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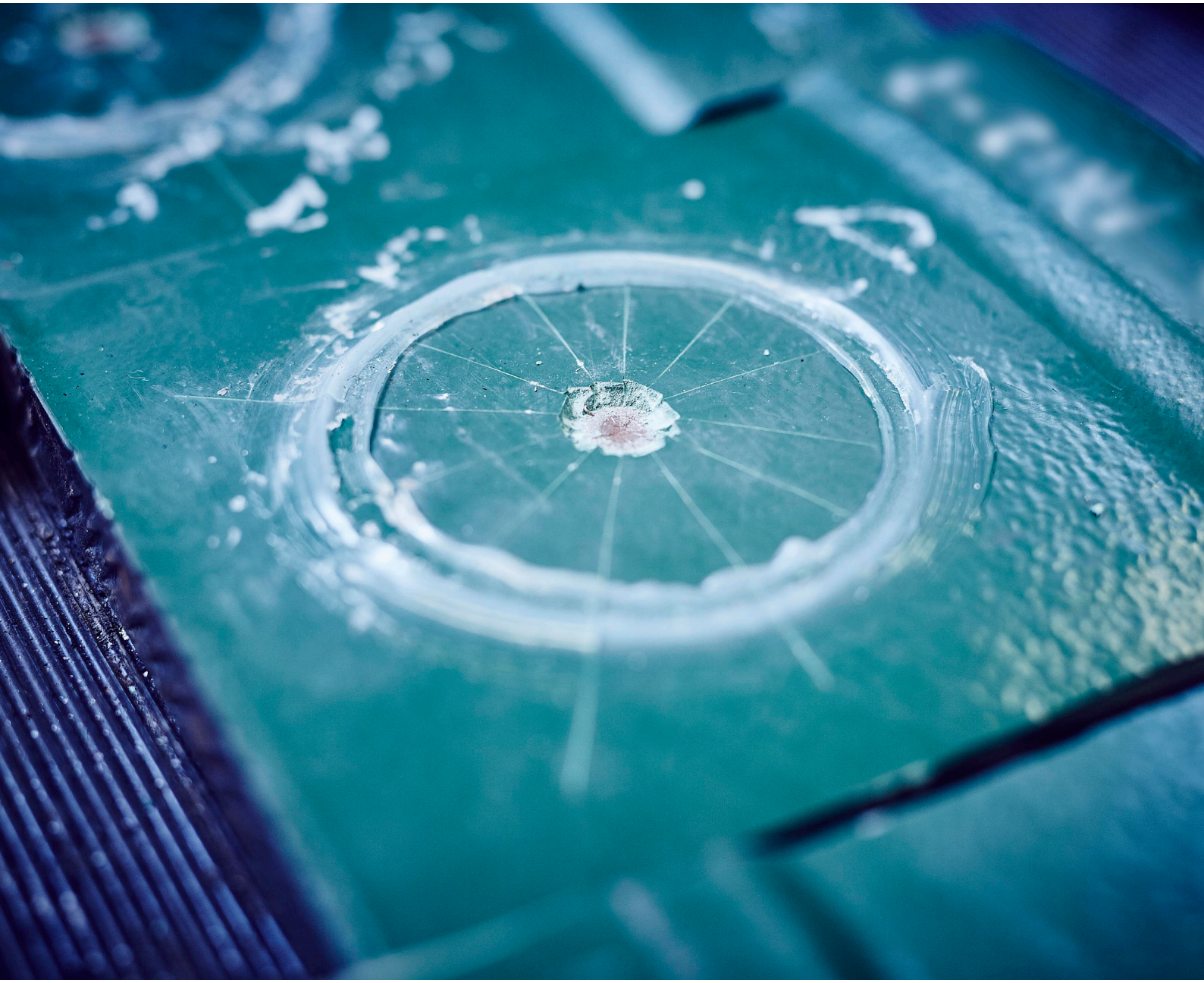

PAINTS AND COATINGS FAILURES

A GUIDE BOOK ON CAUSES AND REMEDIES

CONTENTS

BACKGROUND

Paints and coatings of all types cover a very large range of diverse uses in a variety of sectors, including the marine, oil and gas, automotive, aerospace and industrial to name but a few.

Besides providing aesthetic appeal and decorative value to surfaces and products, they are primarily used to protect critical assets from damage by the external environment, thus extending service life and increasing efficiency.

In order to provide these functions, it is important that paints and coatings are successfully applied to a properly prepared surface, and remain intact and adherent to the substrate material to which they have been applied.

Although the vast majority of paints and coatings perform admirably until an old age, at which time natural deterioration and degradation occur, they can fail prematurely and lose their protective or aesthetic function, particularly when exposed to adverse operating environments. This can result in potential performance problems, costly repairs and downtime.

Failure analysis is a valuable tool when investigating the root causes of asset failure. Not only does it help in assigning financial responsibility, but knowing how a coating has failed is often the first step in developing a corrective action plan and preventing recurrence of the same failure mode.

CAUSES AND REMEDIES OF FAILURE

Paints and coatings are used on a number of applications, each one with different physical and chemical characteristics of their material surfaces, each one exposed to a diverse service environment.

With all the variables involved in the use of paints and coatings, their failure can be attributed to a number of reasons. However, they are typically the result of three main causes:

- improperly prepared surfaces or poor application conditions
- defective coating
- inadequate specification

Based on these causes, failure modes can be divided into three general categories:

FORMULATION-RELATED FAILURES

Formulation-related failures occur because of the ingredients used and their basic formulation in the coating. Resins, pigments and solvents are essential formulation ingredients. Without them, paint and coating products would simply not perform as well. However, an improper mixture of these ingredients during the manufacturing process can lead to early failure of coatings. Any coating system that is formulated inadequately is most likely to fail, no matter how well it has been applied.

SUBSTRATE-RELATED FAILURES

The type of substrate surface is also a factor related to coating failures, and surface cleanliness is of utmost importance for the optimal service life of the coating. Poor or deficient surface preparation is, in fact, the major cause of reduced operational life of products and applications.

Surface contamination, poor surface profile, inadequate thickness control, improper drying and lack of cure prevent the coating to properly adhere to the substrate material, all negatively affecting the coating performance. Correct surface preparation is, therefore, the first essential stage treatment for the success of any protective coating scheme, and in the long run for the integrity of an asset.

PHYSICAL DEFECT-RELATED FAILURES

A number of aesthetic appearances can characterize a premature coating failure. A visual examination of physical defects is the first stage of every coating failure investigation. This is crucial for collecting valuable background data to determine the cause of the failure.

These failure types may act independently or in concert with each other.

A detailed examination of the different failure modes is presented in the following tables.

FORMULATION-RELATED FAILURES

COATING FAILURE	FAILURE APPEARANCE	CAUSE OF FAILURE	REMEDY
ORGANIC COATING FAILURE			
1. CHALKING	Surface is soft and powdery. Easily wiped away.	UV degradation of the resin binder. Improper pigmentation formulation.	Use coatings formulated with UV resistant resins and non catalytic, high hiding pigments.
2. EROSION	Similar to chalking. High spot removal and brush marks.	Chalking and surface weathering and abrasion.	Use a tough chalk-resistant coating with good flow out characteristics that will form a smooth film.
3. CHECKING	Uneven, small, noncontinuous coating fissures which do not penetrate to the substrate.	Surface stresses caused by shrinkage due to weathering and continued coating polymerization and oxidation.	Use coatings formulated with weather-resistant resins and inert reinforcing pigments in addition to non-catalytic colored pigments.
4. ALLIGATORING	Large macro-cracking and cross-hatching pattern.	Internal stresses with greater surface shrinkage. Hard top coat applied over soft undercoat.	Apply thin coats and thoroughly dry before replication. Never apply hard top coats (epoxy) over soft undercoats (asphalt).
5. CRACKING	Small breaks in coating to substrate of various geometries.	Stresses due to continued polymerization/oxidation.	Use non-reactive resins and pigments.
6. MUD CRACKING	Large macro-cracking, curling at cracks, and adhesion loss.	Rapid drying of highly filled coatings, especially water based materials.	Use coatings with strong adhesion. Apply coatings under proper drying conditions. Prevent sags, puddles or areas of excessive thickness.
7. WRINKLING	Furrows and ridges in coating surface.	Surface dries more quickly than underlying coating.	Use coatings with even, thorough drying characteristics. Apply evenly and avoid excessive thickness.
8. BIOLOGICAL FAILURE	Softening or slime reaction. Blotchy brown or black spots causing poor dirty appearance.	Bacterial or fungal degradation. The coating is used as a source of nourishment.	Use permanent fungicides or bactericides in coating.
9. DISCOLORATION	Yellowing, graying or darkening.	Weathering or chemical reaction.	Use color stable resins and pigments.
INORGANIC COATING FAILURE			
1. CHECKING	Fine visible or microscopic checks that do not penetrate to the substrate.	High zinc pigment/binder ratio. Rapid drying conditions.	Use reinforcing pigments, thin layer application and proper drying.
2. MUD CRACKING	Fine to large segments flaking from surface.	Too thick application. Too rapid drying.	Use recommended thickness and proper drying method.
3. PINPOINT RUSTING	Pinpoint spots of corrosion. Early failure can be catastrophic.	Improper zinc/binder ratio. Uneven coating thickness.	Remove and reapply more satisfactory coating at first sign of failure.
4. CHEMICAL	Pinpoint rusting progressing from limited to continuous rusting.	Acid or alkali reaction on both silicate binder and on metallic zinc.	Apply resistant top coats over inorganic zinc coatings.
5. PITTING IN SEAWATER	Strong anodes form in breaks in coating.	Reaction of chemicals with surface of inorganic zinc or galvanizing, causing it to become inert and thus a massive cathode.	Top coat the inorganic zinc with a strongly adherent resistant coating system.

SURFACE-RELATED FAILURES

COATING FAILURE	FAILURE APPEARANCE	CAUSE OF FAILURE	REMEDY
1. ON PREVIOUSLY USED STEEL	Blistering, rust, tubercles, loss of adhesion.	Retention of minute amounts of corrosion product or contaminant, even after abrasive blast.	Wash blasted surface with water or dilute phosphoric acid solution and re-blast. Use anti-corrosive primer with strong adhesion.
2. ON GALVANIZED OR METALLIC ZINC SURFACE	White zinc corrosion product forming under coating or breaking through.	Formation of zinc salts (oxide, sulfide, oxychloride, zinc soap) underneath coating.	Brush blast zinc surface or use commercial zinc treatment. Use anti-corrosive primer with strong adhesion.
3. ALUMINUM	White corrosion product, loss of adhesion, possible blistering.	Smooth aluminum oxide surface. No physical adhesion.	Light blast aluminum surface or use aluminum treatment. Use anti-corrosive primer with strong adhesion.
4. COPPER	Grey-green corrosion product, loss of adhesion.	Smooth copper oxide surface. No physical adhesion.	Brush blast copper surface or use copper treatment. Use anti-corrosive primer with strong adhesion.
5. WOOD	Checking, cracking and flaking of coating. Blistering from trapped moisture in wood.	Expansion and contraction of wood due to varying temperatures and humidity.	Start with clean newly sanded surface. Use elastic, highly penetrating paint with high moisture porosity to allow wood to breathe.
6. CONCRETE	Blistering, peeling or loss of adhesion. Formation of calcium salts under coating.	Chemical reactivity, moisture content and porosity of concrete.	Concrete surface should be clean and dry. Acid etch or light blast. Use elastic, highly penetrating paint with alkali resistance (epoxy).

PHYSICAL DEFECT-RELATED FAILURES

COATING FAILURE	FAILURE APPEARANCE	CAUSE OF FAILURE	REMEDY
1. BLISTERS	Hemispherical bubbles containing moisture or other liquids.	Contamination on surface prior to painting or coating. Moisture in wood substrate.	Clean surface prior to painting. Other means of moisture escape for wood substrates.
2. BUBBLES AND CRATERS	Bubble: dome-like raised area containing vapor. Crater: concave area once covered by bubbles.	Solvent or moisture entrapment during drying or baking.	Application of coating in thin layers. Sufficient flash time before baking.
3. COLOR MISMATCH	Color deviations from one area to another.	Variations of film wetness and build, substrate, thickness, application and agitation.	Consistency required in film wetness, build, thickness, application and agitation.
4. DIRT	Any contaminants found in paint or on painted surfaces.	Inadequate facilities, poor housekeeping, poor painting practices (dirt, dust and general detritus matter embedded in the paint film).	Improve housekeeping and pay attention to painting practices and procedures.
5. FISHEYES	Small depression with a central mound.	Surface contamination in the form of residual oil or grease, especially silicone types.	Keep painting area free from silicone products. Use fisheye eliminators.
6. GLOSS VARIATIONS	Gloss deficient patches of paint film.	Base-coat wet spots, improper oven conditions, insufficient film build.	Control bake oven conditions, proper application, and consistent film thickness.
7. MOTTLE	Metallic paint. Color pigments separate from metallic flake.	Application of paint too thick or excessively wet.	Do not apply the paint too wet.
8. ORANGE PEEL	Repetitive bumps and valleys similar to a dried-out mud flat.	Improper application technique. Freshly applied paint film does not flow out smoothly.	Proper paint spray atomizing pressure, paint viscosity, and film thickness.
9. RUNS, SAGS AND CURTAINS	Downward flow of paints prior to film hardening.	Excessive application of coating material. Application too wet or improper drying conditions.	Proper spray gun cleanliness and operation. Correct solvent amounts.
10. PAINT ADHESION LOSS	Premature lifting of the paint film from the underlying surface.	Contaminants, excessive bake times, condensed moisture.	Proper surface preparation, cleanliness, correct bake parameters, and prevention of condensed moisture.
11. SOFT PAINT FILMS	Coatings cured to hardness below a designated specification.	Improper oven or cure parameters, softening contaminants, excessive solvents and film builds.	Correct bake parameters, avoid softening agents, proper solvent amount and film build.
12. SOLVENT POPPING, BOILING AND PINHOLES	Tiny surface craters on paint films. Small versions of bubbles and craters.	Overly rapid solvent loss from the wet paint escaping as “bursts”.	Avoid pigment clusters, controlling solvent evaporation rates and oven temperatures.
13. SOLVENT WASH	Paint voids or areas with thin paint due to solvent condensation.	Excessive solvent evaporation on entry area of oven, condensation on cool area of part.	Sufficient flash time before painted parts enter an oven.

FAILURE ANALYSIS

Coatings provide critical asset protection against adverse operating environments. Should a coating fail or not perform as expected, investigation of the root causes are needed to solve the problem and improve future performance. Failure analysis is the best insurance against recurrence of coating failure.

Collecting information on the failed coating is essential to identify the underlying factors that may have initiated the failure. Background information on the coating type and application procedure, its service history, the environmental conditions it has been exposed to, and physical evidence of the failed coating are necessary to determine why, how, when, and where a failure may have occurred. The findings will provide the insight to solve the problem, take remedial action, and prevent recurrence.

A wide array of testing methods are available for failure analysis of paints and coatings. However, the failure analysis sequence generally follows an order of increasing "destructiveness" of the test in order to prevent damage caused by previous tests.

A visual, or macroscopic, examination of the surface of the specimen is the most important step of any failure analysis, and precedes all other examination techniques, including those directed at the microscopic level. Many macroscopic features and characteristics can suggest certain failure modes and circumstances.

Physical testing provides important characteristics of a coated specimen which may reveal primary causes for the failure. Important physical tests include thickness testing, pinhole testing, adhesion testing, determination of the plane of delamination, hardness testing, and surface roughness testing.

Performing a chemical analysis of the paint or coating, as well as the substrate and corrosion products is usually the next step. Chemical analysis indicates whether a component is made of the specified material. Subtle variations in composition can often dictate the strength and property values that processing can develop or in adhesion of the paint or coating. In addition, relatively low amounts of impurity elements can cause significant changes in these same properties.

Typical chemical analysis techniques that are used in the laboratory for failure analysis of paints and coatings are fourier transform infrared spectroscopy (FTIR) for organic functional group analysis, gas chromatography – mass spectrometry (GM-MS) for organic compound separation, identification and quantification, differential scanning calorimetry (DSC) for melt range and thermal properties, scanning electron microscopy (SEM) with associated energy dispersive x-ray spectroscopy (EDS) for elemental analysis, and Auger electron spectroscopy (AES) and x-ray photo-electron spectroscopy (XPS) for surface elemental analysis.

CONCLUSIONS

Paints and coatings provide critical asset protection in some of the harshest operating environments. Even a tiny area of coating failure can result in serious operation issues with economic losses.

Also, repairing a damaged coating is often very costly. Failure analysis investigation helps identify the root causes of failures to improve future performance and prevent coating failures of a similar nature.

Element is an international provider of testing, advisory and certification services. We are trusted by many of the world's best organizations to test and advise on the safety, quality and performance of their products and operations.

Element provides failure analysis investigations, on-site inspections and consultancy services in metallurgy, polymers and coatings, specializing in corrosion risk assessment and mitigation. Our experts can help you better understand the causes of asset failure, advise on remedial action and support you in any potential litigation. Whether buildings, oil rigs, chemical plants or ships, failure analysis investigation helps you protect your most critical assets and your bottom line.

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