Chapter 12
Coating Failures

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Introduction

All coatings have limited service lives. Unfortunately, there are occasions when coatings fail much sooner than they should. When this occurs, it is necessary to determine the causes of the failure and what actions must be taken to correct this condition and prevent its recurrence.

There are numerous causes of coating failure. These may be related to structural design, the substrate, the coating itself, surface preparation, coating application, or coating curing, or combinations of these basic causes. Historically, improper or inadequate surface preparation has been the most commonly reported cause of coating failure; more recently, governmental restrictions on coating VOCs and toxic constituents (e.g., solvents, pigments, and biocides) have restricted coating formulations and made them more difficult to apply successfully. This chapter will address the common causes of coating defects on industrial structures and the associated preventative or corrective actions.

Commonly Used Failure Terms

Many different terms commonly used to describe coating failures mean different things to different people. SSPC's *Protective Coatings Glossary* defines failure terms and these definitions are used for all failure terms in this chapter.[1] Some of the definitions of general terms commonly associated with coating deterioration/degradation are:

Catastrophic Coating Failure. A coating failure that is sudden, very dramatic, and serious.

Defect. A surface or film imperfection (flaw), deficiency, or incompleteness that deviates from a specification or industry-accepted condition.

Degradation. A gradual loss of coating materials and/or properties resulting from service conditions and weathering.

Deterioration. See degradation above.

Failure of Coating. Loss of a coating's function or purpose, i.e., when it no longer protects the substrate, provides an attractive appearance, or serves some other function such as providing a non-slip surface. The time of failure is considered to occur when some action is needed to restore its properties to the level necessary to again provide its intended purpose(s).

Failure Analysis. Systematic investigation conducted to determine the causes and responsibilities of coating defects, loss of function, and/or corrosion, if present.

Premature Failure. Failure that occurs significantly before a coating's life expectancy.

Service Life of Coating. The period of time during which a coating provides its intended function(s). This will vary with different exposures and services.

Effects of Structural Design on Metal and Coating Deterioration

It has been shown that structural design may be an important factor in metal and coating deterioration.[2-3] It is important that these design factors be recognized and corrected at the planning stage rather than later when their adverse effects have become apparent. Although each of the major design factors leading to early coating deterioration will be discussed separately, they often occur in conjunction with other factors that further aggravate the deterioration.

Contact of Dissimilar Metals Resulting in Galvanic Corrosion

When two dissimilar metals are in physical contact with each other in an electrolyte (electrically conductive medium), the more active metal will corrode preferentially, while protecting the other metal from corrosion. The greater the difference in electrochemical activity between the metals, the greater will be the rate of dissimilar metal corrosion. The relative surface areas of the touching metals may also greatly affect the corrosion of the more active metal (the

anode in the reaction). A small anode area and a much larger cathode (protected) area may result in extremely rapid corrosion of the smaller anode area. Thus, in painting, care should be taken to ensure that all cathode areas are especially well covered. Galvanic corrosion may also be minimized by using metals of similar composition, or using a non-conductive insulator between them.

Crevices

Crevices are likely to occur in structural components that are bolted, riveted, or skip-welded together. Inside crevice areas, there is invariably a lower concentration of oxygen as compared to the air outside the crevice. This results in a corrosion cell with accelerated corrosion occurring within the crevice area. Thus, continuous welding is the preferred method of joining metal components. Welds should be ground smooth and weld spatter removed before coating in order to obtain good coating adhesion in these areas. Also, back-to-back angle designs should be avoided because they have crevices between them.

Water Traps

Water traps are design features, such as upward facing angle iron, that collect the rain that accelerates deterioration of coatings and corrosion of metals. Such designs should be oriented downward so that the water drains. Drill weep holes into existing water traps to permit collected water to drain.

Sharp Edges

When sharp edges are coated, the paint tends to draw back from the edge to leave a much thinner coat of paint there than on flat areas. In order to produce a coating film of more equal thickness (and thus equal barrier protection) on all surfaces, edges are usually striped (brushed with an additional coat of primer) before or after applying a full coat to the substrate. Relatively recently, new edge-retentive coatings (usually amine-cured, solvent-free epoxies) have been developed to address this problem.

Faying Surfaces

Faying surfaces are contacting surfaces where joints in steel structures are formed by riveting or by the use of high-strength bolts. Most coatings are unsuitable for use in the joint itself, because they do not provide the proper coefficient of friction to maintain the joint in a static state. However, inorganic zinc-rich silicate coatings have adequate coefficient of friction to perform well in this service.

Limited Access to Work

Limited access to surfaces to be cleaned and coated often results in poor quality work and consequently early coating deterioration. Thus, structures should be designed for access both for the original work and for subsequent maintenance painting.

Effects of Substrate Properties on Coating Performance

It has been shown that the chemical and physical natures of a surface to be coated may have a very profound effect on the performance of the coating system.[4] It should be noted that, in general, textured surfaces provide more bonding sites and thus have greater coating adhesion than smooth areas of similar composition.

Hot-Rolled Steel

Most structural steel is made by the hot-rolling process. This process results in a loosely bonded layer of iron oxide called mill scale. Mill scale must be removed before the steel is coated, or its subsequent loss with time will result in coating deterioration.

Coatings on metal structures are susceptible to underfilm corrosion. Undercutting of a coating film by corrosion at breaks or pinholes in the barrier film may result in rapid loss of coating and its protection.

Cold-Rolled Steel

Cold-rolled steel is used more for manufacturing office furniture, appliances, and automobile bodies than for applications where structural strength is required. Cold rolling produces a denser, smoother surface than hot-rolling. Coatings do not bond as well to these surfaces. Thus, chemical treatments such as phosphating are often used to promote coating adhesion. Abrasive blasting can also be used to produce a profile to improve coating adhesion.

High-Strength Alloy Steels

In some environments, high-strength alloy steels may require a coating system to supplement its natural corrosion resistance. In these cases, the

cleaning requirements are similar to those of conventional steels, but harder abrasives (e.g., silicon carbide, aluminum oxide, or garnet) may be necessary to produce the desired surface profile. Because of their inherent corrosion resistance, they will normally have less corrosion and undercutting of coating at film holidays.

Figure 1. Corrosion undercutting of coating at scratch.

Zinc-Coated Surfaces

Zinc-coatings, both galvanizing and zinc-rich, always have alkaline surfaces created by the natural corrosion of zinc. This alkalinity will saponify (hydrolyze) alkyds and other coatings that cure by oxidation of drying oils.

New galvanized surfaces are sometimes given a thin coat of oil or chromate conversion coating to protect them from corrosion called wet storage stain or white rust during exterior storage. These treatments must be removed prior to coating to permit good coating adhesion. The oil is best removed by solvent cleaning (i.e., SSPC-SP 1), and the chromate conversion coating can be removed chemically or by prolonged weathering.

Aluminum

Epoxies normally bond quite well to aluminum. For other coatings that do not, one the

following treatments may be used:
- Chemical treatment such as phosphating
- Wash priming (good with alkyds)
- Blasting with a soft abrasive (e.g., plastic) to produce a suitable profile

Aluminum is susceptible to exfoliation, an advanced stage of intergranular corrosion characterized by a delamination of metal along grain boundaries. Rolled metal products such as aluminum alloy plate are especially susceptible to exfoliation due to their longitudinal grain structure.

Coated aluminum is particularly susceptible to a form of corrosion called filiform. It is characterized by threadlike directional growths proceeding away from damaged areas. In the past, chromate inhibitive pigments were widely used to control filiform corrosion; chromate-free inhibitive pigments are now used.
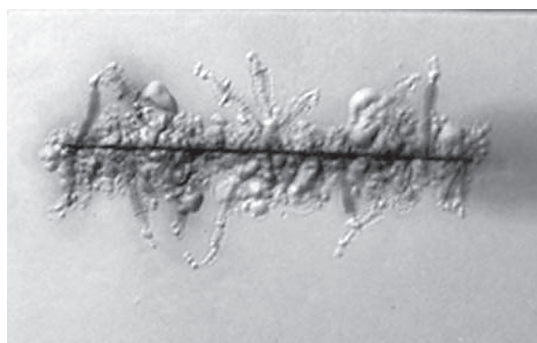
Figure 2. Filiform corrosion.

Concrete

Concrete has unique properties (e.g., alkalinity and porosity) that make its coatings especially susceptible to certain defects. These are described extensively in SSPC's *The Fundamentals of Cleaning and Coating of Concrete*.[5]

Wood

The properties of woods vary greatly with the types of tree from which they came. Soft woods such as redwood and fir are penetrated by coatings to permit good bonding much more easily than are hard (dense) woods such as ash and oak.

Pine and fir have variable grain structures, while redwood and cedar have uniform grain and brown color. The brown color of the latter two woods comes from water-soluble dyes that may bleed through latex coatings to cause staining, unless sealed

before painting. An oil-based or water-borne stain-blocking primer can be used for this purpose.

Resinous materials in some trees, such as lower grades of pine, may seep to the wood surface after painting to cause staining and paint deterioration. This can be minimized by using weathered wood and sealing it before use.

Woods are very sensitive to moisture so that they swell during periods of high humidity and shrink during periods of low humidity. Rigid coatings on wood may crack when they are unable to expand and contract with dimensional changes.

Coatings hide wood grain and greatly reduce water permeability. However, water that enters into the wood interior may try to escape through impermeable coatings to cause blistering and/or delamination. For this reason, latex coatings that permit the passage of water vapor (sometimes called breathing) may minimize this problem. Many people prefer to use semi-transparent stains that do not seal the surfaces of wood.

Defects/Failures Associated with the Coating Itself

Some coating defects and failures are directly related to the coating itself. These include:
• Errors by the manufacturer in production of the coating
• Coatings that have exceeded their shelf life
• Inherent limitations of properly formulated coating
• Incompatibility of a coating with its substrate or undercoat

Coatings with Errors in Manufacture or that Have Exceeded Their Shelf Life

Errors in coating manufacture do not occur very often. They can usually be detected in the field before use by testing for condition in container, as described in Federal Test Method Standard 141. If the viscosity does not appear to be at the proper level, it can be checked in the field using a viscosity cup. Also, a test patch of coating can be applied to the intended substrate to check for such properties as ease of application, hiding, leveling, and complete curing.

If a stored coating has exceeded its shelf life, it may have deteriorated to the extent that it can no longer be successfully utilized. Such coatings should be checked for condition in container before use.

Limitations of Coating Formulations

All coating formulations have some limitations that restrict their uses to appropriate environments and services. In this section, some of the more important limitations are addressed.

Figure 3. Chalking.

Chalking. Chalking is the formation of loose powder on the surface of coatings. It is typically caused by deterioration of the organic coating binder by ultraviolet light (usually from the sun) to leave a loose residue of pigment and oxidized binder. All organic coating binders chalk to some extent, but those containing aromatic chemical groups (e.g., epoxies and phenolics) chalk much faster than others.

Some pigments such as the anatase form of titanium dioxide chalk very freely, while other pigments such as rutile, another crystalline form of titanium dioxide, are quite chalk-resistant. Opaque pigments, of course, reduce chalking of underlying organic binders by shielding them from sunlight. Leafing aluminum pigments formulated to float to coating surfaces protect underlying binders especially well.

Chalking of finish coatings can best be controlled by proper selection of pigments and binders and by use of additives such as ultraviolet light absorbers.

Erosion. Erosion is the gradual loss of coating by wear or weathering. Thus, coatings that chalk freely are more susceptible to erosion than are coatings that are more chalk-resistant. Erosion may also be caused by wind-blown sand or rain.

Accelerated erosion may significantly reduce coating thickness and even expose undercoats. Erosion may be minimized by selecting a

chalk-resistant coating with good leveling properties.
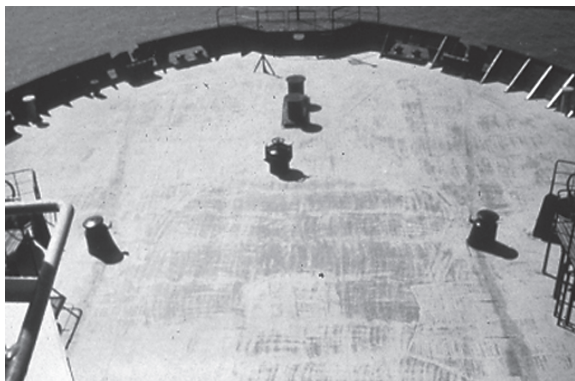
Figure 4. Erosion of topcoat on deck of a ship.

Discoloration. Discoloration is the change in coating color after application (usually an undesirable darkening), normally caused by exposure to sunlight or chemical atmospheres. Thus, lead pigments are blackened by the attack of hydrogen sulfide gas. To minimize discoloration, coating formulations should have stable pigments and binders.

Fading. Fading is the reduction of color intensity, usually by sunlight. This adverse cosmetic effect can also be minimized by using formulations with stable pigments or binders.

Loss of Gloss. Loss of gloss is still another defect that is caused by sunlight and can best be minimized by selecting ultraviolet-resistant coating components. All coatings lose gloss in sunlight to some extent, but some do much more than others. This cosmetic defect, as well as discoloration and fading, is especially distracting when it occurs on the side of a structure that is partially shaded so that there is an uneven loss of gloss or color.

Mildew Defacement. Mildew defacement is an unsightly appearance on coated or uncoated structures caused by the growth of micro-organisms, particularly fungi. This is more of a cosmetic effect than one that adversely affects coating film properties. Mildew defacement may be controlled in architectural coatings (i.e., drying oil and water-borne latex coatings) by using EPA-approved mildewcides. Also, smooth, chalk-free coating surfaces in dry locations exposed to sun light are less susceptible to mildew than other coated surfaces.

Figure 5. Uneven loss of gloss.
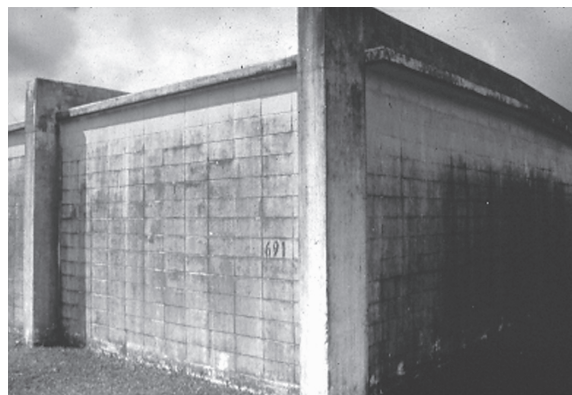
**Figure 6. Mildew defacement.**

Moisture Blushing. Moisture blushing is the formation of a milky opalescence that may occur in humid environments where solvent evaporation reduces the temperature of an uncured coating to the dew point so that moisture condensation occurs on it. This cosmetic defect most commonly occurs with fast evaporating coatings such as vinyl lacquers. Moisture blushing may also occur by the reaction of moisture in the air with polyurethanes and other moisture sensitive coatings on humid days. Moisture blushing can best

be prevented by avoiding the application of moisture-sensitive coatings on humid days.

Figure 7. Moisture blushing.

Amine Blushing. Amine blushing is the formation of a milky opalescence on the wet-film surfaces of amine-cured epoxies by the reaction of the amine with carbon dioxide and water in the air to form an amine carbam-ate. This film may cause adhesion problems for topcoats if not removed as recommended by the epoxy manufacturer.
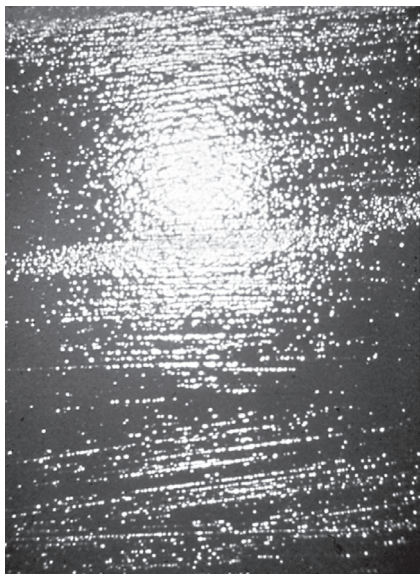

Figure 8. Brush marks.

Brush Marks. Brush marks may occur in brush-applied coatings with insufficient leveling for the wet film to flow together to form a film of uniform thickness. Localized areas of lesser film thickness almost always exhibit deterioration before areas of greater film thickness.

Orange Peel. Orange peel is similar to brush marks in that it is caused by insufficient leveling of the wet film. However, this defect occurs with spray rather than brush application of coatings.
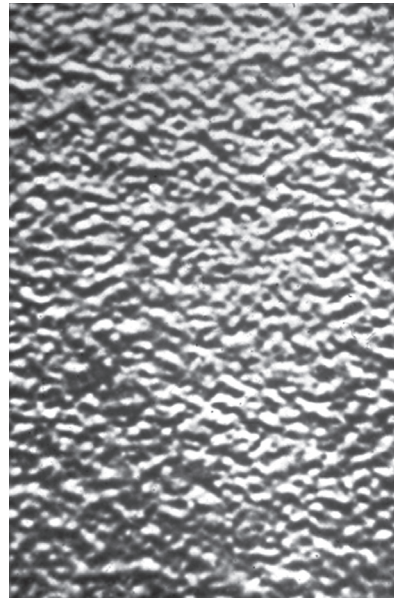

Figure 9. Orange peel.

Wrinkling. Wrinkling is a defect that results in the formation of small furrows or ridges in coating films. It occurs most commonly with thick films of alkyds and other drying oil-curing coatings. In these cases, curing by air oxidation occurs much more rapidly at the coating surface than below it, and a surface skin is formed that prevents further curing of the underlying binder. Contraction of the surface skin causes the wrinkling. Through-dry metal driers will help accelerate complete film curing, but the use of lead driers (some of the best through-driers) is now greatly restricted. Wrinkling can also be minimized by avoiding thicker film than recommended by the manufacturer.

Chemical Attack on Coatings. Chemical attack on coatings will occur when the coating system is not resistant to the environment. This most commonly occurs to linings in storage tanks where they come into contact with stored chemical liquids. Chemical attack may also occur in atmospheric service where harsh chemical fumes or vapors come into contact

with the coating.

High-Temperature Attack on Coatings. High-temperature attack is likely to occur to organic coatings even during intermittent high-temperature service. Thus, heat-resistant inorganic coatings are usually used at temperatures above 450°F (230°C).
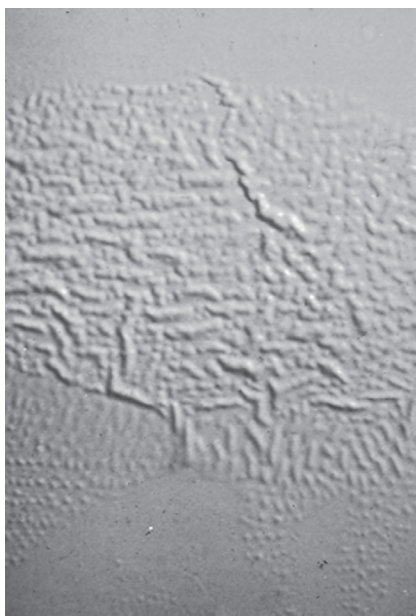
Figure 10. Wrinkling.

Figure 11. Mottling.

Mottling. Mottling is the presence of differently colored spots or blotches on a painted surface. It is commonly caused by pigment overload (using more pigment than can be completely wetted by the limited amount of resin present).

Osmotic Blistering by Soluble Pigments. Osmotic blistering may occur to coatings with primer pigments having significant water solubility. This is especially likely to occur during water immersion service. These pigments can be detected during a laboratory failure analysis of the water (sometimes colored) in filled blisters.

Osmotic blistering may also occur if soluble salt contaminants are not completely removed from substrates during surface preparation.

Flooding and Floating. Flooding and floating are two cosmetic formulation defects that are sometimes confused with each other. Flooding is the segregation of pigments in a coating system caused by different rates of settling in the wet film to form a uniform appearance different from that expected. Floating is the segregation of individual pigments in a coating system during curing related to differential movement in the surface tension currents caused by solvent evaporation to produce a varigated paint surface.

Figure 12. Cracking.

Cracking. Cracking is a general term for the splitting of a coating film to relieve stresses. Most of these stresses originate by shrinking during curing, by solvent evaporation, and/or polymerization. Stresses increase with further polymerization and weathering. When stresses exceed the cohesive strength of the coatings, they crack to relieve the stress.

The greater the coating thickness, the more rigid it is and thus the greater its tendency to crack. Different types of cracking, other than common cracking, include hairline cracking, checking, crazing,

alligatoring, other intercoat cracking, and mud cracking. Cracking usually occurs all the way through the coating to expose the substrate.

Figure 13. Checking.

Checking. Checking is the fine surface cracking that develops in coating films during prolonged curing and/ or weathering that does not penetrate to the underlying substrate. Wetting and drying, heating and cooling, and exposure to sunlight all contribute to checking.

Alligatoring. Alligatoring is a type of crazing or surface cracking with a definite pattern, as indicated by its name. The effect often occurs when a relatively rigid coating is applied over a more flexible undercoat. The resulting stresses cause the topcoat to crack to expose the undercoat but not the substrate.

Intercoat Cracking. Cracking from intercoat stresses may occur when a relatively rigid topcoat is applied over a more flexible undercoat. These stresses are similar to those previously described for alligatoring, but cracking does not always occur in such a regular pattern.

Mud Cracking. Mud cracking is a cracking pattern that resembles the irregular cracking of drying mud. It typically occurs when a rigid coating is applied too thickly. This defect often happens with inorganic zinc-rich coatings, which are very rigid.

Figure 14. Alligatoring with bleeding.
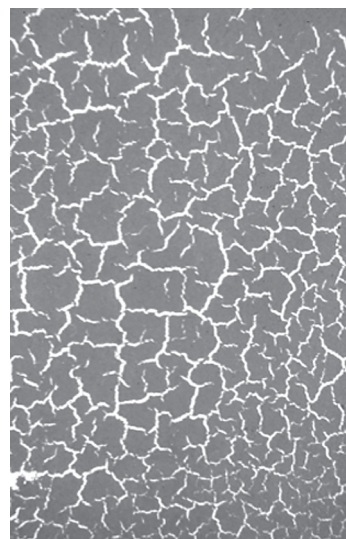
**Figure 15. Mud cracking of inorganic zinc-rich coating.**

Coating Incompatibilities

Incompatibilities may occur between individual coats in a total coating system or between an existing system and a topcoat to be applied over it. It is wise to obtain all coatings for a total system that are known to be compatible with each other and that are produced by the same manufacturer. Five types of

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incompatibility between coatings are described here.

Topcoat Solvent Attack on Undercoat Binder. Topcoat solvent attack on undercoat binder may cause the latter to soften, swell, or disbond. In any case, the intercoat adhesion is significantly diminished. An example of this is a chlorinated rubber or an epoxy coating with a strong solvent being applied over a vinyl dispersion (latex) coating.
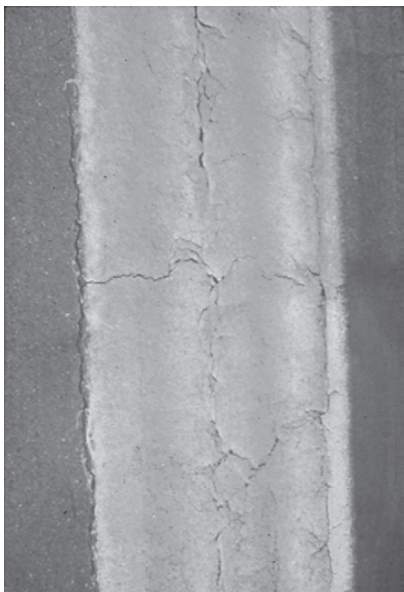
Figure 16. Bleeding of alkyd coating on asphalt pavement.

Bleeding. Bleeding often occurs when a topcoat with a strong solvent is applied to a coal-tar or asphalt coating. The solvent dissolves some of the colored material in the existing coating and allows it to migrate through the topcoat to impart a brown surface discoloration. This defect is somewhat similar to the previously described bleeding from an asphalt pavement and migration of water-soluble dyes from wood through latex coatings.

Limited Adhesion. Limited adhesion and subsequent peeling may occur to a water-dispersed (latex) coating applied over a smooth oil-based enamel. There is often insufficient solvent in the topcoat to penetrate the existing coating to achieve good intercoat adhesion.

Intercoat Cracking. Cracking from intercoat stresses was described earlier in the discussion of different forms of cracking.

Saponification (hydrolysis). Saponification may occur to an alkyd or other drying oil applied over a zinc-rich primer. As with concrete, the surface alkalinity on the zinc-rich primer causes this chemical degradation.

Figure 17. Saponification of alkyd coating.

Incompatibilities with Cathodic Protection

There are three basic mechanisms by which coatings may be deteriorated by cathodic protection systems. Coatings to be used in conjunction with cathodic protection to control the corrosion of steel must be resistant to these problems.

Saponification of Coatings. Alkalinity is always produced on cathodically protected surfaces. If coatings on these surfaces are not alkali-resistant, they are subject to saponification.

Blistering of Coatings by Hydrogen Gas Evolution. Blistering of coatings by hydrogen gas evolution may occur on cathodically protected surfaces where the voltages are excessively high (e.g., in excess of −1.1 volts). This seldom occurs if steel-to-soil or

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steel-to-water potentials are regularly monitored.

Electroendosmosis. Electroendosmosis is a mechanism of coating deterioration in which excessive cathodic potentials causes electrolyte to penetrate rapidly through a coating film. It normally results in coating blistering and peeling.

Coating Defects/Failures from Inadequate Surface Preparation

Inadequate surface preparation is generally recognized as being the chief source of coating defects and failures. Surface preparation inadequacies are either caused by inadequate removal of contaminants or by improper profile height. Each commercially available primer has a surface preparation recommended by its manufacturer. These recommendations should be carefully followed.

One of the best ways of minimizing adverse effects of surface preparation is by careful inspection of the cleaned surfaces and immediate correction of any deficiencies found. These deficiencies cannot be corrected after coating application.

The coating manufacturer also provides the recommended ranges of ambient conditions suitable for successful application of each company product. These recommendations may be as important as any other manufacturer recommendation.

Inadequate Surface Cleanliness

Inadequately cleaned surfaces are very difficult to wet with coatings, because the remaining contaminants reduce the number of bonding sites. Intimate contact between coating and substrate is necessary for good adhesion.

Disbonding, Peeling, and Blistering. Disbonding, peeling, and/or blistering may result from incomplete removal of rust, mill scale, dirt, or other loosely held contaminants from the substrate surface or from the presence of moisture. Flash rusting of properly cleaned steel before coating is another source of these defects.

Incomplete removal of contaminants from an existing coating before topcoating may result in intercoat disbonding, peeling, and/or blistering.

Crawling (Fisheyes). Crawling, sometimes called fish eyes, is the drawing back of a liquid film from a

uniformly thick layer to form areas of little, if any, thickness. It occurs when the surface tension of a coating is greater than the surface tension of the substrate. Crawling is caused by substrate contamination with oil or some other low surface energy contaminant.
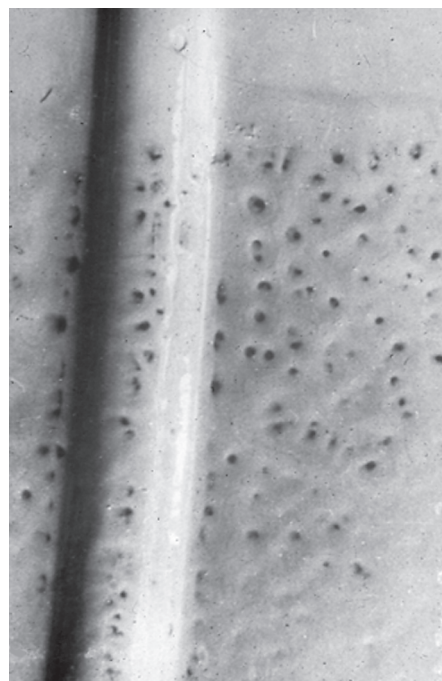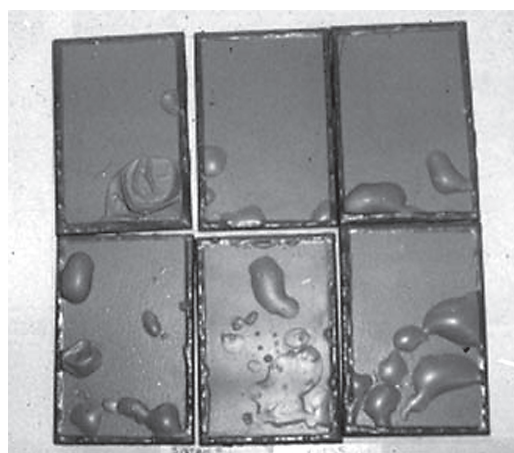

Figure 18. Crawling (fish eyes).

**Figure 19. Osmotic blistering caused by inadequate removal of soluble salts.**

Osmotic Blistering by Incomplete Removal of Soluble Salts. Incomplete removal of soluble salts during

surface preparation may result in osmotic blistering of coatings subsequently applied. These salts are usually not readily visible and so must be removed and analyzed using special techniques.[6] The adverse effects of soluble salts are much greater on coatings in immersion service than in atmospheric service.

Improper Surface Profile

Each primer has a profile height recommended by its manufacturer for best performance. Any significant deviation from this recommendation may result in reduced coating system performance. In general, recommended profile heights vary directly with the primer film thickness. Thus, primers with greater film thickness usually have higher recommended surface profiles.

Insufficient Profile Height. Insufficient profile height of cleaned surfaces may provide insufficient bonding areas for adequate coating adhesion. This, in turn, usually results in early coating loss by disbonding and peeling.
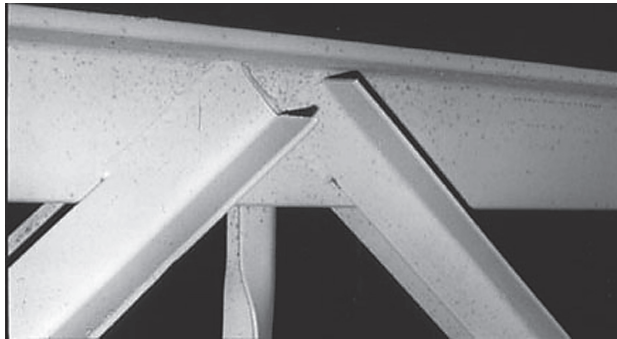
Figure 20. Pinpoint rusting.

Excessive Profile Height. Pinpoint rusting may occur on coated steel structures where abrasive blast cleaning has produced so high a profile that it is not adequately protected by a relatively thin primer. Pinpoint rusting may also occur when erosion significantly reduces coating film thickness.

Coating Defects/Failures from Improper Coating Application

As with surface preparation, the best way to avoid coating failures resulting from improper coating application is by (1) carefully following the coating manufacturer's recommendations for application and (2) carefully inspecting the work to permit early detection of defects and their immediate correction. It is much easier to prevent coating problems associated with improper spray application than to correct them after application.

When applying two-component thermosetting coatings, careful attention must be paid to the manufacturer's recommendations for induction, pot life, and recoat times. If this is not done, catastrophic failure may occur.

Mixing Coatings

Although coatings are prepared ready to apply, settling of the heavier pigment portion may occur during storage. Thus, all paints should be thoroughly mixed before application to ensure that the material being applied is the homogeneous blend originally manufactured. Improper mixing can lead to uneven color in cured paint, inadequate film thickness, poor coating adhesion, and checking or cracking of the paint film.[7]

Coatings should not be overmixed to avoid entrapping air into them. Thus, a mechanical mixer should be used at a speed set so that a small rather than a large vortex or depression on the paint surface is created in the center of the can. Use of paint shakers is not recommended. Allowing stirred paint to set for several minutes before application may permit the release of entrapped air.

Two-component coatings such as thermosetting epoxies and polyurethanes are normally supplied in kits composed of Component A and Component B. The components of each kit must be properly proportioned for mixing together to achieve proper curing and optimum coating performance. Therefore, use of complete kits rather than partially filled kits are recommended. Each component should be mixed separately and then mixed together in the order specified by the coating manufacturer.

Plural-component spray application systems combine Components A and B together automatically in a specific ratio. However, the proportions should be checked before beginning coating application to be sure that the proportions are those specified by the manufacturer. When spraying with plural-component equipment, it is common practice not to use the triggering technique commonly used with other spray equipment because the ratio of components may vary significant at the start and stop of each trigger stroke. Skilled applicators are required for the successful use

of plural-component application equipment.

Thinning

Coatings are manufactured for application as received without thinning. However, low temperatures or other conditions may necessitate thinning to reduce the viscosity for effective application. When necessary to use a thinner, it should be of the type and in the amount recommended by the coating manufacturer. Thinner should be added to the coating slowly and with thorough mixing to avoid overthinning one portion of the paint and the possibility of curdling the coating or flocculation of the pigment.
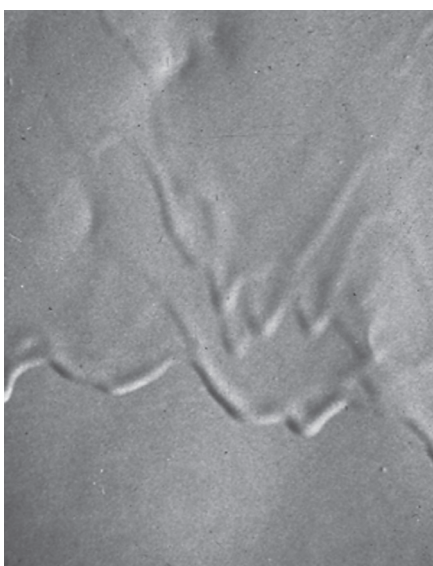

Figure 21. Sagging.

Straining

Coatings should be strained after mixing to eliminate any skins, lumps, or other foreign matter to avoid clogging spray equipment. Inorganic zinc-rich coatings are especially susceptible to clumping.

Effects of Improper Coating Thickness

It is important that coatings be applied uniformly, holiday-free, and in the thickness range specified by the manufacturer. Otherwise, maximum coating performance will not be achieved. Use of a wet film thickness gauge, as described in ASTM D 4414, *Practice for Measurement of Wet Film Thickness by Notch Gages,* will help ensure that the desired dry film thickness is achieved.

Insufficient Coating Thickness. If a coating is applied with less than the specified minimum thickness, its barrier protection will be lessened, and thus its service life will be reduced. As discussed earlier, a thinner than desired coating may contribute to pinpoint rusting on steel surfaces.

Excess Coating Thickness. If a coating is applied too thickly, its weight may cause the wet coating to flow downward to form sags, runs, or curtains. Such defects should be detected and corrected as soon as observed.

Excessive coating thickness may lead to the acceleration of common cracking, mud cracking, and/or disbondment of relatively rigid coatings. As described earlier, thicker films have more rigidity than thinner films and thus are less able to expand and contract with substrate dimensional changes.

Excess coating thickness may be gradually built up by application of additional coats to an existing coating system during periodic maintenance painting. When the total stress built up in the coating system exceeds the adhesion at its weakest point (usually primer to substrate), disbondment will occur. Disbondment may take the form of chipping, flaking, peeling, or delamination.

As described earlier, wrinkling occurs more often with thicker than thinner coatings that cure by oxidation of drying oils. Excess thickness may also result in other types of incomplete or improper curing.

Non-Uniform Coating Thickness. If coating thicknesses vary significantly outside the specified range, the first signs of deterioration invariably occur in areas of low film thickness. Thus, low thickness areas limit the performance of the total coated area.

Coatings with variable film thicknesses tend to be resin-rich in localized areas of greater thickness. This often results in unsightly glossy areas sometimes called hot spots.

Effects of Improper Spray Techniques

The most uniform coating application and the best looking finishes are achieved by spray application. Deviation from the recommended gun-to-substrate distance, constant rate of gun travel, proper spray pattern, and standard triggering can results in defects and early coating failure.

Figure 23. Pinholing.
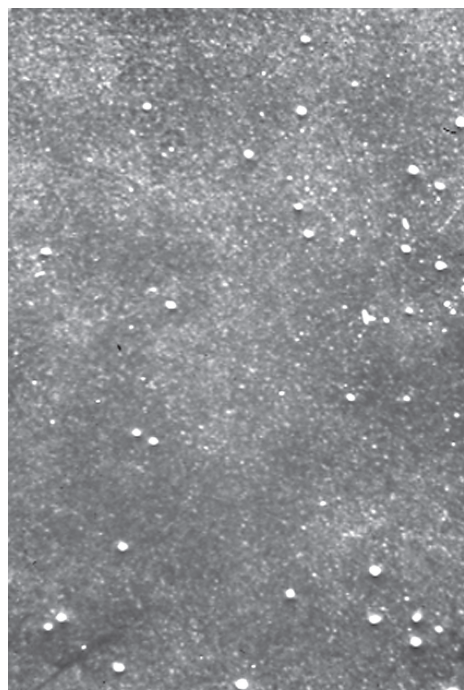

Figure 22. Dry spray.

Dry Spray. Dry spray is a rough, powdery, non-coherent film produced when an atomized coating partially dries before reaching the intended surface so that the coating cannot flow to form a uniform continuous film. This condition most commonly occurs with fast drying coatings. Holding the spray gun too far from the substrate may also contribute to dry spray. Dry spray film have little, if any, protective value.

Dry spray should not be confused with overspray. Overspray consists of atomized paint particles that deflect from or miss the surface being sprayed and fall on unintended surfaces.

Pinholing. Pinholing is the formation of small holes that extend through the entire thickness of a coating. It occurs most often with lacquers and other coatings that contain fast evaporating solvents. Solvent imbalance is an important source of pinholing.

Pinholing is sometimes caused by holding the spray gun too close to the surface with excessive atomization pressure or a combination of a low atomization pressure and excessive material pressure.

A special case of pinholing often occurs during the topcoating of inorganic zinc-rich coatings on warm days. Topcoat solvent that enters the naturally porous film of the inorganic zinc-rich coating evaporates in the warm environment, and the resulting vapors rise to the surface of the uncured topcoat to form pinholes. This phenomenon is somewhat similar to outgassing of wet coatings on concrete, in which, during periods of rising temperature, interior air and solvent vapors rise to the concrete surface to form small bubbles in the topcoat.

Cratering is a special form of pinholing caused by foreign matter in or deposited on the wet film.

Coating Holidays. A holiday is a pinhole, skip, discontinuity, or void in a coating film that exposes the substrate. Unless detected and corrected, holidays constitute a source of early electrolyte penetration and coating deterioration. Holidays in coatings are best discovered using holiday detectors, as described in the chapter of this book on coating inspection.

Topcoating Outside of Recommended Recoat Window

Manufacturers of two-component thermosetting coatings specify a window of time during which

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their coatings can be successfully topcoated. If topcoated too soon, the curing of both coats may be adversely affected. If topcoated too late, the topcoat will have limited adhesion to the undercoat.

Coating Defects/Failures from Improper Curing

Most coatings require special conditions for proper curing. These include ranges of temperature and relative humidity. Curing wet coatings at temperatures significantly above or below the recommended range may result in improper or incomplete curing.

Moisture-curing polyurethanes and alkyl silicate inorganic zinc-rich coatings cure to a solid film by reaction of their binders with moisture from the air. They must cure within a specific relative humidity range to achieve complete and proper curing.[8] Moisture-blushing of coating surfaces during periods of high humidity was discussed earlier in this chapter.

Coatings applied in confined spaces such as storage tanks may require both heating and ventilating to remove coating solvents and permit complete curing or curing to the extent required for topcoating. Otherwise, osmotic blistering may be caused by the entrapped solvent.

Summary

There are many causes of coating deterioration. In order to avoid or minimize deterioration, the following actions should be taken:
• Proper selection of a high-performance coating system appropriate for the particular environment and service
• Preparation of a job specification that includes all requirements necessary to achieve long-term coating performance
• Appropriate surface preparation for the environment, service, and coating system, as recommended by the coating manufacturer
• Appropriate application of the coating system, as recommended by its manufacturer
• Thorough inspection of all phases of the work to ensure that all specification requirements are met
• Rapid corrective actions to address any deviations from recommendations or early signs of coating defects.

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About the Author

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Dr. Richard W. Drisko has been the senior technical advisor to SSPC: The Society for Protective Coatings since January 1995. Prior to this, he was employed for over 40 years at the Naval Civil Engineering Laboratory, Port Hueneme, California, where he conducted research, evaluation, and testing, and served as the Navy's center of expertise on coatings for shore structures. He is a professional engineer in the state of California, an SSPC certified protective coatings specialist (PCS), and a NACE International certificated corrosion specialist. Dr. Drisko received his BS, MS, and PhD degrees from Stanford.

		Approximate Conversions to SI Units				Approximate Conversions from SI Units			
	Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
Length	in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
	ft	feet	0.3905	meters	m	m	meters	3.28	feet	ft
	yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
	mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
Area	in^2	square inches	645.2	millimeters squared	mm^2	mm^2	millimeters squared	0.0016	square inches	in^2
	ft^2	square feet	0.093	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
	yd^2	square yards	0.836	meters squared	m^2	ha	hectares	2.47	acres	ac
	ac	acres	0.405	hectares	ha	k^2	kilometers squared	0.386	square miles	mi^2
	mi^2	square miles	2.59	kilometers squared	k^2					
Volume **	fl oz	fluid ounces	29.57	millimeters	mL	mL	millimeters	0.034	fluid ounces	fl oz
	gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
	ft^2	cubic feet	0.028	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^2
	yd^2	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^2
Mass	oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
	lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
	T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.102	short tons (2000 lb)	T
Temperature (Exact)	°F	Fahrenheit temperature	5 (F-32)/9	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
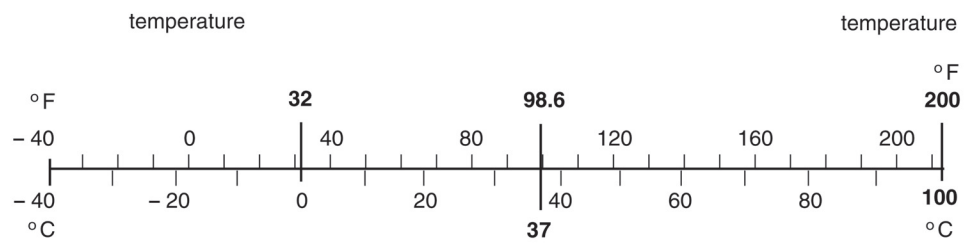
* SI is the symbol for the International System of Measurement.

** Volumes greater than 1000 L shall be shown in m^3.