Coating Failures and Defects

A Comprehensive Field Guide

Corrosionpedia.com in partnership with Fitz's Atlas 2 and ASM Handbook Volume 5B

Coating Failures and Defects

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Coating Failures and Defects

Overview

Coatings are a complex combination of raw materials that must be mixed, applied to a prepared substrate, and dried and cured correctly to perform to their maximum capability. They must be able to be applied in diverse environmental conditions and then be expected to protect the substrate from the damaging effects of rain, sunlight, wind, heat, cold, humidity, and oxygen in various combinations and cycles and still retain their integrity and often their aesthetic qualities. Some coatings, such as those applied to ships, also must be resistant to abrasion, in the case of cargo hold coatings, and cyclic changes of chemicals and tank cleaning, in the case of tank linings. Therefore, it is not surprising that those coatings can suffer from premature failure and/or exhibit defects that may or may not result in failure. It is not generally straightforward to establish the reason for the failure of a coating due to the many potential factors that may be involved. These could include formulation, surface preparation, application, drying and curing times and conditions, and environmental exposure, with more than one contributing factor often being involved.

Failures and defects can manifest themselves at various times in the life of a coating. Prior to application, they can take the form of settlement and skinning, during application as runs and sags, shortly after application as solvent popping and orange peel, and during service as blistering and rust spotting. To determine the cause and mechanism of coating failure, all possible contributory factors must be evaluated together with a detailed history from the time of application to the time the failure was first noted. Many coating failures require further evaluation and analysis to be carried out by a qualified chemist or coating specialist, often using specialized laboratory equipment.

Most of the following examples of failures and defects, together with descriptions, probable causes, and suggested preventative measures, are reproduced by the kind permission of Fitz's Atlas 2, although some photographs have been included from other sources. Fitz's Atlas 2 contains sections on welding faults, surface conditions, marine fouling, and microscopy in addition to the main section of 237 photographs of coating defects and failures in 93 separate categories.

Coating Failures and Defects

Fig. 1 The mechanical action of rubbing, scraping, scratching, gouging, or erosion.

Abrasion

Probable Causes: Removal of a portion of the surface of the coating or, in severe cases, removal to expose the substrate by contact with another object, such as the use of metal chains for lifting, cargo, fenders, or the grounding of a ship.

Prevention: Use of abrasion-resistant coatings formulated with particular regard to resins and extender pigments. With severe cases of abrasion, the effects will be reduced or limited only by an abrasion-resistant coating.

Coating Failures and Defects

Fig. 2 Paint fails to adhere to substrate or underlying coats of paint.

Adhesion Failure

Probable Causes: Surface contamination or condensation, incompatibility between coating systems, or exceeding the overcoating time.

Prevention: Ensure that the surface is clean, dry, and free from any contamination and that the surface has been suitably prepared. Use the correct coating specification and follow the advised overcoating times.

Coating Failures and Defects

Fig. 3 Very large (macro) crazing/cracking that resembles the skin of an alligator or crocodile. Cracks may penetrate through to the undercoat or down to the substrate.

Alligatoring (Crocodiling)

Probable Causes: Internal stresses in the coating where the surface shrinks faster than the body of the paint film. Excessive film thickness and limited paint flexibility. Application of a hard topcoat over a more flexible softer undercoat. Application of topcoat before the undercoat has dried.

Prevention: Use correct coating specification and compatible materials. Avoid excessive film thickness. Avoid application at high ambient temperatures.

Coating Failures and Defects

Fig. 4 Staining of a paint film by diffusion of a soluble colored substance from the underlying paint to give undesirable discoloration or staining. Often seen where bituminous- or tar-based products are overcoated with topcoats in which the tar or bitumen is soluble. Also occurs with emulsion paints.

Bleeding

Probable Causes: Bleed through is generally a full or partial redissolving of the previous coat or an ingredient of a previous coat and can occur when strong solvents are used in the topcoats.

Prevention: Use correct coating specification and materials. Use compatible materials. Use appropriate sealer coat if possible.

Coating Failures and Defects

Fig. 5 Dome-shaped projections or blisters in the dry paint film through local loss of adhesion and lifting of the film from the underlying surface. Blisters may contain liquid, vapor, gas, or crystals.

Blistering

Probable Causes: Many mechanisms can be involved, including osmotic gradients associated with soluble salts, soluble pigments, corrosion products, retained solvents, and solvents from cargoes. Nonosmotic blistering is associated with cathodic disbonding, thermal gradients related to cold-wall effects, and compressive stress.

Prevention: Ensure correct surface preparation and application. Apply a suitable coating system after testing for soluble salts. Consider the possibility of the different blister mechanisms in the particular environment.

Coating Failures and Defects

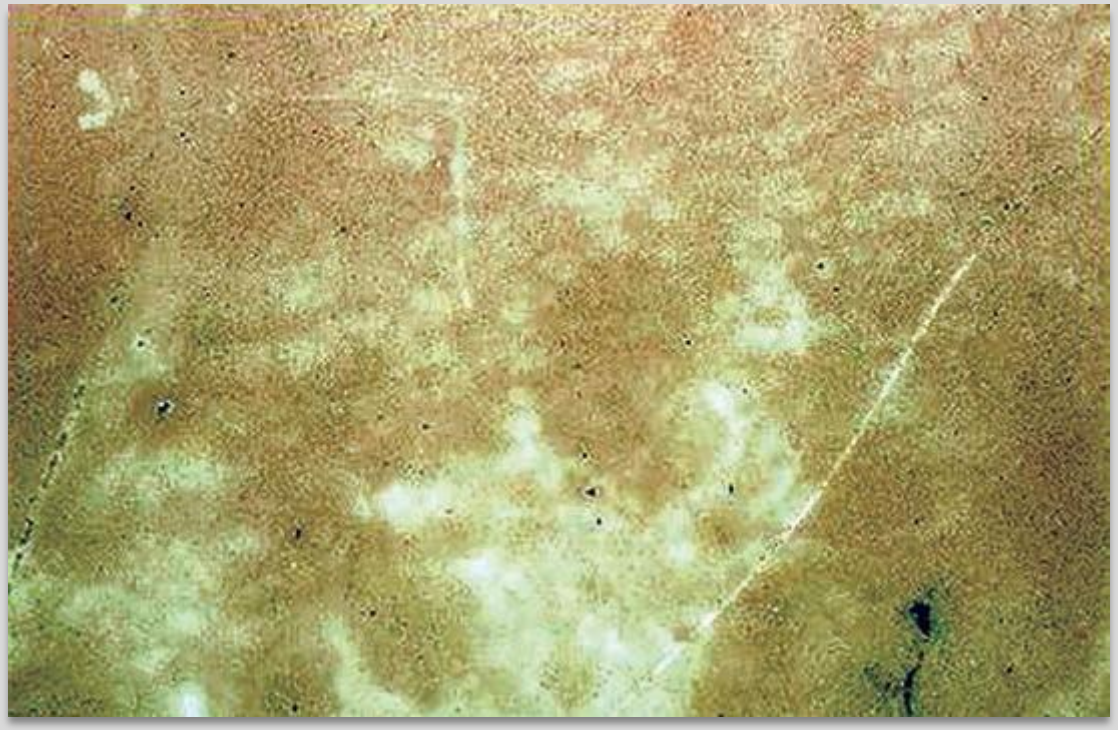

Fig. 6 A hazy deposit on the surface of the paint film resembling the bloom on a grape, resulting in a loss of gloss and a dulling of color.

Bloom (Blush)

Probable Causes: Paint film exposed to condensation or moisture during curing, especially at low temperature (common phenomenon with amine-cured epoxies). Incorrect solvent blend can also contribute to blooming.

Prevention: Apply and cure coating systems under correct environmental conditions and follow the manufacturer's recommendations.

Coating Failures and Defects

Fig. 7 The covering over of unfilled gaps such as cracks or corners with a film of coating material. This introduces a weakness in the paint film, which may crack or flake off.

Bridging

Probable Causes: Poor application. High-viscosity paint system. Failure to brush paint into corners and over welds.

Prevention: Brush-apply a stripe coat into corners and welds and fill all cracks or weld them prior to application of the full coating system.

Coating Failures and Defects

Fig. 8 Bubbles within a paint film appear as small blisters. These may be intact or broken (leaving a crater). Can be found in excessively thick paint films, especially if spray applied, and also with roller application. This should not be confused with blistering.

Bubbles or Bubbling

Probable Causes: Trapped air/solvent within the coating that is not released before the surface dries. Air entrainment during mixing. High ambient temperature during application. Also seen when overcoating antifouling without removal of the leached layer and zinc silicates. Can be found with factory-applied coatings where application is by dipping, electrodeposition, or roller coating.

Prevention: In spray application, adjust viscosity with thinners and follow data sheet requirements for maximum application temperature. Use correct mixing equipment to ensure air is not stirred in during mixing. Apply a mist coat. Add defoaming agent to emulsion paints.

Coating Failures and Defects

Fig. 9 Blistering and delamination of a coating system around bare steel areas and coating defects associated with cathodic protection on buried pipelines, immersed structures, and the hulls of ships.

Cathodic Disbonding

Probable Causes: High overvoltage principally from impressed current systems but also to a lesser extent with sacrificial anodes when the number of anodes is excessive. Factors are incorrect installation, poor monitoring, and incompatible coating systems.

Prevention: Use a well-designed cathodic protection system, regularly monitored with well-placed reference electrodes, and application of an alkali-resistant coating system.

Coating Failures and Defects

Fig. 10 A friable, powdery layer on the surface of a paint film. A change of color or fading is also seen. Chalking rates vary with pigment concentration and choice of binder. Chalking is a known characteristic of certain paints, for example, epoxy paints.

Chalking

Probable Causes: Disintegration of the paint binder on exposure to weathering and/or ultraviolet light.

Prevention: Apply a suitable topcoat with high resistance to chalking and with ultraviolet resistance.

Coating Failures and Defects

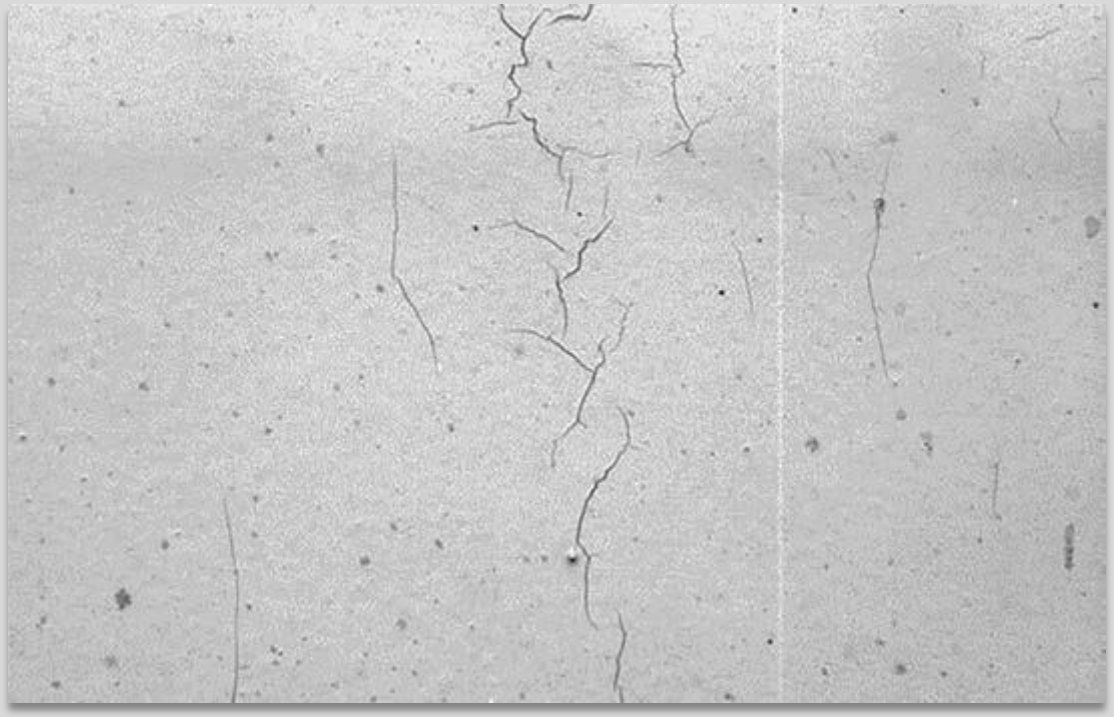

Fig. 11 Fine cracks that do not penetrate the topcoat of a paint system. Some checking can be so minute that it is impossible to see without magnification.

Checking

Probable Causes: Typically a formulation and/or a specification problem. As with cracking, stresses are developed that cause the surface of the paint film to become brittle and crack. Limited paint flexibility.

Prevention: Use a correctly formulated coating system.

Coating Failures and Defects

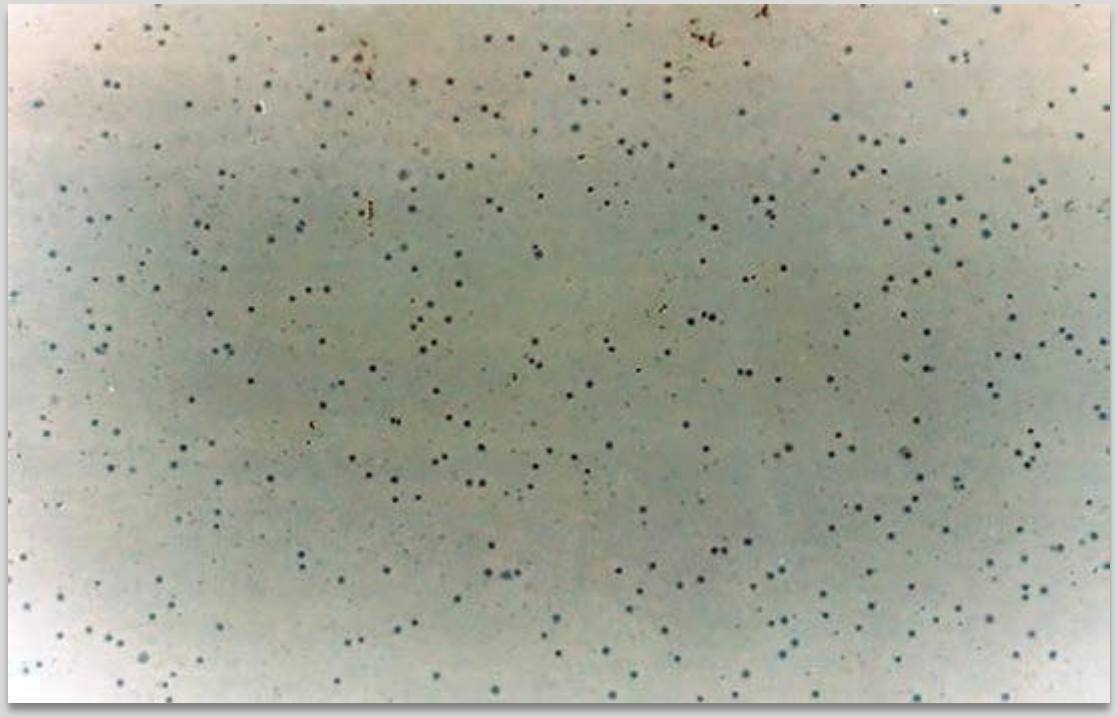

Fig. 12 Surface breaks in a wet paint film, where the paint has receded to expose the underlying substrate. The paint is unable to wet–out the substrate. Can be very large.

Cissing

Probable Causes: Surface contamination by either moisture or foreign matter such as oil, grease, or silicone. Also known to happen when incorrect solvent blends have been used.

Prevention: Ensure surface is clean and free from grease, oil, and other contaminants prior to application of coating.

Coating Failures and Defects

Fig. 13 The production of fine filaments instead of normal atomized particles when some solutions of high-molecular-weight polymers are sprayed. Traditionally when applying chlorinated rubber coatings by conventional spray.

Cobwebbing

Probable Causes: Too high a viscosity with some types of polymer solutions. Will occur with chlorinated rubber at almost any viscosity.

Prevention: Reduce the spraying viscosity. Select a more suitable solvent blend. Change the spraying conditions.

Coating Failures and Defects

Fig. 14 The splitting of a dry paint film through at least one coat to form visible cracks, which may penetrate down to the substrate. Cracking comes in several forms, from minute cracking to severe cracking.

Cracking

Probable Causes: Cracking is generally a stress-related failure and can be attributed to surface movement, aging, absorption and desorption of moisture, and general lack of flexibility of the coating. The thicker the paint film, the greater the possibility it will crack.

Prevention: Use correct coating systems, application techniques, and dry-film thicknesses. Alternatively, use a more flexible coating system.

Coating Failures and Defects

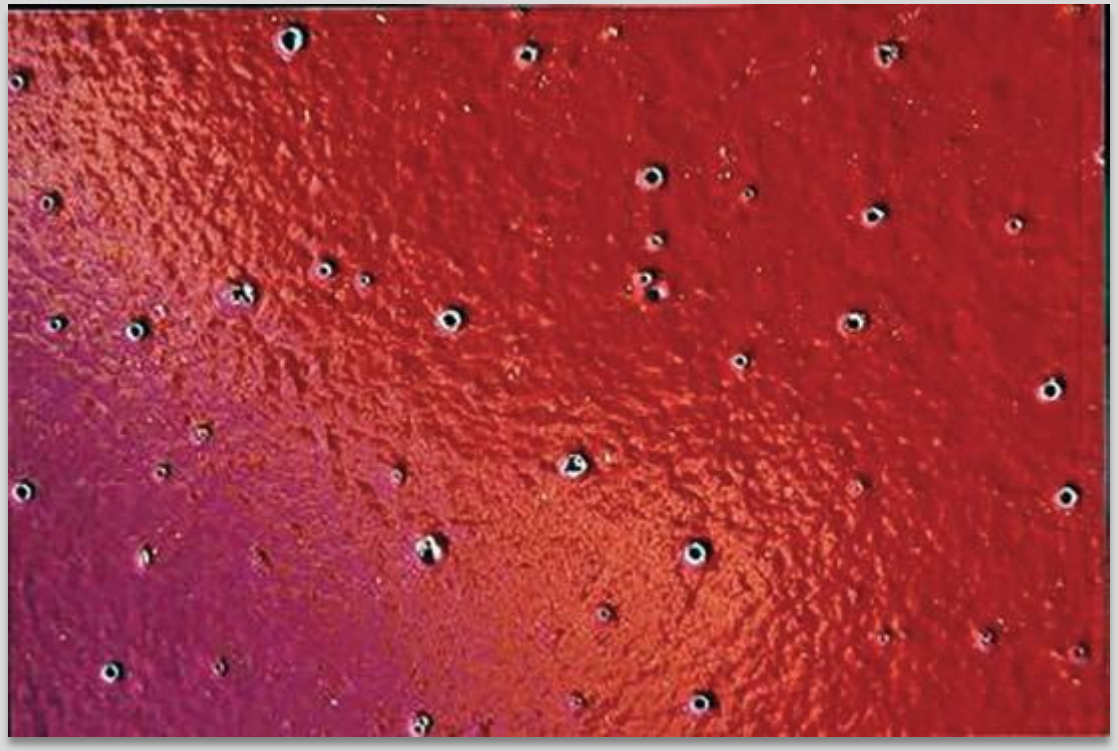

Fig. 15 The formation of small bowl-shaped depressions in the paint film. Not to be confused with cissing.

Cratering

Probable Causes: Trapped air or solvent bubbles that have burst, leaving small craters as the coating dries. The coating has insufficient time to flow into a uniform film.

Prevention: Improve spray technique, apply a mist coat, and avoid air entrainment during mixing. Add thinners as recommended by the paint supplier.

Coating Failures and Defects

Fig. 16 Similar to checking but the cracks are generally wider and penetrate deeper into the film.

Crazing

Probable Causes: Application temperature too low, incompatibility with previous coating, aging, or high film thickness.

Prevention: Apply a thinner coat of paint, add slower-drying solvent, check that application and drying conditions are correct for the paint system used, and check compatibility.

Coating Failures and Defects

Fig. 17 The development of small wrinkles in the paint film in a pattern resembling a crow's foot.

Crowsfooting

Probable Causes: Usually due to the surface drying rapidly to form a skin, which then wrinkles as solvent slowly evaporates from the soft underlying paint.

Prevention: Apply a thinner coat of paint, add slower-drying thinners, and check that application and drying conditions are correct for the paint system used.

Coating Failures and Defects

Fig. 18 Loss of adhesion between coats of paint.

Delamination

Probable Causes: Provided that compatible paint materials have been used, delamination defects are generally related to poor surface preparation and application defects, such as contamination between coats, exceeding overcoat times, or application to a glossy surface.

Prevention: Ensure that no contamination occurs between paint coats. Follow the recommended overcoating intervals. Lightly abrade and clean glossy surfaces between coats.

Coating Failures and Defects

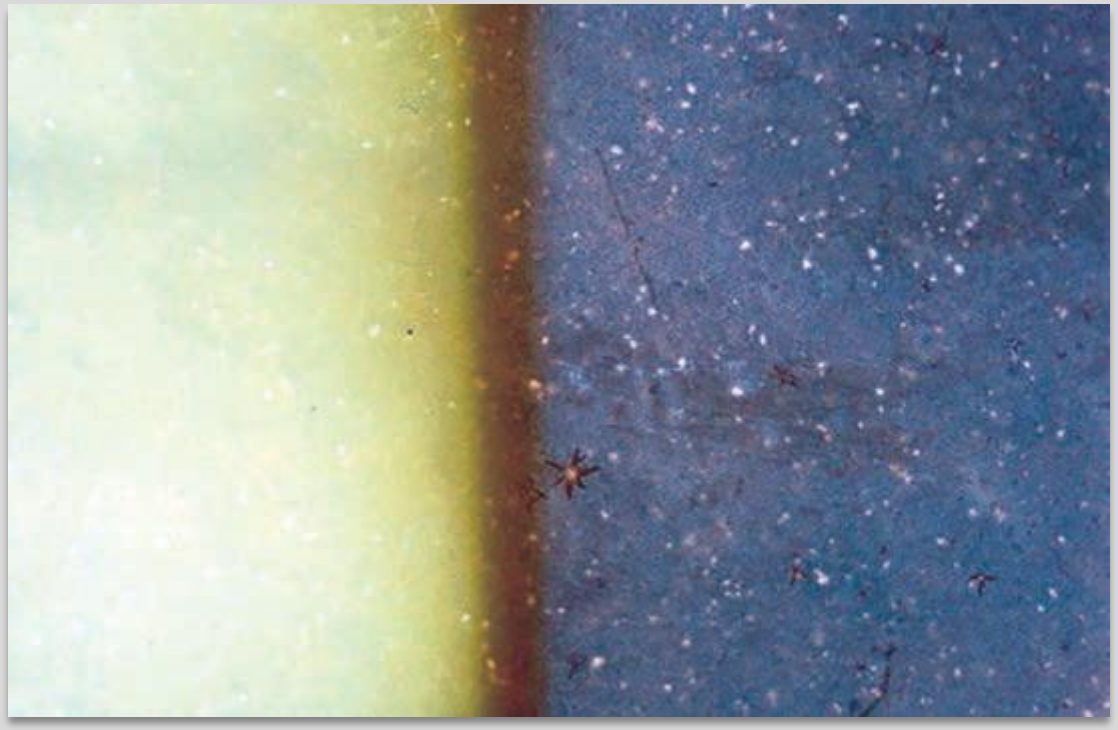

Fig. 19 Discoloration or gradual decrease in color of paint when exposed to sunlight/weather. May be accompanied by loss of gloss. In some situations, it may resemble chalking but without the powdery surface. Fading tends to accelerate in the presence of moisture.

Fading

Probable Causes: Incorrect pigmentation, use of non-light-stable organic pigments, atmospheric contamination, porous substrate.

Prevention: Use correct coating systems that resist ultraviolet light and fading. Use a coating with light-stable pigments.

Coating Failures and Defects

Fig. 20 A form of adhesion failure where paint flakes from the substrate. A familiar sight on wood substrates and on galvanizing.

Flaking

Probable Causes: Incorrect paint system used. Either no or an incorrect pretreatment used for certain substrates, for example, nonferrous or galvanized. Also poor application techniques. May also be attributed to differential expansion and contraction of paint and substrate, for example, wood. Can be the result of aging of the paint system.

Prevention: Use correct coating system and pretreatment.

Coating Failures and Defects

Fig. 21 The underlying surface is visible through the paint film due to inadequate hiding power of the coating material. This is sometimes called grinning-through. Often seen where dark colors are overcoated with lighter colors.

Grinning

Probable Causes: Low film thickness of topcoat. Poor opacity and covering power of topcoat. Strong color of primer/undercoats.

Prevention: Apply adequate dry-film thickness between individual coats. Use opaque coatings with good opacity.

Coating Failures and Defects

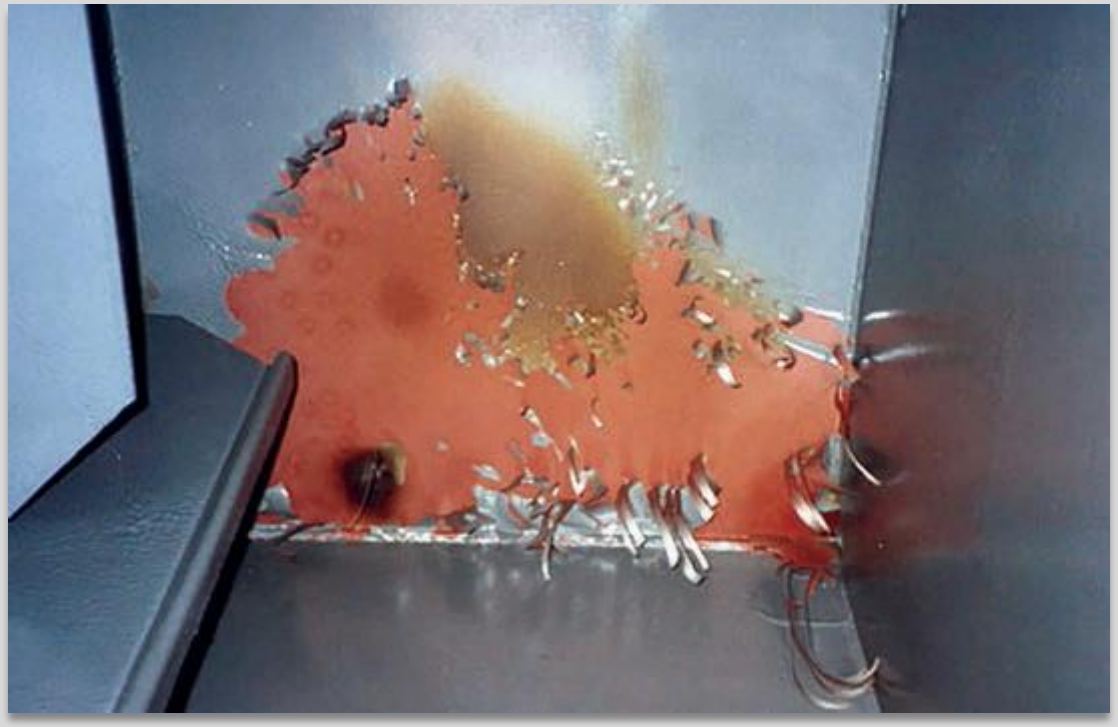

Fig. 22 Discoloration, detachment and/or blistering, and general degradation of a paint film.

Heat Damage

Probable Causes: Effect of high temperature often applied to the reverse side of a steel plate from burning, welding, or fire.

Prevention: Ensure that all welding/burning is completed prior to painting.

Coating Failures and Defects

Fig. 23 Cracks that radiate from a point of impact.

Impact Damage

Probable Causes: Impact damage to a relatively brittle coating. Often seen on glass-fiber-reinforced plastics. Also occurs when steel is deformed by impact.

Prevention: Prevent impact damage.

Coating Failures and Defects

Fig. 24 Cracks that radiate from a point of impact.

Intercoat Contamination

Probable Causes: The contamination could be present due to inadequate washing down, salts from weathering of shop primer, or deposits from nearby operations.

Prevention: Carefully inspect and test the surface before paint application, and wash down with fresh water if required.

Coating Failures and Defects

Fig. 25 The dried paint film has the appearance of a dried-out mud flat. The cracks appear as a network that can vary in size and amount.

Mud Cracking

Probable Causes: Generally, overapplication of heavily pigmented primers such as inorganic zinc silicates or water-based coatings, although can occur with other overthick systems.

Prevention: Apply only the recommended coating thickness. Use recommended application techniques with suitably formulated products.

Coating Failures and Defects

Fig. 26 A uniform, pock-marked appearance, in particular of a spray-applied coating, in which the surface of the paint film resembles the skin of an orange.

Orange Peeling

Probable Causes: Failure of the paint film to flow out. Usually caused by poor application techniques, incorrect solvent blend, or too-high thixotropy.

Prevention: Use correct application techniques with suitably formulated products.

Coating Failures and Defects

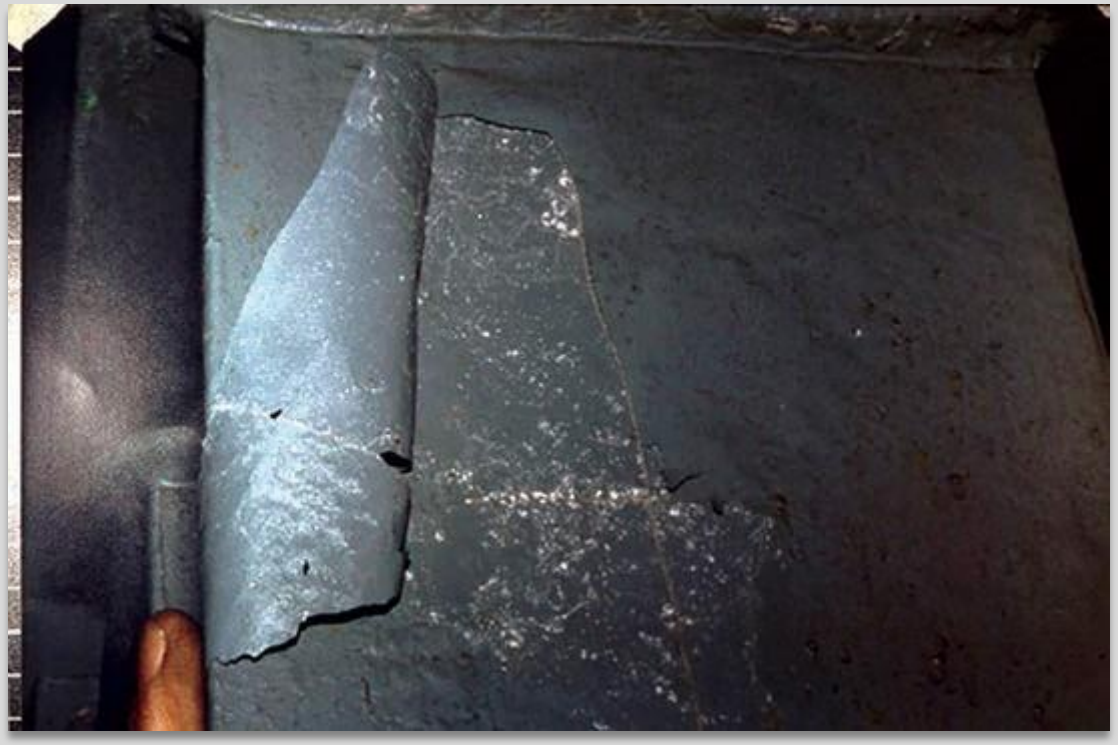

Fig. 27 Similar to flaking, although peeling tends to be associated with soft and pliable fresh coatings that can be pulled away from or spontaneously flake away from the substrate or from between coats, due to loss of adhesion.

Peeling

Probable Causes: Peeling is the reduction in bond strength of the paint film due to contamination or incompatibility of coats.

Prevention: Use correct coating system and specification applied to clean and uncontaminated surfaces.

Coating Failures and Defects

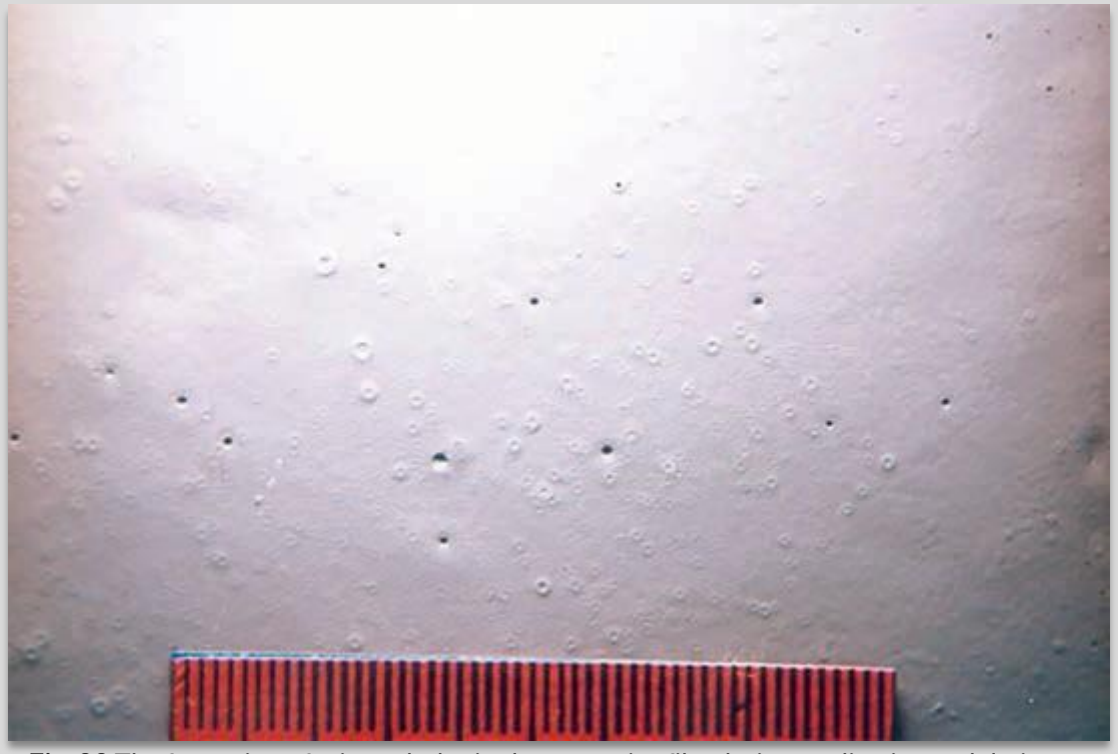

Fig. 28 The formation of minute holes in the wet paint film during application and drying, due to air or gas bubbles that burst, giving rise to small craters or holes that fail to coalesce before the film has set.

Pinholes

Probable Causes: Solvent or air entrapment within a paint film. A common problem when coating porous substrate such as zinc-filled primers, zinc silicates, and metal-sprayed coatings. Pinholes can also be caused by incorrect spray application or incorrect solvent blend.

Prevention: Use correct application techniques with suitably formulated products. Correct solvent blends and environmental conditions. Check spray equipment and distance of spray gun from the surface. Apply a mist coat.

Coating Failures and Defects

Fig. 29 A rippled effect on the surface of the paint.

Rippled Coating

Probable Causes: Strong wind blowing across the surface of wet paint causes it to ripple. Where this occurs on the underside, the ripples can hang down in the form of small stalactites. Can also be caused by poor application techniques.

Prevention: Do not apply paint under unfavorable conditions. Use correct application equipment and workmanship.

Coating Failures and Defects

Fig. 30 A narrow downward movement of a coat of paint, often apparent from accumulation of excessive quantities of paint at irregularities such as cracks and holes where the paint continues to flow after the surrounding surface has set.

Runs

Probable Causes: Overapplication of paint, excessive use of thinners, incorrect (or lack of) curing agent, or poor workmanship.

Prevention: Use correct application techniques and apply at the recommended dry-film thickness.

Coating Failures and Defects

Fig. 31 Fine spots of rust that appear on a paint film, often a thin primer coat. The initial spots rapidly spread over the surface, resulting in a film of rust through which the individual spots are difficult to discern. Also from holidays.

Rust Rashing

Probable Causes: Low film thickness, often in combination with a high surface profile.

Prevention: Ensure that an adequate thickness of a primer coat is applied to cover the surface profile, and check that the surface profile is not too large.

Coating Failures and Defects

Fig. 32 Individual spots of rust that appear on a paint film and frequently start as localized spotting but rapidly increase in density.

Rust Spotting

Probable Causes: Low film thickness (more likely creating rust rashing), voids and holidays (more likely creating rust rashing), but also defects in the steel, such as laminations and inclusions. Too high a surface profile may cause penetration of peaks through a paint film and cause rust spotting. May also occur from metallic contamination of a coated surface by grinding dust and so on.

Prevention: Ensure that an adequate thickness of a primer coat is applied to cover the surface profile. Use a thicker coating system or a lower blast profile. Protect coating from contamination with grinding dust and so on.

Coating Failures and Defects

Fig. 33 A light staining on the surface of the paint caused by the precipitation of ferrous oxide from adjacent exposed steel.

Rust Staining

Probable Causes: Water runoff from a rusty surface above a soundly coated surface. Rust staining occurs when the rust is wetted-out and contaminated water runs over and discolors other items or locations. Usually more of an eyesore than a defect. The coating itself may not be defective, only stained.

Prevention: Ensure adequate design and suitable maintenance.

Coating Failures and Defects

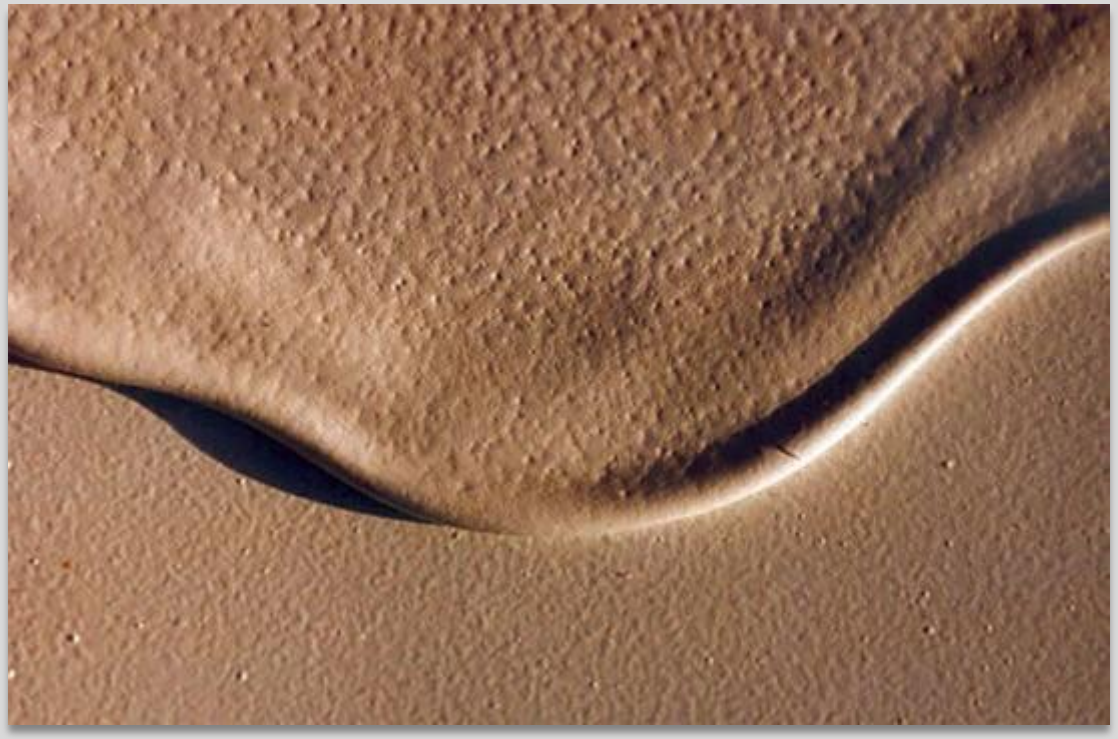

Fig. 34 Sags are caused by the downward movement of a coat of paint that appear soon after application and before setting, resulting in an uneven area with a thick lower edge. They are usually apparent on local areas of a vertical surface and, in severe situations, may be described as curtains.

Sags

Probable Causes: Overapplication of paint, excessive use of thinners, incorrect (or lack of) curing agent, or poor workmanship. Could, in extreme circumstances, be a formulation problem.

Prevention: Use correct application techniques with suitably formulated products.

Coating Failures and Defects

Fig. 35 The sedimentation of the solid constituents comprising pigments and extenders from the binder and solvent while standing in a container. Settlement that occurs after mixing and during application can result in different shades and performance in different areas.

Settlement

Probable Causes: Old stock, heavily pigmented paint, and incorrect formulation of product. Can be a problem with zinc-rich primers.

Prevention: Use products within shelf life. Use adequate mixing procedures. Keep paint mixed or recirculated during spray application.

Coating Failures and Defects

Fig. 36 Formation of a layer of skin on the paint surface in a container.

Skinning

Probable Causes: Absence of antiskinning agent, use of nonairtight container, hot storage conditions. Often occurs in partly-used cans.

Prevention: Use airtight container, and store according to data sheet.

Coating Failures and Defects

Fig. 37 Eruption of the surface of the paint film. Wrinkling and blistering, which lead to a weak surface and ultimate coating breakdown.

Solvent Lifting

Probable Causes: Incompatible paint systems used. Topcoats with a strong solvent blend can react with previous and weaker solvent-blended coatings. Overcoating before the previous coat has adequately hardened.

Prevention: Use correct coating specification, overcoating times, and materials. Conduct compatibility trials with undercoat/topcoats.

Coating Failures and Defects

Fig. 38 Solvent (clear) bubbles on the surface of the paint film soon after application.

Solvent Popping

Probable Causes: Incorrect solvent blends, porous surfaces, incorrect environmental conditions, or high surface temperature.

Prevention: Use correct coating specifications and materials, and ensure correct application techniques and environmental conditions.

Coating Failures and Defects

Fig. 39 Discoloration of a coating system.

Staining

Probable Causes: Contact with a solid or liquid that imparts a discoloration or stain to the coating.

Prevention: Avoid contact with solids and liquids that are prone to cause staining, or use dark-colored coatings where any staining would not be so apparent.

Coating Failures and Defects

Fig. 40 Paint coatings with visible cracks, which may penetrate down to the substrate.

Stress Cracking

Probable Causes: Stress cracking can be attributed to surface movement, aging, absorption and desorption of moisture, thermal cycling, and general lack of flexibility of the coating. The thicker the paint film, the greater the possibility that cracking may occur. Often occurs around welds and changes in section.

Prevention: Use correct coating systems, application techniques, and dry-film thicknesses, or use a more flexible coating system.

Coating Failures and Defects

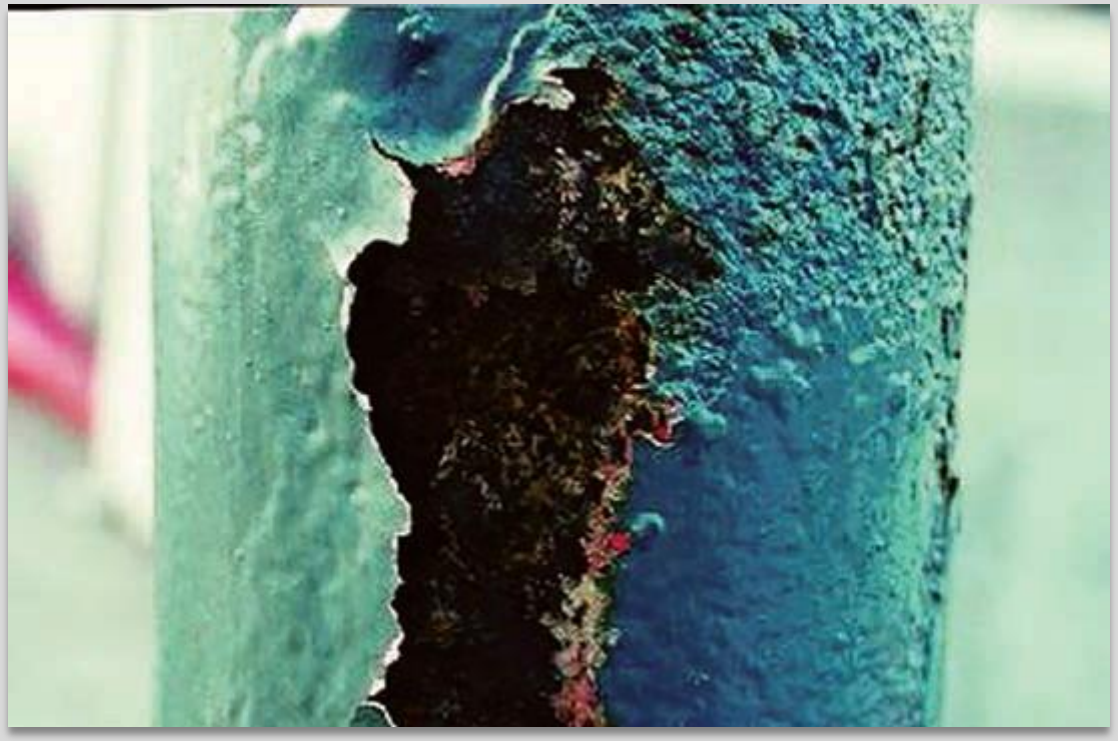

Fig. 41 Visual corrosion beneath a paint film, often called creep. Corrosion travels beneath the paint film and lifts the paint from the substrate. Severe cases can show as blistering, flaking, cracks, and exposed rust.

Undercutting

Probable Causes: Application of paint to corroded substrate. Rust creep from areas of mechanical damage and missing primer coat. Can be found in areas of poor design or access, where inadequate preparation and coating thickness was applied. Could also be due to lack of maintenance.

Prevention: Use adequate coating specifications and maintenance procedures. Apply a suitably formulated primer.

Coating Failures and Defects

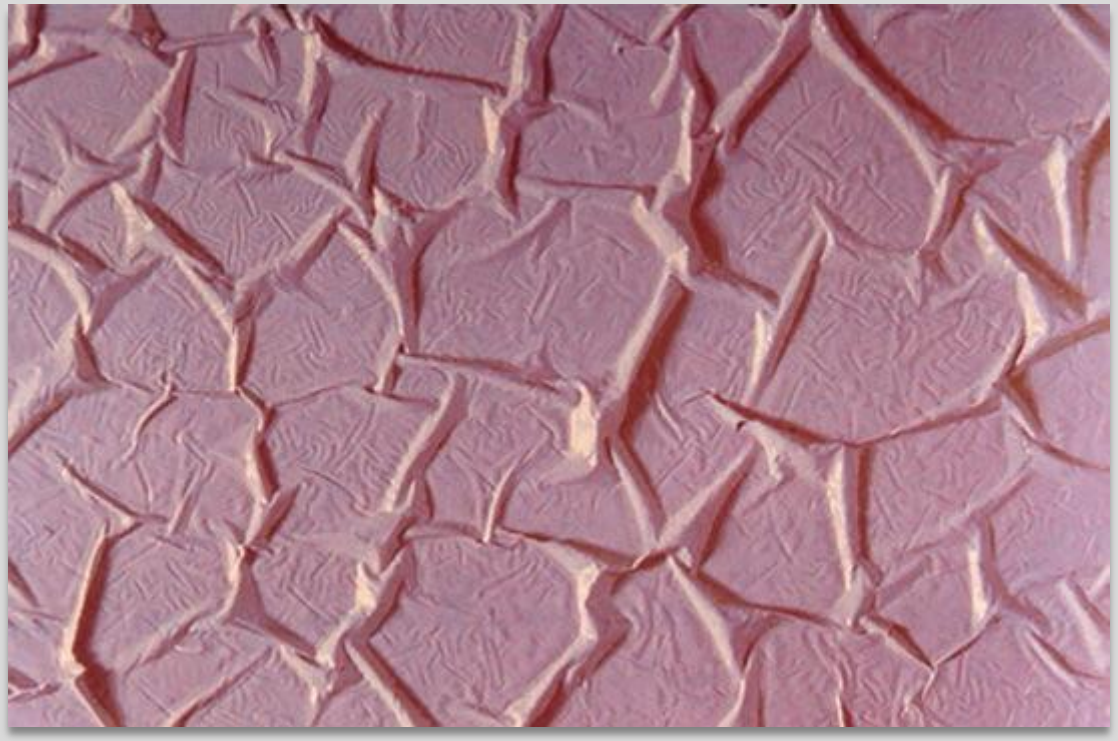

Fig. 42 The development of wrinkles in the paint film during drying.

Wrinkling

Probable Causes: Usually due to the initial formation of a surface skin with solvent-based paints. Can arise from overcoating before the previous coat has adequately hardened. Overthickness, particularly with alkyd coatings.

Prevention: Use correct coating specification and materials, and ensure adequate mixing, application, and curing by following the paint supplier's recommendations.

References

1. B. Fitzsimons and T. Parry, *Fitz's Atlas 2 of Coating Defects*, MPI Group, Surrey, U.K., 2011

2. Kenneth B. Tator, *ASM Handbook Volume 5B: Protective Organic* Coatings, ASM International, Ohio, USA, 2015