**

- Staff should be suitably trained to ensure they can carry out their job function. Keep records of experience, education and training to identify their capabilities.
- Future training requirements can then be implemented together with any new skills that may be needed as the business evolves.
- Using this information, one will be able to identify any gaps in experience if new equipment is installed or new products added

## Regular Internal Quality Auditing

- Regular Internal Quality Auditing of the system is required. Persons within the organisation who are independent of the function being audited may carry these out.
- The Internal Auditor will check that procedures in the Quality Manual are being followed and will identify any areas of concern to be rectified.
- There must be a procedure for how audits are to be planned, conducted and recorded.

## ISO 9001 key elements

- System
  - The company shall establish, document, implement and maintain a quality management system and continually improve its effectiveness in accordance with the standard
- Management responsibility
  - The top management shall provide evidence of its commitment to the development and implementation of the quality management system and continually improving its effectiveness
- Documentation
  - Quality policy & quality objective
  - Quality manual
  - Documented procedures
  - Documents needed to ensure effective planning, operation and control of its processes
  - Records

## ISO 9001 - main issues

These issues apply to all phases of the business, from raw material via production, warehouse and supplying to installation (meaning handling / application of paints)

- Customer focus
  - Ensure customer requirements are determined and met, with the aim of customer satisfaction
- Management review
  - Identify improvement opportunities
- Internal audits
  - Determine whether the system conforms to the planned arrangements and to the standard
- Human resources
  - Competence, education, training, skills, experience
- Design and development
  - Control the design and development of the product
- Identification and traceability
  - Identification and traceability of the product throughout the whole business chain
- Product realization
  - Plan and develop the whole production process, including verification, validation, monitoring, inspection and testing
- Control of nonconforming product

- Identify and control any product that does not conform to requirements, to prevent its unintended use or delivery
- Corrective actions
  - Eliminate the cause of nonconformity to prevent its reoccurrence
- Quality control
  - An integral part of all processes (activities) to ensure the products meet their specifications

## **ISO 9001 and ISO 14001**

Continual improvements shall be achieved by using the “Plan / Do / Check / Act” model:

### ***Plan:***

- Quality aspects
- Regulatory
- requirements
- Objectives
- Action plans

### ***Do:***

- Training
- Communication
- Organisation
- Documentation
- Document control
- Operational control

### ***Check:***

- Records
- Internal audits
- Monitoring and measurements
- Corrective and preventive actions

### ***Act:***

- Management review

## **Benefits of ISO 9001**

***Customers and users benefit by receiving products that are:***

- Conforming to requirements
- Dependable and reliable
- Available when needed
- Maintainable

***Owners and investors benefit by:***

- Increased return on investment
- Improved operational results
- Increased market share
- Increased profit

### **People in the organisation benefit by:**

- Better working conditions
- Increased job satisfaction
- Improved health and safety
- Improvable moral

### **Society benefits by:**

- Fulfilment of legal and regulatory requirements
- Improved health and safety
- Reduced environmental impact
- Increased security

Quality is not an issue only for a few within the company. To achieve a certain agreed quality for a product and /or service, all employees at all levels have an impact on the final quality, for example Coating Inspectors:

- We need clear instructions for how to do a certain task or job
  - How often to calibrate your instruments?
  - Who shall do the calibration?
  - Where to find evidence that the instruments are calibrated?
- All employees in a company must have a job description.

## **Standard**

### **What is a Standard?**

English dictionaries give several definitions of “Standard”, such as:

- The level of quality or excellence reached by somebody or something
  - Example: Rolls Royce cars has a high standard
- A level of quality or excellence that is accepted as the norm
  - Example: meeting NORSOK standard
- A pattern or model that is generally accepted
  - Example: ISO 9001 Quality Assurance Management System
- A level of quality or excellence by which actual attainments are judged
  - Example: Blast cleaning to Sa 2.5
- An authorized model used to define a unit of measurement
  - Example: Kilogram (kg)
- The usual way of doing something
  - Example: Standard Operating Procedure

### **Published Standards**

- Standards are very widely used and generally regarded as trustworthy
- Standards are an important type of technical documentation for our industry
- Although company in-house standards may be useful, the important ones are the officially published standards, such as international standards, national standards and industry-wide standards
- Published standards are considered to be impartial, they will not favour anybody or anything, only describe their requirements and recommendations in an objective and neutral way
- Standards are often regarded as “benchmarks”, whereby an object or the result of some work or of a test

may be compared to this benchmark and evaluated against it

## **Purpose of a published standard**

### **A standard may give a detailed description of:**

- how something should be done
- how some equipment or installation should be operated
- what properties an object or substance (or paint) should have
- etc.

### **By following such a detailed description one can ensure that:**

- a result can be replicated (repeated)
- different results can be evaluated against each other
- different equipment can be compared to each other
- etc.

By using or referring to published standards, many misunderstandings and/or disputes may be avoided

## **A world without standards?**

- Try to describe a special colour via telephone to the factory and ask them to make this for you. Will they succeed?
  - Not without referring to a colour standard! (our colour card is actually an in-house standard!)
- Tell a contractor to do blast cleaning to a very good standard. Will his idea of "very good" be the same as yours?
  - Not without referring to a surface preparation standard!
- A supplier guarantee that a coating can protect against corrosion for 10 years. After 5 years, you experience complete break-down. Reason?
  - He had successfully tested it on the external corrugated metal cladding of a warehouse, while you had applied it to the legs of a semi-submersible drilling rig in the Atlantic Ocean. You didn't use a common performance standard!

## **Examples of the benefits standards provide**

- Standardization of screw threads makes sure bolt and nuts fit together, so things don't fall apart and can be replaced during maintenance
- Standards on terminology make exchange of information easier and safer, so people have identical understanding of the same word
- Without the standardized dimensions of sea and freight containers, international trade and transportation would be complicated
- Without the standardization of telephone and banking cards, life would be much more complicated both at home and abroad
- A lack of standardization may prevent the disabled access to shops, public transport and buildings if the dimensions of wheel-chairs and entrances are not standardized
- Standardized symbols provide danger warnings and information across language barriers
- Agreement on the number of variations of a product is beneficial for both producers and consumers, like the standardization of paper sizes (A3, A4, A5, etc.)

## Using standards

Jotun use published standards in several different areas, such as:

- Management systems (ISO 9001, ISO 14001, OHSAS 18001)
- Research & Development (R & D Laboratory)
- Quality Control (QC Lab in production)
- Inspection & evaluation (Technical Service)
- Guarantees
- Specifications, records & reporting
- Product performance & certification
- Quality of surface preparation and application:
  - Preparation of the steel surface before surface treatment
  - Surface treatment prior to applying the coating / coating system
  - Inspection of the coating during and after application
  - Special inspection requirements such as Pinhole Detection in Tank Linings or Immersed Coated Steel before the coating is “put to work”

**USE STANDARDS:** You should refer to published standards whenever possible, in order to avoid misunderstandings and disputes

## Important aspects of quality

- Storage and handling of paints/coatings
- Storage and handling of consumable materials, abrasives etc.
- Waste handling
- Use and maintenance of equipment for pre-treatment and application
- Defects during pre-treatment and application
- Control of the process relative to the plan
- Use and calculations for consumable materials, abrasives etc.
- Inspection plan
- Inspection instruments:
  - calibrated
  - standards
  - acceptance criteria

## Useful Check Points at site

- Specification: Available, clear and correct
- TDS & MSDS: Available
- Order: Placed, confirmed, delivery arrangements
- Product arrival: Correct type, volume, colour, shelf life, thinner
- Product storage: See next section
- Pre-treatment: , standard, ambient conditions, daily log data
- Application: Batch nos., spec., ambient conditions, daily log data
- Drying / curing: , ambient conditions, daily log data
- Final inspection: Complete records

[FROSIO DAILY LOG 2017.pdf](#)

## **Storage and handling of paints/coatings/abrasives**

*Focus on:*

- Ambient conditions
- Temperature
- Humidity
- Shelf life
- Safety
- Security
- Refer to product documentation SDS, TDS  
(See example of SDS and TDS)

## **Chemical waste**

Although rules and regulations for waste handling vary considerably between different geographical areas, there is a clear increased focus on how we deal with waste in most countries. If not handled responsibly, chemical waste can have serious consequences for planet earth, including:

- All living creatures (people, animals, birds, fish, etc.)
- Vegetation (crops, forests, soil erosion, etc.)
- Even our climate may be influenced (global warming)
- Chemical waste is one of the focus areas of United Nation
- Increasing pollution of water in rivers, lakes, oceans and even in under-ground reservoirs is a major concern to the modern world

*Typical chemical waste generated by surface treatment activities:*

- Debris from blast cleaning and grinding
- Polluted water from cleaning
- Dirty solvents
- Used paint tins and cans
- Un-used paints & coatings which is not recycled
- Solvent vapour released to the atmosphere

It is very important that common sense and local regulations are strictly followed when disposing of this waste. In addition to the health and environmental aspect, such waste may also be a fire hazard and must be segregated from other waste and from possible sources of ignition.

## **Consumption of abrasives and capacity**

Parameters, abbreviations:

- Abrasive usage per m<sup>2</sup>
- Number of m<sup>2</sup> per time unit
- Labour cost
- Abrasive cost

## **Quality evidence**

*An inspector's daily log is vital:*

- It is a document that shows whether the different steps are done and approved
- Shall be short but to the point, the relevant standards will tell how to report an observation
- Shall contain as a minimum:
  - Date done
  - Inspectors name
  - Project name
  - Position name
  - Which activity (And many more depending on type of activity)

Keeping an up-to-date daily log is important for both yourself and for your company

# Standards for assessment of coating performance

## Film thickness

A coating can only be expected to provide the projected protection if the dry film thickness (DFT) meets the specified/recommended film thickness.

### **A. Wet film thickness (WFT)**

By controlling the wet film thickness during application, we will also control the dry film thickness, provided no unauthorised thinner has been added to the coating. When we know the %VS, we can easily calculate the resulting DFT from an applied WFT. Refer to ISO 2808 Method 1A and 1B for how the WFT shall be measured.

#### **Comb Gauge ISO 2808 Method 1A**

Comb gauge is a plate with a lot of teeth on its edge(s). Those teeth have various height indicating WFT. The comb gauge can be made from different materials, such as stainless steel or solvent resistant plastic (disposable type). Comb gauge is the most popular tool onsite.

#### *Procedure*

1. Select appropriate side of gauge
2. Insert gauge vertically into wet film just after movement of nozzle
3. Observe two neighbouring teeth, one with paint and the other without
4. The actual WFT is in between those two teeth
5. Practically the highest tooth with paint is identified as the WFT



#### Wheel Gauge ISO 2808 Method 1B

- Wheel gauge consist of a wheel with two ground rims in one axes, and a third middle eccentric rim with a slightly smaller diameter. Scale on one of the ground rims can indicate result of WFT.

#### Procedure

- Insert gauge vertically into wet film just after movement of nozzle
- Roll the wheel in the wet film until a break in the picked-up paint shows on edge of the eccentric rim
- Record the figure on ground rim where break is located

#### For all WFT readings

- Measurement must be taken immediately after all passes are finished

- Accuracy is affected by fast evaporation solvent containing paint, such as zinc rich paint
- In multi-layer physically drying system, the methods can work well for first coat but not subsequent coats
- Clean the gauge with solvent every time after use
- The gauge is applicable only on flat substrates

## B. Dry film Thickness (DFT)

Methods to measure DFT can be categorized in two groups: non-destructive and destructive. There are also different principles and instruments used for various substrate and coatings.

- Non-destructive:
  - Magnetic Pull-off (Ferrous substrates)
  - Magnetic induction (Ferrous substrates)
  - Eddy current (Non-ferrous substrates)
  - Ultra sonic (Non-metallic substrates)
- Destructive:
  - I.G. (Paint Inspector Gauge) (Any substrate)

### **Non-destructive: Ferrous**

*Magnetic Pull-off Gauge ISO 2808 Method 7A*

- Mechanical without battery
- Simple to operate
- Not very accurate

*Magnetic Induction gauge ISO 2808 Method 7C*

- Low-frequency electromagnetic field
- Various verification methods for accuracy
- Some with internal memory and printing function

*Using a magnetic induction DFT gauge*

- Used for non-magnetic coatings on ferrous substrates
- Verify gauge according to manufacture recommendation or referred standards
- Check with your calibration foil frequently
- Plastic material foils wear easily, replace frequently
- Newer models have internal memory, statistical functions and Bluetooth transfer facility of data to computer and smart-phone

*Factors influencing accuracy*

- Standards to be referred
- Thickness & composition of substrate
- Structure of testing area (surface profile)
- Edge effects
- Vibration
- Calibration
- Verification method
- Frequency and extent of readings taken
- Acceptance/rejection criteria

Photo by Akzo Nobel



Checking DFT

#### **Non-destructive: Non-Ferrous metals**

Eddy current gauge ISO 2808 Method 7D

- High-frequency electromagnetic field
- Commonly used on non-ferrous substrates
- For aluminium, copper, stainless steel, etc.

This gauge can be used for non-conductive coatings on electrically conductive substrates. Method to use gauge is very similar as magnetic induction gauge

#### **Non-destructive: Non-metallic**

- Paint is also applied on non-metallic substrate, such as concrete, plastic, wood, etc.
- Purpose to apply paint on such materials are:
  - Protection
  - Decoration
  - Signal
  - Fire fighting
  - Prevent bacteria
- These film thickness gauges are based on ultra-sonic principle

## **Destructive DFT Measurement - P.I.G.**

- Paint inspection gauge (P.I.G.)
- It is a destructive method that can measure dry film thickness for each individual coat in a paint system
- Repair must be carried out on the spots where measurement has taken place
- I.G. is not used in daily inspections
- The use of P.I.G. is described in ISO 2808 Method 5B

### *Apparatus*

- Marker pen: colour contrast with topcoat
- Magnifier: 50 x
- Blade: cut film to form a surface for observation

### *How to Use P.I.G.*

1. Take the coated product
2. Using the marker pen, make a line across the coating
3. Using the PIG, make a cut at right angles to the marker line, all the way down to the substrate
4. Using the microscope, measure the number of divisions across a coating layer, using the sharp cut
5. Using the Scale factor (number of microns or mils per division), calculate the coating thickness of each layer in the coating system

Remember that the Scale factor is depending on the angle of the V-cut made by the blade:

Blade No.	Angle	Range (um)	Factor (um)
No. 1	45°	20 - 2000	20
No. 4	26.6 °	10 - 1000	10
No. 6	5.7 °	2 - 200	2

## **Common Standards for DFT Measurement**

Various standards are used within the industry:

- ISO 2808 Paints and varnishes — Determination of film thickness
- ISO 19840 Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Measurement of, and acceptance criteria for the thickness of dry films on rough surfaces
- SSPC PA2 Measurement of Dry Coating Thickness with Magnetic Gages

*Inspector can refer to above standards for:*

- Verification of gauge
  - Has it been set to zero on smooth steel or on steel with a blast profile? Should you use a corrective value?
- Sampling plan
  - How many DFT measure should be taken in a given area?
- Measurement
- Acceptance / reject criteria

- 80/20 rule
- Test report

## Adhesion strength

The adhesion of a paint film to its substrate is probably the most important factor for a successful result.

Two types of adhesion testing are being used in field:

- Cutting by sharp blade (Cross-cut, X-cut)
- Pull off

These are described in the following standards:

- ISO 2409
- ISO 4624
- ISO 16276

### Cross Cutting test

#### Principle

Six parallel cuts are made in the paint film using a sharp blade and another six cuts are made at 90° angle to the first six. Adhesive tape is applied over the intersection of the cuts and pulled off. Evaluate how much of the paint was removed by the tape.

#### Two types blade can be used:

- Single blade
- Multi-blades

#### ISO 2409

- This method is appropriate to DFT up to 250 µm
- Six cuts are specified in ISO 2409
- Space between each cut is based on DFT of coating system:

Dry film thickness µm	Spacing of cuts
Up to 60	1 mm, for hard substrates
Up to 60	2 mm, for soft substrates
61 to 120	2 mm, for both hard and soft substrates
121 to 250	3 mm, for both hard and soft substrates

#### Procedure

1. Cut the coating down to substrate with appropriate spacing guide
2. Repeat this operation, making further parallel cuts of equal number, crossing the original cuts at 90°angle

3. Brush the panel lightly with the soft brush
4. Rub the tape firmly with a fingertip or fingernail
5. Remove the tape by angle 60°
6. Evaluate the results with illustration in standard

Assessment - ISO 2409	
0	The edges of the cuts are completely smooth; none of the squares of the lattice is detached
1	Detachment of small flakes of the coating at the intersections of the cuts. A cross-cut area not greater than 5 % is affected
2	The coating has flaked along the edges and/or at the intersections of the cuts. A cross-cut area greater than 5 %, but not greater than 15 %, is affected
3	The coating has flaked along the edges of the cuts partly or wholly in large ribbons, and/or it has flaked partly or wholly on different parts of the squares. A cross-cut area greater than 15 %, but not greater than 35 %, is affected
4	The coating has flaked along the edges of the cuts in large ribbons and/or some squares have detached partly or wholly. A cross-cut area greater than 35 %, but not greater than 65 %, is affected
5	Any degree of flaking that cannot even be classified by classification 4

## X Cutting test

Only a single blade is used for this test

### Procedure

1. Make two cuts, resembling an "X", 40 mm long
2. They should cross each other near their middle, at an angle of 30 - 45°
3. Apply adhesive tape at intersection
4. Pull off rapidly (not jerked) at 180° angle
5. Inspect for removal of coating, rate in accordance with scale in standard

## Assessment - ISO 16276

Level 0 - No peeling or removal of coating

Level 1 - Trace peeling or removal along cuts or at their intersection

Level 2 - Jagged removal along cuts, extending up to 1,5 mm out on either side

Level 3 - Jagged removal along most of the length of the cuts, extending up to 3,0 mm out on either side

Level 4 - Removal from most of the area of the X-cut under the tape

Level 5 - Removal of coating beyond the area of the X-cut

## Pull-off Testing - Apparatus

### Principle

Small metal "dolies" are glued to the paint film and pulled off with a special instrument. The pull off force is measured and is a measure of the paint's adhesion.

## **Equipment**

- Pull off tester:
  - Hydraulic
  - Pneumatic
  - Manual
- Dolly
- Adhesive
- Blade

## **Procedure**

1. Check DFT and climatic condition, record
2. Clean the surface of testing area and dolly with sand paper
3. Apply glue onto dolly and attach it firmly to test area
4. Let glue cure / dry
5. Cut surrounding film of dolly down to substrate
6. Pull off dolly with appropriate tester
7. Record fracture strength
8. Analyse failure type, location and area percentage
9. Make report

## **Analysing testing result**

Study the two surfaces where the adhesion break happened and identify what the measured pull-off force is related to:

- Adhesion between paint and substrate
- Adhesion between different coats within the paint system
- Cohesion within a coat of paint
- Adhesion between the dolly and the paint (glue strength)
- A combination of some or all of the above possibilities

The break will usually be a combination of different breaks. All involved parties should agree on acceptance criteria corresponding to different failure types. It is important to identify recurrences of different failures in a paint system.

## **What should be reported?**

- Breaking strength
- Nature of fracture
  - Adhesive failure
  - Cohesive failure
  - Glue failure
- Location of failure
- Percentage of each failure
- Inspection date
- Inspector name
- Standard to be referred
- All details of substrate

- All details of surface preparation
- Description of sampling
- Acceptance criteria
- Ambient condition
- All details of system to be tested
- All details of apparatus to be used

The type of break (and their percentages) should be reported as described in ISO 4624.

## Holidays

### **Holiday detection**

Two methods to detect holidays in film by different standards:

- Low voltage (wet sponge) detector
- High voltage (spark) testing

### **Low voltage (wet sponge) testing**

- Refer to ISO 29601 or NACE SP 0188 or ASTM D 5162 Method A
- It is used to locate discontinuities in a nonconductive coating applied to a conductive substrate
- Appropriate to dry film thickness up to 500 µm
- Using a wetting agent can increase sensitivities of test
- However, if a wetting agent is used, it must be completely removed by rinsing the holiday area prior to repair
- It is a non-destructive testing

### **Procedure**

1. Check DFT to select proper voltage if necessary
2. Connect clamp to bare steel
3. Wet sponge with conductible water
4. Move sponge onto test areas with speed 0,3 m/s by double passes
5. Once gauge beeps, turn corner of sponge to find exact location of holidays
6. Record

### **Factors influencing measurements**

- Topcoat must be non-conductive
- Tested coating(s) must be fully dried
- Surface should be free from contamination
- Total film thickness should less than 500 µm
- The substrate must be conductible
- Sponge shall be wetted “sufficiently to barely avoid dripping”

### **High voltage (spark) testing**

- Refer to ISO 29601 or NACE SP 0188 or ASTM D 5162 Method B
- Appropriate to dry film thickness above than 500 µm
- This method can detect:

- Holiday
- Low film thickness
- Discontinuous in film

### **Procedure**

1. Check DFT to select proper voltage
2. Connect clamp to bare steel
3. Move electrode onto test areas with speed 0,3 m/s by single pass
4. Once gauge beeping and see spark, remove electrode from testing surface and mark for repairing

### **Factors influencing measurements**

- Topcoat must be non-conductive
- The coating(s) must be fully dried. Otherwise, spark may ignite solvent (vapor)
- Surface should be free from contamination
- Generally, this method is aiming at thicknesses exceeding 500 µm
- The substrate must be conductible

## Drying / curing

### **Determine curing of Ethyl Silicate Zinc-Rich Primers**

- Inorganic Zinc ethyl silicate (IOZ) is a moisture curing paint
- If over coated before fully cured, the IOZ will lack moisture and will never cure
- It is important to identify curing degree prior to over-coating
- MEK rubbing according to ASTM D 4752 is a common test method in the industry

ASTM D 4752: Standard Test Method for Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc-Rich Primers by Solvent Rub

### **Procedure**

1. Clean the testing area with clean cloth to remove loose dust
2. Fold a clean white rag to double size
3. Saturate rag with MEK
4. Double rub the test area for 50 times or see substrate exposed
5. Find an adjacent area to do same procedure but with dry rag
6. Compare two rub areas and grade

### **Classification of result**

- 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 double rubs or less

## Identify hardness of paints

- Pencil hardness testing is a simple field testing method according to ASTM D 3363
- Other, more accurate laboratory test methods are available

## Apparatus

- Pencils: 6B-6H
- Mechanical Lead Holder

## Procedure

1. Prepare the lead in the pencil as described in the standard
2. Fix the hardest pencil (6H) to Mechanical Lead Holder
3. Push pencil away from operator on test surface
4. If the tested paint shows cut or scratch or crumble of lead, use the next hardest pencil
5. Continue until a pencil do not cut the film, record hardness of the pencil as film hardness

## Report

- Gouge Hardness: The hardest pencil that will leave the film uncut for a stroke length of at least 3 mm (1/8 in.)
- Scratch Hardness: The hardest pencil that will not rupture or scratch the film

## Solvent test

- Coatings will have different solvent resistance depending to their drying/curing process
- We can determine drying/curing process of an already dried/cured coating by using the solvent test
- Based on the test result, a compatible repair system can be specified

## Procedure

- Place a piece of cotton or textile on the test surface and saturate this with strong solvent
- Cover the test area with a lid to reduce evaporation
- Wait for reaction about 20 minutes
- Observe the surface condition:
  - Dissolves – physically drying paint
  - Wrinkles – oxidatively curing paint
  - No reaction – chemically curing paint

## Paint defects

### ISO 4628 Evaluation of degradation of coatings

Facilitates identification of different types of defects in terms of:

- Intensity
- Quantity
- Size

The standard ISO 4628 consists of nine parts:

- Part 1: General introduction and designation system

- Part 2: Assessment of degree of blistering
- Part 3: Assessment of degree of rusting
- Part 4: Assessment of degree of cracking
- Part 5: Assessment of degree of flaking
- Part 6: Assessment of degree of chalking by tape method
- Part 7: Assessment of degree of chalking by velvet method
- Part 8: Assessment of degree of delamination and corrosion around a scribe
- Part 10: Assessment of degree of filiform corrosion

## **Intensity**

Used for uniform deterioration (e.g. chalking)

- Rating scheme for designation the intensity of deterioration consisting of a uniform change in the visual appearance of the paint coating

## **Quantity**

Used for scattered defects (e.g. blisters, cracking, rust-penetration)

- Rating scheme for designating the quantity of defects consisting of discontinuities or other local imperfections of the paint coating

## **Size**

Rating scheme for designating the size (order of magnitude) of defects

## **Report**

- All details necessary to identify the coating examined
- A reference to the relevant part of ISO 4628
- The type of surface examined, its size and, if appropriate, its location
- The result of the assessment
- An indication of the illumination under which the assessment was carried out
- Any unusual features (anomalies)

# Standards, specifications & procedures

## Standards

### What is a Standard?

A Standard is an established norm or requirement that relates to a technical system for testing, measurement or materials.

- Standards are developed to ensure a common understanding between all involved parties
- Standards may be international, national, state or industry specific
- A Standard is not legally binding until it forms part of a legal document (such as a contract or specification)

### Who authors and published Standards

Common publishers of standards used by the surface preparation industry:

- **ISO:** International Organization for Standardization
- **IMO:** International Maritime Organization
- **ASTM:** American Society for Testing and Materials
- **SSPC:** The Society for Protective Coatings
- **AS/NZS:** Australian / New Zealand Standards
- **NACE:** National Association of Corrosion Engineers (USA)

The FROSIO Coating Inspectors Course mainly addresses *ISO Standards*, but coating Inspectors need to be aware of specific standards used in other regions as well.

### What information is in a Standard

A typical ISO Standard will include:

- Standard number, title, version or revision/edition number
- Foreword
- Scope: Where the Standard can be applied, where is cannot be applied
- Normative references: Other references or Standards required when using the Standard
- Introduction
- Main text: Definitions/ assessment/ results/ reporting
- pictures
- Annex: Informative, but not required information

### Standards for field testing

#### **Field testing Standards - surface preparation**

#### ***ISO 8501 - Preparation of steel substrates before application of paints and related products.***

Visual assessment of surface cleanliness.

- Part 1: new steel
- Part 2: previously coated steel

- Part 3: steel imperfections
- Part 4: water jetting

### **Field testing Standards - surface preparation**

#### ***ISO 8502 - Preparation of steel substrates before application of paints and related products - Tests for assessment of surface cleanliness.***

- Part 3: dust
- Part 4: probability of condensation
- Part 6: sampling for soluble salt measurement - Bresle method
- Part 9: conductometric determination of soluble salts

#### ***ISO 8503 Surface roughness characteristics***

- Part 2: surface roughness (comparator)

#### ***ISO 8504 Surface preparation methods***

- Part 2: Abrasive blast-cleaning
- Part 3: Hand- and power-tool cleaning

#### ***ISO 11127 Test methods for abrasives***

- Part 4: Hardness by glass slide test
- Part 6: Water soluble contaminants by conductivity measurement

### **Field testing Standards - painting & coating performance**

- ISO 2808 Determination of Film Thickness (WFT & DFT; destructive and non-destructive; ferrous and non-ferrous substrates)
- ISO 19840 Measuring DFT on a rough surface
- ISO 2409 Adhesion (cross cut test)
- ISO 4624 Adhesion (pull off test)
- ASTM D5162 Holiday (low & high voltage discontinuity test)
- ASTM D4752 Curing of IZS (MEK solvent rub test)
- ASTM D3363 Curing of organic coatings (pencil hardness test)
- ISO 4628 Paint failures (rust, blistering, cracking, flaking, chalking)

### **Standards for specifications**

A simple way to make a coating specification is to refer to published Standards. No reason to re-invent the wheel when referencing a recognised Standard is more powerful than a single "stand alone" specification.

Standards widely used in the industry:

- ISO 12944 Part 5
- NOSOK M-501
- PSPC

#### ***ISO 12944 - Paints and varnishes — Corrosion protection of steel structures by protective paint***

## systems

- Part 1: General introduction
- Part 2: Classification of environments
- Part 3: Design considerations
- Part 4: Types of surface and surface preparation
- Part 5: Protective paint systems
- Part 6: Laboratory performance test methods
- Part 7: Execution and supervision of paint work
- Part 8: Development of specifications for new work and maintenance
- Part 9: Protective paint systems and laboratory performance test methods for offshore and related structures

## Reference areas - ISO 12944 Parts 7 and 8:

### **Reference areas are suitable (and accessible) areas on the structure used to:**

- Establish a minimum acceptable Standard for the work
- Check that data provided by a manufacturer or contractor is correct
- Enable the performance of the coating to be assessed at any time after completion

### **A reference area must be:**

- An area with typical corrosive stresses / exposure for the structure concerned
- Available for inspection at any time
- Visibly marked or labelled "Reference area: Do not over-coat or paint"

### **Surface preparation and application must be controlled to meet the written specification by all interested parties. All involved parties should agree upon:**

- Location of the reference area
- Size (m<sup>2</sup>) of the reference area
- Number of reference areas

### **All involved parties are required to inspect:**

- steelwork
- cleaning
- surface preparation (blast cleaning)
- ambient conditions
- Application of all coats in the system
- drying / curing
- completed system

When the reference area is finished, all interested parties shall sign off their attendance and agreement that the area meets the specification.

## **Guidelines for number and size of reference areas - ISO 12944 - 7**

Size of structure (painted area) m <sup>2</sup>	Recommended maximum number of reference areas	Recommended maximum percentage of reference area relative to total area of structure	Recommended maximum total area of reference areas m <sup>2</sup>
< 2.000	3	0,6	12
2.000 to 5.000	5	0,5	25
5.000 to 10.000	7	0,5	50
10.000 to 25.000	7	0,3	75
25.000 to 50.000	9	0,2	100
>50.000	9	0,2	200

### **NORSOK Standard M-501 - Surface preparation and protective coating**

The NORSOK Standard M-501 is developed by the Norwegian Petroleum Industry, represented by The Norwegian Oil Industry Association and Federation of Norwegian Industry.

The Standard gives the requirements for protective coatings to be applied during the construction and installation of offshore installations and associated facilities. The requirements are related to:

- Selection of coating materials
- Surface preparation
- Application procedures
- Inspection

This NORSOK Standard cover both paints, metallic coatings and sprayed on passive fire protective coatings.

#### **Main content**

- General requirements
- Health, safety and environment
- Surface preparation
- Paint application
- Thermally sprayed metallic coatings
- Sprayed on passive fire protection
- Qualification requirements
- Inspection and testing
- Annex A (Normative) Coating systems

### **Performance Standard for Protective Coatings - PSPC**

International Maritime Organization (IMO) declared: The Maritime Safety Committee (MSC), at its 82nd session held from 29 November to 8 December 2006, adopted Resolution MSC.215(82) *Performance standard for protective coatings of dedicated seawater ballast tanks on all new ships and of double-side skin spaces of bulk carriers*, which will be made mandatory by way of amendments to SOLAS regulations II-1/3-2, also adopted at the session.

The standard is often referred to as **Performance Standard for Protective Coatings - PSPC** and applies to the marine industry:

- Seawater ballast tanks (all types vessels) and double side skin spaces (bulk carrier)
- Cargo oil tanks of crude oil tankers
- Void Spaces (bulk carriers and oil tankers)

The first two are now enforced and implemented.

### ***Main content of PSPC Standard***

- General principles
- Coating Standard
- Coating system approval
- Coating inspection requirements
- Verification requirements
- Alternative systems
- Appendix:
  - Testing methods for pre-qualification of coating systems
  - Reports
  - Dry film thickness measurements

### ***Process requirements to pre-qualify a coating system***

There are various requirements and procedure to pre-qualify the performance of coating systems in ISO 12944, NORSO M-501 and PSPC

- ISO 12944: refer to Part 6
- NORSO M-501: refer to ISO 20340
- PSPC: refer to Annex 1

## Standards for laboratory testing

### **Typical laboratory testing and assessment carried out during research and development**

- Outdoor exposure
- Artificial weathering
- Weather-o-meter
- Salt spray chamber
- Cyclic testing
- Abrasion resistance
- Hardness
- Flexibility
- Chemical resistance
- Water resistance
- Solvent resistance
- Gloss retention
- Colour retention
- Cathodic disbondment
- Corrosion resistance
- Fouling resistance

- Recoating properties

### Typical quality control testing carried out during manufacturing

- Pot-life
- Drying times
- Specific gravity
- Application properties
- Sag resistance
- Colour
- Gloss
- Viscosity

### Standards related to physical / mechanical properties

Property	Standard / Test method
Abrasion resistance	ASTM D4060
Adhesion (Cross cut) Adhesion (Pull-off) Adhesion (Shear strength)	ISO 2409; 16276-2; DIN 53251; BS 3900-E6; ASTM 3359 ISO 4624; 16276-1; ASTM 4541; BS 3900 - E10 ASTM D 1002 (Specified for passive fire proofing)
Gloss	ISO 2813
Hardness Hardness Hardness	ISO 2815 (Buchholz - method) ISO 1522 (König - pendulum) ASTM D2583 (Barcol)
Elasticity Flexibility	ISO 1520 (Cupping test) ISO 6860, ASTM D522; BS 3900 - E11 (Conical mandrel)
Impact resistance	ISO/TR 6272 - 79E; ASTM D 2794 - 84 DIN 55669; BS 3900 - E3

### Standards related to exposure testing

Test method	Standards	Test method	Standards
Salt spray	ISO 9227	Humidity chamber	BS 3900
Prohesion test	ASTM G85	Weathering	ISO 2810
UV-cabinet	ASTM G53	Resistance to liquids	ISO 2812
Condensation chamber	ISO 6270		

### Standards related to evaluation of paint films

Test method	Standards	Test method	Standards
Blistering	ISO 4628-2	Flaking	ISO 4628-5
Rust	ISO 4628-3	Chalking	ISO 4628-6
Cracking	ISO 4628-4	Scribe	ASTM D1654

## Standards related to evaluation of liquid paint

Test method	Standards
Viscosity (flow cups)	ISO 2431
Viscosity (rotary viscometers)	ISO 2884
Application properties (test spraying)	

# Summary of standards

## Surface cleanliness

ISO 8501	<b>Preparation of steel substrates before application of paints and related products - Visual assessment of surface cleanliness</b>
ISO 8501-1	<b>Rust grades and preparation grades of uncoated steel substrates and of steel substrates after removal of previous coatings.</b>
	<p>Written descriptions and photos of:</p> <ul style="list-style-type: none"> <li>Four levels of mill scale and rust: rust grades A, B, C, D</li> <li>Blast cleaning preparation grades Sa 1, Sa 2, Sa 2½, Sa 3 for the various rust grades, using quartz sand</li> <li>Hand tool and power tool cleaning grades St 2 &amp; St 3 for rust grades B, C &amp; D</li> <li>Flame cleaning grades Fl for the various rust grades</li> <li>Example of the change of appearance imparted to steel when blast-cleaned with different abrasives (one photo showing rust grade C blast-cleaned to Sa 3 with 6 different abrasives)</li> </ul>
ISO 8501-2	<b>Preparation grades of previously coated steel surfaces after localized removal of previous coatings</b>
	<p>Localized blast cleaning: P Sa 2, P Sa 2½, P Sa 3</p> <p>Localized hand &amp; power tool cleaning: P St 2, P St 3</p> <p>Localized machine abrading: P Ma</p> <p>Seven sets of pictures showing four typical cases of very thorough localized blast cleaning (P Sa 2½) and three typical cases of localized machine abrading (P Ma). Each set consists of "before" and "after" photos of the same substrate, and includes items like welding seam, bracket and rivets.</p>
ISO 8501-3	<b>Preparation grades of welds, cut edges and other areas with surface imperfection</b>
	<ul style="list-style-type: none"> <li>P1 Light preparation</li> <li>P2 Thorough preparation</li> <li>P3 Very thorough preparation</li> </ul>
ISO 8501-4	<b>Initial surface conditions, preparation grades and flash rust grades in connection with high-pressure water jetting</b>
	<p>Twenty-three photos showing:</p> <p>Initial surface conditions</p> <ul style="list-style-type: none"> <li>DC A: coating system degraded to R13 (ISO 4628-3)</li> <li>DC B: coating system degraded to R14 (ISO 4628-3)</li> <li>DC C: coating system degraded to R15 (ISO 4628-3)</li> <li>DP I: degraded iron oxide shop primer</li> <li>DP Z: degraded zinc silicate shop primer</li> </ul> <p>Surface appearance after cleaning</p> <ul style="list-style-type: none"> <li>Wa 1: Light high-pressure water jetting</li> <li>Wa 2: Thorough high-pressure water jetting</li> <li>Wa 2½: Very thorough high-pressure water jetting</li> </ul> <p>Flash rust grades</p> <ul style="list-style-type: none"> <li>L: Light flash rust</li> <li>M: Medium flash rust</li> <li>H: Heavy flash rust</li> </ul>
ISO 8502	<b>Preparation of steel substrates before application of paints and related products - Tests for assessment of surface cleanliness</b>
ISO 8502-1	<b>Field test for soluble iron corrosion products</b>
	"Swab test" for sampling, followed by indicator paper
ISO 8502-2	<b>Laboratory determination of chloride on cleaned surfaces</b>
	Washings sampled from surfaces on site, determine by titration
ISO 8502-3	<b>Assessment of dust on steel surfaces prepared for painting (pressure sensitive tape method)</b>
	Sample the dust by means of adhesive tape and compare with pictorial references in the standard
ISO 8502-4	<b>Guidance on the estimation of the probability of condensation prior to paint application</b>
	<ul style="list-style-type: none"> <li>Sling hygrometer</li> <li>Guidance on the estimation of the probability of condensation on a surface to be painted. May be used to establish whether conditions at the job site area are suitable for painting or not.</li> </ul>
ISO 8502-6	<b>Sampling of soluble impurities on surfaces to be painted - The Bresle method</b>
	Sampling using distilled water, adhesive patches and syringes
ISO 8502-9	<b>Field method for the conductometric determination of water-soluble salts</b>
	Salt concentration determined via conductivity measurement (used together with Bresle sampling)

## Surface roughness

ISO 8503	<b>Preparation of steel substrates before application of paints and related products - Surface roughness characteristics of blast-cleaned steel substrates</b>
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	Comparator for either grit or shot - FINE: equal to segment 1 and up to but excluding segment 2 (grit: 25-50 micr. / shot: 25-35 micr.) - MEDIUM: equal to segment 2 and up to but excluding segment 3 (grit: 50-85 micr. / shot: 35-60 micr.) - COARSE: equal to segment 3 and up to but excluding segment 4 (grit: 85-130 micr. / shot: 60-85 micr.) - VERY COARSE: segment 4 and above (grit: above 130 micr. / shot: above 85 micr.)
ISO 8503-1	<b>Specification and definition for ISO surface profile comparators for the assessment of abrasive blast-cleaned surfaces</b>
ISO 8503-2	<b>Method for the grading of surface profile of blast-cleaned steel - Comparator procedure</b>
ISO 8503-3	<b>Method for the calibration of ISO surface profile comparators and for the determination of surface profile - Focusing microscope method</b>
ISO 8503-4	<b>Method for the calibration of ISO surface profile comparators and for determination of surface profile - Stylus instrument</b>

## Preparation methods

ISO 8504	<b>Preparation of steel substrates before application of paints and related products - Surface preparation methods</b>
ISO 8504-1	<b>General principles</b>
ISO 8504-2	<b>Abrasive blast-cleaning</b>
ISO 8504-3	<b>Hand- and power tool cleaning</b>
	Describes the principles and methods for the two types of cleaning.

## Corrosion protection of steel structures by protective paint systems

ISO 12944	<b>Paints and varnishes - Corrosion protection of steel structures by protective paint systems</b>
Part 1	<b>General introduction</b>
	<b>Introduction to the other parts</b> Establish "durability" ranges: - Low (L): 2 to 5 years - Medium (M): 5 to 15 years - High (H): more than 15 years
Part 2	<b>Classification of environments</b> - C1 very low - C2 low - C3 medium - C4 high - CS1 very high (industrial) - CS5 very high (marine) - Im1 Immersion in fresh water - Im2 Immersion in sea or brackish water - Im3 buried in soil
Part 3	<b>Design considerations</b> Corrosion-traps, access, drainage, thermal bridges (risk of condensation), gaps, openings, crevices, sharp edges, notches
Part 4	<b>Types of surfaces and surface preparation</b> - Water / solvent / chemical cleaning - Mechanical / chemical / thermal surface preparation - Preparation grades - Surface profile - Assessment of prepared surface - Temporary protection (shopprimer) - Preparation of existing metal coatings
Part 5	<b>Protective paint systems</b> Eight tables listing possible paint systems for the different corrosivity categories when applied on low-alloy carbon steel, hot-dip galvanized steel and thermally sprayed metal surfaces. Selection criteria: - Generic types of paint - Paint systems - No. of coats - Dry film thickness - Expected durability
Part 6	<b>Laboratory performance test methods</b> Test methods that are to be used when the performance of the paint system is to be assessed
Part 7	<b>Execution and supervision of paint work</b> - Coating material (supply & storage) - Execution of paint work (application conditions and methods, evaluation before work commences) - Supervision of the paint work (at all stages, qualified & experienced people, test instruments, checking) - Reference areas
Part 8	<b>Development of specifications for new work and maintenance</b> - Definitions - How to develop a spec - Contents - Project spec - Protective paint system spec - Paint work spec - Inspection & assessment spec
Part 9	<b>Protective paint systems and laboratory performance test methods for offshore and related structures</b> - Terms and definitions - Field application - Relationship between artificial ageing and natural exposure - Paints - Protective paint systems - Application testing of paints - Performance testing of paint systems - Test report

## Abrasives

<b>ISO 11124</b>	<b>Preparation of steel substrates before application of paints and related products - Specifications for metallic blast-cleaning abrasives</b>
Part 1	General introduction and classification
Part 2	Chilled-iron grit
Part 3	High-carbon cast-steel shot and grit
Part 4	Low-carbon cast-steel shot
Part 5	Cut steel wire
<b>ISO 11125</b>	<b>Preparation of steel substrates before application of paints and related products - Test methods for metallic blast-cleaning abrasives</b>
Part 1	Sampling
Part 2	Determination of particle size distribution
Part 3	Determination of hardness
Part 4	Determination of apparent density
Part 5	Determination of percentage defective particles and of microstructure
Part 6	Determination of foreign matter
Part 7	Determination of moisture
<b>ISO 11126</b>	<b>Preparation of steel substrates before application of paints and related products - Specifications for non-metallic blast-cleaning abrasives</b>
Part 1	General introduction and classification
Part 2	Silica sand
Part 3	Copper refinery slag
Part 4	Coal furnace slag
Part 5	Nickel refinery slag
Part 6	Iron furnace slag
Part 7	Fused aluminium oxide
Part 8	Olivine sand
Part 9	Staurolite
Part 10	Garnet
<b>ISO 11127</b>	<b>Preparation of steel substrates before application of paints and related products - Test methods for non-metallic blast-cleaning abrasives</b>
Part 1	Sampling
Part 2	Determination of particle size distribution
Part 3	Determination of apparent density
Part 4	Assessment of hardness by a glass slide test
Part 5	Determination of moisture
Part 6	Determination of water-soluble contaminants by conductivity measurement
	100 g abrasive + 100 ml water, shake 5 min, stand 1 hour, shake 5 min, conductivity measurement
Part 7	Determination of water-soluble chlorides
Part 8	Determination of abrasive mechanical properties
<b>ASTM D 4940</b>	<b>(Checking the abrasive)</b>
	Checking abrasives for salt and oil contamination: 300 ml abrasive + 300 ml water, stir 1 min, stand 8 min, stir 1 min, conductivity measurement & visual for oil

## Adhesion

<b>ISO 2409</b>	<b>Paints and varnishes - Cross cut test</b>
	<p>Six parallel cuts, another six more cuts at 90 degree angle:  - Up to 60 micr.: spacing 1 mm for hard substrate (e.g. metal)  - Up to 60 micr.: spacing 2 mm for soft substrate (e.g. wood)  - 61 to 120 micr.: spacing 2 mm for hard &amp; soft substrate  - 121 to 259 micr.: spacing 3 mm for hard &amp; soft substrate  adhesive tape pull-off  classify in accordance with table in standard</p>
<b>ISO 16276-2</b>	<b>Cross-cut testing and X-cut testing</b>

	Use cross cut as in ISO 2409 Use knife to make X-cut and rate from figures in standard
<b>ASTM 3359</b>	<b>Standard test method for: Measuring adhesion by tape test</b>
	- Test method A: X-cut test (single cross by knife) for DFT above 125 micr. - Test method B: similar to ISO 2409, 2 mm spacing only, recommended only up to 125 micr.
<b>ISO 4624</b>	<b>Paint and varnishes: Pull off test for adhesion</b>
	Glue on dolly, measure force to pull it off again with pull-off instrument
<b>ISO 16276-2</b>	<b>Pull-off testing</b>
	Glue on dolly, measure force to pull it off again with pull-off instrument

## Holiday detection

<b>ISO 29601</b>	<b>Paint and varnishes - Assesment of porosity in a dry film</b>
	Low-voltage pinhole detection High -voltage spark testing
<b>ASTM D 5162</b>	<b>Standard recommended practice - Discontinuity (Holiday) testing of non-conductive protective coating on metallic substrates</b>
	Test method A: Low voltage wet sponge Test method B: High voltage spark tester

## MEK test

<b>ASTM D 4752</b>	<b>Standard test method for: Measuring MEK resistance of ethyl silicate (inorganic) zinc-rich primers by solvent rub</b>
	50 double rubs with white cloth and MEK, smear indicate inadequate curing

## Evaluation of degradation of paint coatings

<b>ISO 4628</b>	<b>Paints and varnishes - Evaluation of degradation of paint coatings - Designation of intensity, quantity and size of common type defects</b>
<b>Part 1</b>	<b>General principles and rating schemes</b>
<b>Part 2</b>	<b>Designation of degree of blistering</b>
<b>Part 3</b>	<b>Designation of degree of rusting</b>
<b>Part 4</b>	<b>Designation of degree of cracking</b>
<b>Part 5</b>	<b>Designation of degree of flaking</b>
<b>Part 6</b>	<b>Designation of degree of chalking</b>

## Film thickness

<b>ISO 2808</b>	<b>Paint and varnishes - Determination of film thickness</b>
	Specifies a number of methods for measuring the thickness of organic coatings, both wet and dry film thickness
<b>ASTM D 4138</b>	<b>Measuring dry film thickness by destructive means</b>
	Paint Inspection Gauge (PIG)
<b>ISO 19840</b>	<b>Measurement and accept criteria for measuring on rough surfaces</b>
	Use of correction value depending on surface roughness

# Specifications and procedures

# Specifications

## Why make a specification?

- It clarifies what the client shall receive in return for paying the agreed price (expectations)
- It states what the contractor must do to get paid (obligations)
- The specification provides a contractual document for the technical aspects of the operation in order to reduce disputes to a minimum

## Any of these may make a specification for a project:

- The owner
- A consultant, appointed by the owner
- A management company, appointed by the owner
- The contractor, if the owner says so
- The paint supplier, if the owner says so
  - Rather often the owner or consultant ask the paint supplier

The final decision is with the one paying the bill, meaning the owner

## Quality criteria must be specified:

- What tests shall be carried out?
- What methods are to be used?
- What are the acceptance criteria?
- Consequences if work is non-conforming?
- Comments

# Procedures

## ISO 12944 defines what a procedure is:

- The part of the document that describes the way the paint work is to be carried out, in conformance with the project specification and the protective paint system specification, as well as with the inspection and assessment specification

## The link between specifications and procedures:

- **Specification:** A document stating **what** we wish to achieve (To what quality level a certain piece of work must be carried out).
- **Procedure:** A document explaining **how** we shall achieve the requirements in a specification (Processing instruction, check points, quality control).



# Health, safety & environment

## Surface preparation (HSE)

### Hazards from surface preparation

#### **Safety**

- High speed and/or pressurized abrasive media with high kinetic energy
- Electric shock
- Collapse due to a lack of oxygen (confined space or contaminated breathing air in the blast helmet)

#### **Health**

- Dust
- Noise
- Old paint (Heavy metals, dust)
- Temperature

#### **Environmental**

- Disposal of contaminated media and old paint

#### **A. Dust**

Oxygen enters the body through the lungs and diffuses into the blood system. The cells lining the air tubes in the lungs are covered in tiny hairs called cilia. The cilia move back and forth to sweep the mucus upwards towards the throat. This helps to remove the dust and micro-organisms. The mucus is usually swallowed.

- Dust may become trapped in the lungs and create a barrier against the uptake of oxygen
- Small particles (<5 microns) are worst, they will enter deep into the lungs and reduce the effect of the tiny hairs, leading to accumulation of dust, mucus and micro-organisms in the lungs
- A suitable mask will filter the dust away and allow clean air to enter the lungs

Dust entering the lungs may cause several diseases:

- Silicosis (Inhalation of silica from abrasives and quartz)
- Asbestosis (From dust of asbestos)
- Siderosis (From dust of iron oxide)
- Lung cancer (quartz)

#### **B. Noise**

The noise levels are often very high when working with surface preparation. Levels in the range of 120 - 130 decibels are common. In many countries ear protection is prescribed at levels above 85 decibels. Air compressors, air tools, abrasive blasting and water jetting activities all use equipment that can produce noise levels above 85 dB. Temporary or permanent reduction in hearing is a typical consequence of excessive noise exposure.

# Equipment safety

## Pressurised equipment

- Abrasive Media / Water travels in hoses at very high speeds which can create static electricity conditions
  - Abrasive media can travel at speeds above 300 km/hour (>185 mph)
  - Water pressure (UHPWJ) can be higher than 210 MPa
- All blasting, painting and water jetting equipment shall be grounded to earth and use antistatic hoses to avoid electrical sparks jumping from the unit to substrate which could shock the operator
- Blasting Pots must be pressure tested, rated and within test parameters and expiry date before use
- Airless paint hoses, water pressure hoses, blast-cleaning hoses and compressed air hoses must be approved for the applicable operating pressures with a large safety margin
- Only use correct & approved hose couplings, dead-man valves, guns, nozzles, etc.

## Impact and vibrating tools

Exposure to hand tools that vibrate can lead to an irreversible condition called "White Finger" which is caused by damaged blood circulation. Avoid long work periods with such equipment, stay within the permitted time and have regular breaks to allow the circulation to recover.

## Personal Protective Equipment (PPE)

### Typical PPE used for blast cleaning or water jetting:

- Hood with separate operator air supply with additional filters
- Face shield (with or without respirator)
- Cut and puncture resistance gloves
- Ear protectors
- Safety boots
- Boiler suits & coveralls
- Turtleskin Water Armour

### Examples of equipment to protect:

#### *The lungs*

- Disposable dust mask
- Half mask equipped with two filters
- Full face mask (possible to connect with breathing air filter)
- Blasting hood with breathing air filter

#### *The Body*

- Boiler suit
- Respirator with half coverall
- Turtle skin water armour

#### *Ears, Eyes, Hands and Feet*

- Safety goggles
- Ear muffs
- Cut and puncture resistance glove
- Safety glasses

- Ear plugs
- Safety boots

### Using Scaffolding

- Scaffolding must be tightly fixed and be stable
- Scaffold should not obstruct access to substrate to be treated
- Emergency exit location should be identified
- Handrail, kickboard and life net
- Safety belt – when at height
- Inspector must confirm the safety of scaffolding (tag system)
- Do not access scaffold that is not tagged

No one has the right to force people to work in an insecure situation!

### Inside Tanks and Confined Spaces

- The air must be tested to ensure the airspace is free from explosive or toxic gases and there is sufficient oxygen to support life before entering the confined space
- Forced ventilation / extraction must be installed
- Appropriate lighting provided (some countries now legislate)
- In some circumstances, fresh air-fed respirator can be worn for short term visit / inspection

### Lighting

- Adequate lighting for application and inspection should be installed
- Avoid poor lighting in corners or shadow areas
- All electrical systems must be explosion proof if paint-work is carried out
- All electrical connections must be in an explosive proof cabinet

Do not carry out electrical or equipment repairs inside a confined space – take it outside

# Paint & paint application (HSE)

Health hazards and protection

### Introduction

#### **Common HSE - Risks associated with coatings**

- Health - Inhalation and skin contact
- Safety - Explosion and fire
- Environment - Emission to air (VOC), to water and to soil

#### **Sources for health hazards when using paints**

*Binders (in the paint)*

- Skin contact
- Particularly Epoxy; Amines and Isocyanates may cause skin irritation and Allergic reactions

*Solvents - may enter the body in three ways:*

- By inhalation
- By Skin contact
- By Ingestion (swallow / drinking)

*Other constituents:*

- Tar, Heavy metals

### ***Skin contact - examples of damage to the skin***

- Sensitisation
- Allergic
- Skin burning
- Photo
- Corrosion
- Sensitisation

## **A. Health hazards - Epoxies**

*Hazards*

- Eczema and allergic reactions on the skin
- Liquid Epoxies with low molecular weighs (below 700) are most likely to give an allergic reaction
- An allergic reaction to Epoxy is irreversible
- Hyper-sensitive persons must stay away from epoxies

*Protective measures*

- Protective clothes covering the whole body and gloves
- Proper cleaning with water, soap and cleaning cream
- Use disposable overalls

### ***Health hazards with epoxy resins***

The degree of toxicity of epoxy resins depends on the molecular weight of the particular resins

- Low molecule weight epoxy resins are generally low viscosity and highly volatile
- Lower viscosity compounds are easily dispersed on the skin or in the contents of the gastrointestinal tract, which may increase absorption
- On the other hand, higher viscosity compounds are difficult to remove from clothing and skin and residues may remain unnoticed. Complete removal may require organic solvent, which may increase the risk of solvent hazards

High volatility may lead to respiratory and skin exposure to vapours

## **B. Health hazards - Tar containing paints**

Health authorities have designated tars such as coal tar to be Class 1 Carcinogens. Many paint manufacturers do not manufacture and sell coatings that contain bitumen, tars and coal tars, they stopped years ago.

### *Hazards*

- The main hazard with tar containing paints is the risk for developing cancer, especially when exposed to strong sunlight
- Long term exposure to vapours may damage internal organs, cause inheritable genetic defects and birth defects
- Short term exposure to fumes and vapours may cause irritation to the nose, throat and eyes
- Splashes to skin causes irritation

### *Protective measures*

- Protective mask to avoid breathing vapours
- Protective clothes covering the whole body and gloves

## **C. Health hazards - Isocyanates**

Isocyanates are found in Polyurethane paints. The monomer is more volatile than the pre-polymer and is therefore more dangerous.

### *Hazards*

- Irritation of eyes, skin and airways
- Sensitization by inhalation and skin contact
- Asthma

### *Protective measures*

- Protective mask to avoid breathing of vapours
- Protective clothes covering the whole body, boots and gloves

## **D. Health hazards - antifoulings**

### *Hazards*

- Biocide used in Antifouling poses a risk to human health
- Cuprous oxide can cause acute effects, such as headache, Eczema, nausea, etc.; Long term exposure may cause irritation to eyes and skin

### *Protective measures*

- Protective mask to avoid breathing of spray mist / droplets
- Protective clothes covering the whole body, boots and gloves

## **E. Health hazards - Solvent exposure**

### *Acute effects*

- Headache
- Abnormal tiredness
- Dizziness
- Nausea

### *Long term effects*

- Irritability
- Loss of memory
- Organ damage (kidneys, liver, CNS)
- Reduced reaction ability
- Reduced evaluation ability

#### *Skin irritations*

- Eczema
- Dry and cracked skin

#### **Inhalation of solvents**

##### *The most dangerous solvent hazard*

- Solvents will be transported by the blood stream to internal organs of the body
- Amount absorbed and the effect on the body will depend on:
- Type of solvent, period of exposure, concentration and work load

##### *May cause damage to:*

- Central nervous system, respiratory system, liver, kidneys and reproductive systems

#### *Protective measures*

- Proper ventilation
- Use approved, protective mask

#### **Protection against dust and gas**

- Use an approved respirator assembly
- Mask with correct filter
- Unit consisting of support belt, air flow control valve, breathing tube, hood/helmet with filter unit

##### *Different contaminants require different filters*

- Dust: Filters P1 / P2 / P3
- Gas from organic solvents: Filters A1 / A2 / A3
- Combination-filters (P and A) are recommended

#### **Filter types**

##### *Dust*

- P1: Lowest degree of protection (not good enough against paint droplets/dust at site/yard)
- P2: Medium degree of protection
- P3: Highest degree of protection

##### *Gas from organic solvents*

- A1: Lowest degree of protection
- A2: Medium degree of protection
- A3: Highest degree of protection

Other types might be required for acid and alkaline

Safety Data Sheet (SDS) describes which filter to use when painting. Change filters regularly

#### **Check filter package before opening: Check it is sealed**

- Select correct type of filter for the job (SDS)
- Absorption of particles and solvents starts when the seal is broken. Store it in a closed bag when not in use
- Make sure it fits!

Use approved masks and filters only! (Be aware that beard may cause leaks!)

#### **Forced Air Mask**

- Usually used in confined spaces
- The air supply for these masks is supplied from outside the confined space and is filtered for moisture, oil, dust and toxic gases
- The air passes through a gas monitoring cabinet / filter before delivery to the operator

#### **F. Health hazard - splashing paint and solvents into eyes**

- Solvents can irritate or injure eyes
- Consult the Safety Data Sheet (SDS)
- Use approved safety glasses or a visor
- If paint or solvent in eyes: Flush eyes for at least 15 minutes with tempered clean water and seek medical assistance
- Make sure you know the location of all emergency eye wash and deluge shower stations

#### **G. Health hazards - paints containing heavy metals**

Sometimes heavy metals are used in pigments, additives or paint driers

##### *Hazards (Metal fumes, dust from hot work)*

- Zinc: Dust and fumes: Zinc fever, chills, coughing, irritation
- Copper: Fumes: Metal fever and chills
- Lead: Dust and fumes. Damage blood cells, Anaemia, skeletal damage, reduced fertility and damage to the central nervous system
- Chromium: Dust and fumes: Sensitisation, cancer
- Nickel / Cobalt: Sensitisation

##### *Protective measures*

- Protective mask to avoid breathing vapours
- Protective clothes covering the whole body, boots and gloves

##### *Proper PPE covers the entire body*

- Disposable suit

- Mask
- Gloves
- Boots

Disposable suits are particularly recommended when working with epoxies

## Safety hazards and protection

### General

### Safety

Safety hazards when using paint are often related to solvents

Most solvents used in paint are:

- Flammable
- Volatile

### How flammable is paint?

“Flash point” can tell us the flammability of paint. The flash point is the lowest temperature at which a spark causes the vapours of a liquid to ignite (measured under specified test conditions)

- Category 1: Flash point below 23 °C and initial boiling point below 35 °C
- Category 2: Flash point below 23 °C and initial boiling point above 35 °C
- Category 3: Flash point above 23 °C and below 60 °C
- Category 4: Flash point above 60 °C and below 93 °C

This information can be found in the Safety Data Sheet

### Working with solvents represents a safety risk

- Solvents are heavier than air
- The solvents may flow to lower compartments or areas
- Hot work may ignite the solvents
- A fire or an explosion may occur

### Precautions when painting in confined spaces

- Ensure good ventilation
- Exhaust points for fumes / solvents must be close to the bottom
- Start application from the bottom and then upwards
- Always use non-sparking tools
- Use antistatic clothing with hood
- Use masks with remote air supply
- Use boots and gloves
- Safety lines
- Sufficient rest periods

Never smoke or use open flames !

### **Concentration where an explosion might occur**

- Below the Lower Explosion Limit (LEL), the concentration of gas is too low for an explosion to take place
- Above the Upper Explosion Limit (UEL), the concentration of gas is too high for an explosion to take place
- The dangerous concentration level is between LEL and UEL, where an explosion can easily take place

*Typical range for solvents:*

- Between 1 vol.% (10,000 ppm) and 8 vol.% (80,000 ppm)

REMEMBER: Solvent vapours are heavier than air!

### **Limit Values - Maximum Exposure Levels for a Workplace**

#### **TLV: The threshold limit value (TLV)**

TLV of a chemical substance is a level to which it is believed a worker can be exposed day after day for a working lifetime without adverse effects. TLV is a reserved term of the American Conference of Governmental Industrial Hygienists (ACGIH). TLVs issued by the ACGIH are the most widely accepted occupational exposure limits both in the United States and most other countries.

#### **OEL: Occupational exposure Limit (OEL)**

OEL is an upper limit on the acceptable concentration of a hazardous substance in workplace air for a particular material or class of materials. It is typically set by competent national authorities and enforced by legislation to protect occupational safety and health. It is an important tool in risk assessment and in the management of activities involving handling of dangerous substances. Occupational Exposure Limits (OELs) have been established for airborne workplace chemicals by multiple regulatory and authoritative organizations around the world for well over 60 years now.

#### **Administrative norm, particularly in Norway**

This was an earlier system to establish Norwegian norms for impurities in the workplace atmosphere. In 2013 they were replaced by "Regulations on measures and limit values for physical and chemical factors in the work environment and infection risk groups for biological agents", issued by the Norwegian Ministry of Labour.

#### **How can we notice the presence of solvents?**

The human body has a built-in detection system for solvents: the nose. We can smell the presence of common solvents at a far lower concentration than those that are harmful to our health.

We can smell the Solvents before the Administrative Norm is reached:

- Lower explosion limit (LEL): 000 ppm
- Occupational Exposure Limit (OEL): 50 - 100 ppm
- Odour Threshold: 0,5 - 20 ppm

## **Useful information**

### **Where to find/seek information**

- Legislation and Regulations from authorities
- Yard's or Site's internal safety system
- Product's Safety Data Sheets
- Product's Label on tin
- Experienced colleagues
- Suppliers of equipment or products

### **Information found in the SDS (16 standard items)**

1. Identification
2. Hazard identification
3. Composition and ingredients
4. First aid measure
5. Firefighting Measures
6. Accidental release measures
7. Handling and storage
8. Exposure control and personal protection
9. Physical and chemical properties
10. Stability and reactivity
11. Toxicological information
12. Ecological information
13. Disposal considerations
14. Transport information
15. Regulatory information
16. Other information

## **Globally Harmonized System: Classification & labelling of hazardous chemicals**

- System of uniform classification and Labelling of Chemicals
- Developed within the United Nations (UN) structure
- In Europe, it is covered by the Classification, Labelling and Packaging (CLP) Regulation
- Its purpose is to ensure a high level of protection of health and the environment, as well as the free movement of substances, mixtures and articles

The Globally Harmonized System of Classification and Labelling of Chemicals (GHS) is an internationally agreed-upon system, created by the United Nations beginning in 1992 and as of 2015 was not yet fully implemented in many countries. It was designed to replace the various classification and labelling standards used in different countries by using consistent criteria on a global level. It supersedes the relevant system of the European Union, which has implemented the United Nations' GHS into EU law as the CLP Regulation and United States Occupational Safety and Health Administration standards.

### **Physical hazards**

Physical hazards group: based on the physical or chemical properties of the product – such as flammability, reactivity, or corrosivity to metals.

Substances or articles are assigned to 9 different hazard classes largely based on the United Nations Dangerous Goods System. Additions and changes have been necessary since the scope of the GHS includes all target

audiences.

1. Explosives
2. Gases
3. Flammable liquids
4. Flammable solids
5. Oxidizing substances and organic peroxides
6. Toxic and infectious substances
7. Radioactive substances
8. Substances corrosive to metal
9. Miscellaneous dangerous substances (which includes environmentally dangerous substances)

## **Health hazards**

Health hazards group: based on the ability of the product to cause a health effect – such as eye irritation, respiratory sensitization (may cause allergy or asthma symptoms or breathing difficulties if inhaled), or carcinogenicity (may cause cancer).

- Acute toxicity
- Skin corrosion
- Skin irritation
- Serious eye damage
- Eye irritation
- Respiratory sensitizer
- hazard
- Skin sensitizer
- Germ cell mutagenicity
- Carcinogenicity
- Reproductive toxicity
- Specific target organ toxicity (STOT)
- Aspiration

## **Environmental hazards**

- Acute aquatic toxicity
- Chronic aquatic toxicity

## **Labelling**

Information required on GHS label:

- Signal words: Danger or Warning
- Hazard statements (H-statements)
- Precaution statements (P-statements) and pictograms
- Product identifier
- Supplier identification

## **Hazard statements (H-statements)**

### *Definition*

- A statement assigned to a hazard class and category that describes the nature of the hazards of a hazardous product, including, where appropriate, the degree of hazard

## Precaution statements (P-statements)

### Definition

- The statement is a phrase (and/or pictogram) which describes recommended measures that should be taken to minimize or prevent adverse effects resulting from exposures to a hazardous product, or improper storage or handling of a hazardous product

## GHS label elements

The standardized label elements included in the GHS are:

- Symbols (GHS hazard pictograms): Convey health, physical and environmental hazard information, assigned to a GHS hazard class and category. Pictograms include the harmonized hazard symbols plus other graphic elements, such as borders, background patterns and substances which have organ toxicity. Also, harmful chemicals and irritants are marked with an exclamation mark, replacing the European saltire. Pictograms will have a black symbol on a white background with a red diamond frame. For transport, pictograms will have the background, symbol and colours currently used in the UN Recommendations on the Transport of Dangerous Goods. Where a transport pictogram appears, the GHS pictogram for the same hazard should not appear.
- Signal words: "Danger" or "Warning" will be used to emphasize hazards and indicate the relative level of severity of the hazard, assigned to a GHS hazard class and category. Some lower level hazard categories do not use signal words. Only one signal word corresponding to the class of the most severe hazard should be used on a label.
- Hazard statements: Standard phrases assigned to a hazard class and category that describe the nature of the hazard. An appropriate statement for each GHS hazard should be included on the label for products possessing more than one hazard.

*The additional label elements included in the GHS are:*

- Precautionary statements: Measures to minimize or prevent adverse effects. There are four types of precautionary statements covering: prevention, response in cases of accidental spillage or exposure, storage, and disposal. The precautionary statements have been linked to each GHS hazard statement and type of hazard.
- Product identifier (ingredient disclosure): Name or number used for a hazardous product on a label or in the SDS. The GHS label for a substance should include the chemical identity of the substance. For mixtures, the label should include the chemical identities of all ingredients that contribute to acute toxicity, skin corrosion or serious eye damage, germ cell mutagenicity, carcinogenicity, reproductive toxicity, skin or respiratory sensitization, or Target Organ Systemic Toxicity (TOST), when these hazards appear on the label.
- Supplier identification: The name, address and telephone number should be provided on the label.
- Supplemental information: Non-harmonized information on the container of a hazardous product that is not required or specified under the GHS. Supplemental information may be used to provide further detail that does not contradict or cast doubt on the validity of the standardized hazard information.

## Hazard Symbols

Symbol is a graphical element intended to succinctly convey information

## Hazard Symbols



Caution



Explosives



Corrosive



Gases under pressure



Longer term health hazards



Hazardous to the aquatic environment



Acute toxicity



Oxidising



Flammable

Can be found in the Safety Data Sheet (SDS) and on the paint tin.

## Pictogram

Pictogram is a graphical composition that may include a symbol plus other graphic elements, such as border, background pattern or colour that is intended to convey specific information

## Disposal consideration - hazardous waste

- Hazardous waste is waste that poses a substantial or potential threat to public health or the environment
- There is legislation in various regions or countries to classify waste as hazardous waste
- Strict control of hazardous waste is required in many regions and countries
- Waste disposal shall not endanger human health or harm the environment

## Hazardous waste in painting industry

- Surface preparation: any waste containing dangerous substance after treatment (such as, blasting material, grinding bodies and materials); aqueous washing liquids; steam degreasing wastes
- Paints and painting: waste and (aqueous) sludge containing organic solvents or other dangerous substances
- Hot dip galvanizing: acid, spent flux, phosphatizing sludge, rinsing liquid and degreasing wastes containing dangerous substances
- Other waste containing dangerous substances

Please refer to your local legislation for detailed information, i.e. Hazardous Waste List

### **Regulation, laws for transportation**

The UN Recommendations on the Transport of Dangerous Goods are contained in the UN Model Regulations:

- Prepared by the Committee of Experts on the Transport of Dangerous Goods of the United Nations Economic and Social Council (ECOSOC)
- Covers the transport of dangerous goods by all modes of transport except by bulk tanker
- Not obligatory or legally binding on individual countries, but the recommendations have gained a wide degree of international acceptance
- Forms the basis of several international agreements and many national laws

### **Regulation, laws for transportation**

Transportation of dangerous goods may take place by Sea, Road, Rail and more rarely, by air.

Responsible organizations are:

Mode	Organization	Treaties/Agreement
Air	International Air Transport Association (IATA)	IATA Dangerous Goods Regulations (DGR)
Sea	International Maritime Organization (IMO)	International Maritime Dangerous Goods Code (IMDG)
Road	United Nations Economic Commission for Europe	European agreement on international road transportation of dangerous goods Rail (ADR)
Rail	Intergovernmental Organization for International Carriage by Rail (OTIF)	Regulations concerning the International Carriage of Dangerous Goods by Rail (RID)

### **Equipment - safety**

- An Airless Spray Unit is a highly pressurized piece of equipment, and blast-cleaning equipment uses high pressure air. Operation by unskilled or careless operators may cause injuries
- All hose connections must be checked, fasteners and whip check cables in place and safety pins on blast hoses installed correctly before starting the equipment
- Equipment may accumulate static electricity during operation so the unit must be grounded properly
- Use only pressure approved and electrically conductive air and fluid hose
- Don't use hose for any other purpose than it was designed for and avoid dragging hoses over sharp objects
- Read instruction manual prior to start using equipment

### **Airless spraying can be dangerous**

Don't ever point the gun towards yourself or any other person!

# **Safety data sheet**

See PDF's below.

[SDS Frosiomastic Comp A 2017 v4.pdf](#)

[SDS Frosiomastic Comp B 2017 v4.pdf](#)

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