



Ponderosa Protective Coatings™

Causes and Prevention of Paint Failure

CAUSES AND PREVENTION OF PAINT FAILURE

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Good Painting Practice, Steel Structures Paint Manual,
Volume 1, Chapter 23

Coatings or paints are the principal materials of corrosion protection for all steel structures. This is true almost without regard to the use of the structure, whether it be a bridge, ship, chemical plant tank farm, refinery, high rise office building or underground pipeline. Every exposure of a coating is different, even though it may be used for the same purpose at different locations. Bridges in Florida are exposed to vastly different conditions than bridges in the northern part of the United States or Canada, and a tank farm in California is exposed to conditions quite different from one on the Gulf Coast. As coatings are the primary protection for all of these vastly different exposures, it is understandable that failure of coated surfaces is inherent and that time to failure is the critical dimension in this phenomenon.

Failure can occur for a number of reasons:

1. Improper selection of the coating for the service. Too often, a coating designed for steel surfaces may be extended out over a concrete or wood surface from the steel structure with rapid failure occurring on the non-metallic surface. Also, a coating which might be excellent on the exterior of a storage tank may be a complete failure on a chemical reaction vessel. Proper selection of a coating for any specific purpose is extremely important.
2. The coating may fail from causes inherent to that specific coating. Such failure could be chalking, checking or alligating.
3. Adhesion-related failures are most numerous and can be catastrophic. Such failures are blistering, flaking, and peeling.
4. Failure can occur from the surface to be protected (the substrate). The coating may be incompatible with the surface; there may be a chemical reaction between the surface and the coating; or the density or smoothness of the surface may cause the coating to have poor adhesion.
5. The coating may fail from exterior forces such as chemical exposure, abrasion or severe weathering.
6. The coating may fail because of poor or inadequate surface preparation or application. Here, surface contamination, poor surface profile, inadequate thickness control, pinholes, overspray, improper drying, lack of cure or holidays can cause rapid failure.
7. The design of the structure itself is often a cause for severe failure. Sharp edges, crevices, skip welds, back-to-back angles all are focal points for failure.

All paints, and particularly many of the more advanced coatings, are complex chemical mixtures that must react in place on the surface over which they are applied. Paints and coatings contain a number of interacting ingredients: resins, plasticizers, curing agents, pigments, extenders, catalysts, fungicides and solvents. These are applied to the surface as a very thin film, a few micrometers or thousandths of an inch in thickness. The solvents must evaporate properly. The non-volatile portion of the liquid coating must deposit in a continuous even film over the surface. It must adhere to and possibly react with the surface. It also may react with internal curing agents, with oxygen from the air or with water from the air in order to become an insoluble, relatively inert film of low permeability which has good appearance. This thin film must then withstand rain, wind, the sun's rays, humidity, cold, heat, oxidation, physical abuse, chemicals, biodegradation and other forces. With all of the variables involved in the formation and use of paints or coatings,



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it is obvious that there can be many causes for coating failures.

The common causes for paint or coating failure which are listed above will be taken up individually.

I. SELECTION OF THE COATING SYSTEM

The primary requirement of a coating system is that it shall resist deterioration by the environment in which the coating is to serve as a protection for a substrate. Since no one coating, or type of coating, is resistant to all environments (atmospheric, aqueous, or chemical), many types of coatings have been developed for service under special conditions and for application by various methods. Selection of a paint from among these many types can be made intelligently only on the basis of the following factors: the known performance of coatings in similar applications, the known chemical composition and physical properties of the paints, and the results of exposures of the coatings under consideration to test environments simulating the conditions of use.

Of these factors, the best basis for critical judgment of the relative suitability of a paint system is previous experience with the performance of that coating. Nevertheless, actual first-hand observations of the serviceability of a coating can be misleading if the new environment in which the paint is to serve is dissimilar or if the composition of the paint has been modified. Knowledge of the chemical and physical properties of a coating (e.g., acid and alkali resistance, heat resistance, abrasion resistance, etc.) is a selection aid but should not be the sole basis for final selection.

If the durability of a coating has not been proved in

field tests or by service in commercial uses, the paint should be evaluated by accelerated tests. However, it must be emphasized that evaluation by accelerated tests should be used cautiously and then only for comparison purposes. The results of such tests must not be valued too highly unless there is correlation between their results and the observed performance of the paint in actual use. Unfortunately, correlation between the results of accelerated tests and performance during service is usually not available.

A source of information by which to select a coating is the manufacturer of the paint or the supplier of materials for paints. Yet, such information can be incomplete or misleading if a precise description of the conditions to be met is not given to the persons whose advice is sought or if the basis on which their recommendations are made is not disclosed to the potential user of the coating. Selection of paint on the basis of price only or on the unsubstantiated opinion of a salesman can prove to be extremely costly.

Mixing of paint systems is often practiced by persons with limited knowledge of coatings, usually as a matter of expediency. This can result only in costly failures. The compatibility of one coat with another is extremely important to the satisfactory service life of a paint. Generic types of coatings should generally not be mixed unless recommended by the manufacturer, nor should the products of one manufacturer be mixed with that of another. Only the manufacturer can know the true compatibility characteristics of the paint system which he has developed and is recommending. Selecting parts of paint systems from different manufacturers or from different generic types without basic knowledge of the products is almost a guarantee of failure.



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II. COATING FAILURES WHICH ARE INHERENT WITHIN THE COATING ITSELF (FORMULATION RELATED)

There are many failures of coatings due to the basic formulation, the resins used, the pigments or the many other ingredients used in coatings. The relation of the inherent coating failures to coating classes should be considered: i.e., those based on organic materials and those based on inorganic vehicles.

A. ORGANIC COATINGS, FORMULATION-RELATED FAILURES

1. *Chalking*

With chalking, the organic binder in the coating tends to gradually disintegrate on the surface releasing the pigments and allowing them to remain on the surface as powder or chalk. This is strictly a surface phenomenon. While in some cases it can result in rapid reduction in coating thickness, it is generally a relatively slow process and one which does not result in catastrophic failure or severe corrosion to the substrate. Chalking, or powdering, is primarily caused by the action of the actinic rays of the sun on the organic binder. Permanently shaded areas seldom chalk. Humidity and oxygen from the air also play a part in this phenomenon.

The resins that make up the binder are the key to the chalking rate. As an example, many epoxy coatings have a strong tendency to chalk. Properly formulated, they chalk minimally; however, there have been epoxy formulations that chalk at a sufficient rate so that a coating of eight or ten mils thickness can be reduced to the point where the primer is visible in a one-year period. On the other hand, acrylic, silicone, and polyurethane resins are only slightly affected by the sun's rays, and

a coating system formulated from these may remain in a chalk-free condition for several years.

Pigments also play a very important part in the chalking reaction. Some pigments, such as anatase titanium dioxide, chalk very readily and rapidly, while most rutile titanium dioxide pigments are very resistant to chalking. Many pigments tend to catalyze the chalking reaction. Some black pigments will chalk after a short period of time, while others will remain for years with little surface effect. Iron blue pigments tend to bronze as the first step in their chalking process.

The influence of pigments on chalking is not all bad inasmuch as they tend to reduce chalking by shielding the resin from the sun's rays. Aluminum pigmentation is an excellent example of this type of shielding. The shingle effect of the leafing aluminum flake pigment prevents the sun's rays from penetrating to the coating vehicle. Almost any coating vehicle is more resistant to chalking when formulated with leafing aluminum pigment.

The use of the newer resins, such as the acrylics and aliphatic polyurethanes, combined with chalking resistant pigments and the use of coating additives, such as ultra-violet absorbers, has resulted in paints and coatings which remain free of any surface change or change in gloss over a period of several years.

The chalking reaction has been one used by a number of manufacturers to produce coatings with self-cleaning properties. When chalking is properly regulated through the prudent selection of the coating binder and the pigments, the chalking reaction can be controlled to the point where the surface erodes slowly, but at a sufficient rate to keep the surface free from any grime or dirt which might otherwise accumulate from the atmosphere. In these cases, the reduction in thickness is uniform and relatively constant so that sufficient coating remains to fully protect



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the surface over a number of years. Chalking may result in some color change and a reduction in gloss of the coating, and such factors must be considered in selecting a product.

Of all the types of coating failure that can occur, chalking can be considered preferable to the rest. A clean, chalked surface, which is free from other types of failure or corrosion, is considered a satisfactory surface over which to apply additional coats of paint for maintenance.

2. Erosion

Erosion is a type of failure caused by the wearing away of the coating down to the base surface or to the primer. This wearing away of the surface may be related to the above chalking mechanism. On the other hand, it may often be aggravated by the surface being exposed to heavy rainfall, hail, high winds or a combination of high winds and rain. Sand erosion of the coating caused by high winds and sand, such as encountered in beach areas or in the deserts of the west, cannot be considered in this same category since such erosion may be catastrophic from one storm.

Erosion is often seen in brushed coatings where the high ridges of brush marks are exposed because of the greater erosion of the raised area. Erosion of this type can best be prevented by the selection of a chalk resistant coating as described above and one which tends to flow out to a very smooth film.

ASTM-D 662 describes degree of erosion of exterior paints. ASTM-D 821, describes degree of abrasion and erosion. ASTM-D 913 describes degree of chipping of traffic paint.

3. Checking

Checking is an age-related failure of a coating. It is characterized by uneven and generally nonlinear, non-continuous breaks in the coating. These breaks are primarily a surface phenomenon and do not penetrate the full depth of the coating. Checking can be characterized as “visible” if the checks can be seen with the naked eye, or “microscopic” if they can be seen only under low magnification.

There can be several causes of checking. It is generally a formulation problem, which results in surface stresses in the coating. It can occur when solvents evaporate very rapidly from the surface and cause the surface to shrink more rapidly than the body of the coating. It can be caused by resins which oxidize on the surface or by certain pigments which apparently catalyze the checking reaction on the surface. Essentially, it is a stress set up in the surface, which causes the small checks to appear while the body of the coating is not subject to the same reaction. Wetting and drying, heating, cooling and sunlight exposure may all contribute to the checking of a coating.

While initially the checks in a coating do not penetrate, if the coating is left without maintenance, the coating will eventually break down by further checking in the same area until the checks become cracks and the underlying surface is exposed. Checking is prevented primarily in the selection of the coating. A coating formulated with weather resistant resins should be selected, with pigments that do not contribute to checking and with reinforcing pigments that aid the coating in resisting surface stresses.

ASTM Standard D-660-44, reapproved 1976, provides a standard method for the evaluation of the degree of checking in exterior paints.

4. Cracking

Cracking is also an age-related failure caused by similar conditions to those described under “checking”. It contrasts with checking in that it is not a surface phenomenon



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but one where breaks in the coating penetrate to the underlying surface. This makes it a much more damaging type of failure than checking, since corrosion can rapidly take place at the breaks in the coating. It may occur in an irregular pattern where the coating stresses are rather uniform. It may be linear, following brush marks or even some spray patterns, or it may occur in a curved pattern with the crack meeting and intersecting in a rather typical form. A surface such as wood that rapidly expands and contracts can contribute to cracking. Excessive thickness of coatings can also cause cracking because of increased stresses on drying or curing.

Cracking is a formulation defect which can be overcome by the use of proper weather resistant resins and pigments plus the addition of two additional ingredients that help materially to reduce the interior stresses within the coating. One of these is reinforcing pigments. Such pigments are fibrous or acicular and act very much like chopped glass fibers in reinforced plastics. They definitely add physical strength to the coating film. The second is a permanent plasticizer or soft, compatible resin that increases the elasticity of the coating. Increased reinforcing and elasticity both reduce the physical stresses caused by weathering, heating and cooling or wetting and drying.

Coatings made from oxidizing materials such as oils or alkyd resins, or internal curing resins such as epoxies, are often susceptible to this type of failure since they continue to cure, become more brittle and shrink with time. Fully polymerized materials, such as vinyls, acrylics and chlorinated rubbers, when properly formulated, are less susceptible to cracking since they continue to cure, become more brittle and shrink with time.

ASTM Standard D 661 provides a method for the evaluation of the degree of cracking in exterior paints.

5. Alligatoring

Alligatoring can be considered a macro-checking failure and is caused by internal stresses set up within and on the surface of the coating. The stresses cause the surface of the coating to shrink much more rapidly and to a much greater extent than the body of the coating. The strong surface stresses, because of the shrinkage, tend to create very large checks in the surface that do not penetrate to the substrate. These can be caused by rapid polymerization of the resin on the surface, rapid oxidation of the surface of the coating or a very rapid release of solvents or volatile plasticizers from the surface.

As an example, some air drying or chemically cured coatings, when applied over a cold surface and then heated on the coated surface to speed the drying, often alligator. Such a reaction may be found on coating the interior of tanks or tank cars. This is caused by shrinkage of the surface while the body of the coating, because of the cold metal, does not change at the same rate as the coating surface. Basically, it is a physical phenomenon whereby the coating surface hardens and shrinks at a much faster rate than the body of the coating itself. It may also be caused by the application of a very strong, tough, hard top coat over a softer, more resilient primer. In this case, the undercoat flows and moves, as the top coat tends to shrink.

It is almost a rule of thumb that a hard, tough top coat should never be applied over a soft undercoat. Asphalt and coal tar coatings are often subject to this phenomenon. The surface hardens due to weathering while the body remains soft. It may also occur where oxidizing coatings are applied over an asphalt or a coal tar base. Thick coatings are also more subject to this reaction. While thickness is reduced in the checks of the alligator pattern, sufficient thickness may remain to protect



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the substrate for some period of time. As stated under “checking”, failure will eventually take place in the checks due to the reduced cross section of the coating in these areas.

Where a material is used that may result in the alligator type reaction, a coating with strong reinforcing pigments or fibers should be selected. Thin coats should be applied and each one properly dried before the addition of another coat. Care should be taken to prevent the application of a hard coating that oxidizes or requires polymerization for cure over a permanently softer and more rubbery one.

6. *Mud-Cracking*

Mud-cracking can be considered a macro-cracking phenomenon where the breaks in the coating usually go down to the substrate. In this way, it is a much more dangerous failure than alligatoring. It can cause immediate corrosion and result in the chipping and flaking of the coating from the surface. It is not a common failure of organic coatings that are properly formulated for weather exposure. It may occur where coatings are very highly filled and where they are applied to a surface that dries the coating extremely rapidly.

Mud-cracking is often a phenomenon of water base coatings and improperly cured inorganic zinc-rich primers. Because most water base coating materials are emulsions or dispersions, very rapid drying prevents the resin particles from coalescing into a continuous film. By contrast, where the resins are dissolved in a solvent, a true solution exists and the resin is in a continuous phase as the solvent evaporates. Mud-cracking can be prevented by proper formulation to prevent the too

rapid drying of water base coatings and by the use of reinforcing pigments. Mud-cracking can also be prevented by satisfactory drying conditions, by application of the coatings in thinner films and by elimination of sags or puddles where rapid drying could cause this type of failure. Ethyl silicate zinc-rich primers will mud-crack if applied too thick (over 6 mils). This generally is caused by the lack of moisture (too low humidity). Thus, a heavy film would not allow moisture to penetrate and properly cure the zinc-rich primer.

7. *Wrinkling*

Wrinkling is the formation of furrows and ridges in the surface of a paint system. It occurs when the surface of the paint film expands more rapidly during drying than does the body of the paint. It is proportional to the thickness of the surface layer that dries more rapidly than the body of the paint film and to the difference between the drying rates and the expansion of the surface layer and the main body of the paint.

Wrinkling results from a formulation failure and is most common with oil base paints or alkyds containing driers that increase the rate of drying. Driers serve two general purposes: to dry the surface of the paint, and to dry the body of the paint film; that is, surface driers and body driers, respectively. Cobalt compounds are a common type of surface drier; zinc and lead compounds are classified as body driers.

Ordinarily, paints are formulated so that the drying process proceeds at the same rate on the surface and in the body. However, when a paint contains an excess of surface driers, the surface of the paint will swell by absorption of oxygen and will wrinkle. Such a reaction depends on air temperature, surface temperature and coating thickness. Excessive thickness aggravates the wrinkling process, since the body of the paint cannot cure sufficiently to resist the change in volume of the paint surface. The temperature



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of cure can influence the rate of wrinkling. Paints that cure without wrinkling, at normal temperatures, may wrinkle if curing is accelerated by baking. Also, if the amounts of surface driers and body driers are balanced for curing at a given temperature, a paint may wrinkle at a higher temperature, because the increase in the temperature tends to cure the surface more rapidly than the body of the paint.

To prevent wrinkling, make certain that air-oxidized or air-reacting coatings are properly formulated for the conditions under which the coating will be applied. Where wrinkling of a coating appears to be a problem, the coating should be applied in a thin, even film with no areas of excessive thickness such as runs or puddles.

8. Microorganism Failure

Both bacteria and fungi can cause coating failure. They primarily attack biodegradable coatings where the fungus or bacterium derives their energy from the materials making up the coating. Oil type coatings, alkyds, polyamide epoxies and coatings using biodegradable plasticizers are most often affected. On the other hand, coatings made from vinyl chloride acetate resins or chlorinated rubber coatings using non-biodegradable plasticizers have excellent resistance to biological attack. One example of the comparative resistance of two similar coatings is in their exposure to sewage conditions. A polyamide epoxy may rapidly disintegrate due to bacteria or fungi attack under severe sewage conditions. On the other hand, a polyamine epoxy can remain unaffected under the same exposure. A fungus attack often occurs on the north or shady side of a structure under damp, humid conditions. A coating under these conditions turns grey or green, with black splotchy areas over the surface.

In these areas, a 10-power glass reveals fungus growths acting on and within the coating. Prevention of such attack is primarily by formulation of the coating.

Fungus attack is reduced or completely eliminated in oil type coatings by the addition of zinc oxide, fungicides, bactericides or a combination of the three to the formulation. In non-oil type coatings, such as pure epoxies, vinyls or chlorinated rubbers, plasticizers or modifiers should be nonbiodegradable.

ASTM-D-3274 describes degree of surface disfigurement by fungal growth or soil and dirt accumulation.

9. Discoloration

Because appearance may be as much a function of a coating as its corrosion resistance, coatings that change color after application and become unsightly can be considered to have failed. This type of failure is, of course, one based on formulation and arises from a number of causes.

Many of the resins used to formulate coatings contain unsaturated photosensitive groups, which, on exposure to sunlight, cause darkening, yellowing or other discoloration of the vehicle. Vinyl chloride-acetate coatings, as an example, if used as clear coatings will turn dark brown or even black within a few weeks of exposure to sunlight. Some epoxy resins tend to yellow as do some of the more resistant polyurethane resins. Proper pigmentation to shade the basic resin from sunlight is one of the prime methods of preventing discoloration.

Often, however, pigmentation is not sufficient. Coatings subject to strong sunlight and weather conditions should preferably be formulated with silicones, acrylics or aliphatic polyurethanes in order to reduce any possible color change to a minimum. Many pigments can also cause color change in a coating. Some orange pigments



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are color reactive and darken. Certain yellow pigments tend to grey and whiten. Lead pigments are particularly susceptible to attack in sulfide atmospheres and turn dark or even black. Iron blue pigments tend to bronze or turn brown. Obviously, these pigments should not be used in formulations where the appearance of the coating is important and where it is exposed to severe weather conditions.

10. Sulfide Discoloration

This is the staining of the film by hydrogen sulfide. Hydrogen sulfide attacks paints containing lead or mercury turning them gray or black in patches or streaks. Exposure of copper base anti-fouling paints not only turns them black but can inactivate the copper causing them to foul rapidly. This often occurs in contaminated water.

This blackening may be distinguished from mold growth by treatment with dilute hydrochloric acid; disappearance of the blackening indicates the presence of sulfide.

When repainting or painting in hydrogen sulfide areas, use paints that do not contain mercury, lead or copper pigments or lead driers. If emulsion paints are used for repainting, it would be necessary to remove any undercoats, containing lead or mercury.

B. INORGANIC COATINGS, FORMULATION-RELATED FAILURES

Inorganic zinc coatings also have some inherent failures because they are made primarily from silicate vehicles and metallic zinc.

1. Checking

Inorganic zinc coatings are particularly subject to

checking if the formulation or the application are not proper. These coatings are highly filled with powdered metallic zinc and other pigments. The ratio of the pigment to a relatively low viscosity binder is high, and under these conditions, rapid drying can cause the surface checking of the coating.

Many formulations contain fibrous pigments to help prevent checking as well as special solvents and silicate binders to aid in controlling the drying rate. The tendency to check can also be improved or prevented by proper application. The coating should be applied as thinly as is practical, with a second pass if necessary to reach the recommended thickness. As rapid drying increases the tendency to check, application should be under controlled temperature conditions or under less severe drying conditions, i.e., applying it under cover, or when in the open, in the early morning or late afternoon. The application conditions established by the manufacturer should be closely followed.

Since checking is a surface phenomena and does not extend through the coating, it is much less of a problem with inorganic zinc coatings than with organic coatings. As long as the adhesion of the inorganic zinc is unimpaired, the fine checks will gradually fill with zinc reaction products and the effectiveness of the coating will be maintained. Evaluation of checking is covered by ASTM-D 660.

2. Mud-Cracking

Mud-cracking, because the breaks extend through the coating to the substrate, is a more serious problem than checking. Adhesion is often impaired with the coating flaking from the surface. Mud-cracking is primarily a problem of excessive thickness where the thickness exceeds the manufacturer's recommendations. It is found, for the most part, in runs or puddles or where heavy overlapping occurs.



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The reason for this type of failure is similar to the reason for checking. The volume of the pigmentation is high compared to the volume of the vehicle in the dried film. Where applied in excessive thickness, the volatile ingredients in water base zinc-rich coatings evaporate rapidly with shrinkage taking place throughout the coating before any chemical reaction can occur. Such areas will eventually pull themselves away from the surface and chip or flake.

To eliminate or prevent this problem, apply the coatings in relatively thin films (not over the maximum thickness recommended by the manufacturer).

Heavy coats (over 6.0 mils) tend to mud-crack. For ethyl silicate zinc-rich primers, mud-cracking is caused by lack of moisture needed to cure the coating beneath the surface of the film.

3. Chemical Resistance

Obviously, coatings containing zinc, organic zinc coatings, inorganic zinc coatings or galvanizing should not be used alone or without top coats in a strongly acidic atmosphere. Because of the zinc in the coating, acid attack is rapid and the coating would be subject to failure. Under these conditions, galvanizing would tend to fail faster than the inorganic zinc coatings, inasmuch as the zinc in the inorganic coating is partially protected by the silicate matrix. Strong alkali will tend to react with the silicate vehicle as well as with the zinc at pH values above 10.

4. Pinpoint Rusting

Zinc coatings, either galvanized, inorganic zinc or organic zinc, normally fail at the end of their useful life by pinpoint rusting. This occurs primarily in areas that are thinner

than the remainder of the coating, starting with an isolated pinpoint of rust showing here and there in these thin spots. As time goes by, the pinpoints will become closer together, and finally, at the time of full failure, the spots of pinpoint rust will be almost continuous and general over the entire surface.

Such failure usually occurs after many years of service, even under marine atmospheric conditions. While this type of failure can be expected, it can also be prevented by proper maintenance and repair of the thin areas that first show failure. ASTM Standard D 610 provides a method of evaluating rusting. A maintenance coat of inorganic zinc may be applied over itself or over galvanizing at the time of the first indication of failure. Light abrasion of the surface by hand sanding or brush blast is necessary for proper adhesion of the maintenance coat.

5. Pitting in Seawater

Inorganic zinc coatings or galvanizing immersed in seawater may pit after exposure of from 12 to 24 months. This phenomenon occurs because of the reaction of some of the salts in the seawater with the surface of the zinc to such an extent that the surface becomes insoluble and no longer provides zinc ions to protect the steel surface from corrosion. Normally, zinc coatings provide cathodic protection to the steel surface; however, as the chemical reaction from seawater takes place on the surface of the zinc, the surface becomes inert, although it is still conductive. Under these conditions, since zinc ions are no longer available, the zinc coating becomes cathodic and the holiday or break becomes an anode. When this happens, pitting will take place where breaks occur or where there are sharp edges, abrasion or holidays. Pitting can be prevented with a compatible and proper organic coating system over the zinc, wherever it is exposed to seawater immersion.



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TABLE 1
A SUMMARY OF FORMULATION-RELATED FAILURES

COATING FAILURES	FAILURE APPEARANCE	CAUSE OF FAILURE	REMEDY
Organic Coating Failure			
1. Chalking	Surface soft and powdery. Easily removed by wiping surface.	Surface disintegration by actinic rays of sun on the organic resin binder; improper pigmentation.	Select coatings formulated with radiation resistant resins (acrylics) and non-catalytic, high hiding pigments.
2. Erosion	Similar to chalking. Surface removed on high spots and brush marks to base coating or primer.	Chalking mechanism with coating surface removed by weathering and abrasion.	Select a tough chalk resistant coating with a good flow out to a smooth film.
3. Checking	Surface phenomena – uneven, small, non-continuous fissures in coating which do not penetrate to the substrate.	Surface stresses caused by shrinkage due to weathering and continued coating polymerization and oxidation.	Select coating formulated with weather resistant resins and inert reinforcing pigments in addition to non-catalytic colored pigments.
4. Cracking	Small breaks in coating to substrate. May be linear, cross-hatched, or curved. Cracks may or may not be continuous.	Stress set up in coating due to continued polymerization and oxidation.	Select coating formulated with weather resistant resins and inert reinforcing pigments in addition to non-catalytic colored pigments.
5. Alligatoring	Very large macro-checking, generally cross-hatched pattern.	Internal stresses where surface shrinks more rapidly than body of coating. Hard top coat applied over soft undercoat.	Apply thin coats and thoroughly dry before adding additional coats. Never apply hard top coats (epoxy) over soft undercoats (asphalt).
6. Mud-Cracking	Large macro-cracking. Coating may curl at cracks and lose adhesion.	Rapid drying of highly filled coatings, especially water based materials (water emulsion paints)	Use coatings with strong adhesion. Apply coatings under proper drying conditions and prevent sags, puddles or areas of excess thickness.
7. Wrinkling	Furrows and ridges in coating surface. May be linear or random pattern. Wrinkle may be fine or quite large.	Surface reaction where surface of coating expands more rapidly during drying than does the body of the film.	Choose coatings with even, thorough drying characteristics. Apply evenly, avoid excessive thickness.
8. Microorganism	Softening or slime reaction of coating. Blotchy brown or black spots on coating surface causing poor dirty appearance.	The biodegradation of the coating by bacteria or fungi. The coating is used as a source of nourishment.	Use oil paints which contain permanent fungicides or bactericides. Non-oil coatings should use non-biodegradable modifiers.
9. Discoloration	Yellowing, greying or darkening of coating	Resin or pigment color change due to weather or chemical action.	Select coating formulated with both color stable resins and pigments.
Inorganic Coating Failure			
1. Checking	Usually fine visible or microscopic checks. Do not penetrate to the substrate.	The zinc pigment to binder ratio is high – rapid drying conditions cause surface checking.	Formulation should include reinforcing pigments. Apply coating as thin as recommended. Second coat, if necessary, Apply under favorable drying conditions.
2. Mud-cracking	Fine to fairly large segments (¼") flaking from surface.	Application of coating too heavy. Rapid drying conditions.	Apply coating at no more than recommended thickness. Apply under favorable drying conditions.
3. 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.
4. Pinpoint Rusting	Pinpoint spots of corrosion progressing from a few per square foot to almost continuous.	Uneven coating thickness – thin coated areas show first failure.	This is normal failure pattern for inorganic zinc coatings. Apply maintenance coat at first sign of pinpoint failure.
5. Pitting in Seawater	Strong anodes (rust tubercles) 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.



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III. ADHESION-RELATED FAILURES

1. *Blistering*

Blistering is one of the most common forms of adhesion related coating failure, particularly where the coating is immersed in water, seawater or other liquids. It can also occur in areas of high humidity where there is continuing or intermittent condensation on the surface.

Blistering is caused by gasses or liquids within or under the coating that exert pressures stronger than both the adhesion and the internal cohesion of the coating. This allows the coating to stretch and to form the hemispherical blister. The blister will generally increase in size until the tensile strength of the coating is greater than the internal pressure. If the pressure is greater than the tensile strength, the blister will break. This is often the case where a brittle coating with little extensibility is involved. After the blister breaks, frequently the substrate will be readily attacked, causing rust.

There are several forces that contribute to the formation of the liquid or gas underneath or within the coating. In addition to strength of adhesion the key to most blistering is the moisture-vapor transmission rate of the coating. Each coating formulation has its own characteristic moisture-vapor transmission (MVT) rate, the rate at which molecular water passes through the inter-molecular spaces in the coating. Any area of poor adhesion will tend to accumulate moisture or moisture-vapor at the interface between the coating and the substrate. Moisture-vapor in this area creates a vapor pressure that causes blisters to form.

Generally, coatings with the lowest MVT rate (the greatest resistance to the passage of molecular water through the coating) will have the least tendency to blister. Table 2 lists some typical MVT rates for several of the common coating types. It must be stressed again that these rates are for specific coating formulations and do not necessarily indicate a positive relationship between coating types. Permeation is influenced by film thickness, coating pigmentation and means of application.

TABLE 2
MOISTURE VAPOR TRANSMISSION RATES
OF CHARACTERISTIC COATING TYPES

Coating Type	Permeance Perms ¹	Test Thickness Mils	Grams/100 sq. in./ 24 Hours
Epoxy polyamide	0.16	8.0	0.17
Amine catalyzed epoxy	0.19	7.5	0.30
Vinyl Chloride-acetate	0.31	5.5	0.83
Vinyl acrylic	0.54	5.0	0.83
Alkyd (short oil)	2.4	5.0	3.70

¹Perms = grains of moisture/ 1 hr./ sq. ft. / P (in. of Hg)

As blistering is an adhesion-related failure, there is a general rule of thumb that applies: a coating with excellent adhesion, even with high MVT, will have a low tendency to blister. At this point, it should be stated that there is no correlation between the moisture absorption of a coating and the moisture-vapor transmission rate. Moisture absorption is the amount of molecular water which is held within the molecular structure of the coating. There are some coating materials which may have a rather high moisture absorption but which do not have a high moisture-vapor transmission rate. The converse is also true, there is one synthetic resin material which has zero water absorption, yet has an extremely high MVT rate. This being the case, moisture absorption is not necessarily a good measure of the blistering tendency of a coating.

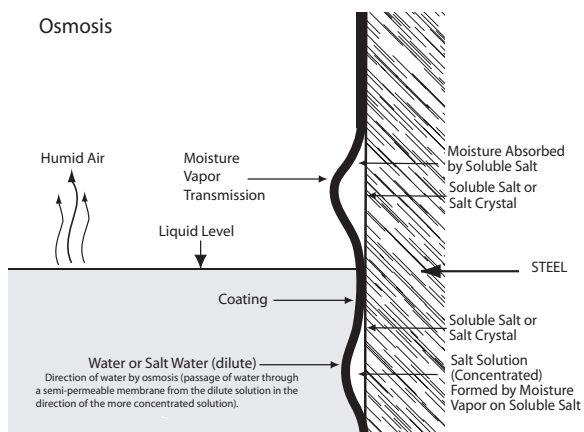
Osmosis also contributes strongly to the transmission of



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water or moisture through a coating. Osmosis occurs when moisture vapor passes through a semi-permeable membrane from the water solution having the lesser concentration to the one with a higher concentration of dissolved solids.



As an example, if a coating were applied in a marine atmosphere to a piece of steel having a salt deposit on the surface, and if after the coating were applied and dry the steel were subject to immersion, moisture would be forced through the coating from the water on the outside of the coating to the salt crystals on the underside of the coating. The salt crystals would absorb a small amount of moisture in the beginning, creating a solution with a high concentration of salt. Osmotic pressure is created by the moisture vapor, which has passed through the coating from the more dilute side to the more concentrated side of the membrane. The pressure built up on the underside of the coating may be quite high (several ounces/sq. in.). Moisture vapor being forced by the osmotic process through a coating with poor adhesion can cause blisters to form. But coating may have adhesion stronger than the osmotic pressure that develops and thus will not blister.

Osmosis can also cause blistering if water soluble materials are incorporated into the coating itself. Oftentimes, primers contain inhibitive pigments having a degree of water solubility, for instance, zinc yellow or zinc chromate. This pigment is an excellent inhibitor of corrosion; on the other hand, if a primer made with zinc chromate is top coated and immersed, blistering will often result. In this case, because of the solubility of the chromate, osmosis conditions are set up within the coating itself forcing water to the area where the soluble chromate is located. Coatings formulated with such soluble pigments should not be used for immersion purposes.

Table 3 lists several chromates that have been used or are presently being used in coatings. The ones with the lowest solubility are preferable from the standpoint of resistance to osmosis and blistering.

TABLE 3
SOLUBILITY OF CHROMATE PIGMENTS

Pigment	Grams of CrO_3 in Solution In 1000 CC. Water @ Equilibrium 25°C
Calcium Chromate	17.0
Zinc Yellow	1.1
Strontium Chromate	0.6
Basic Zinc Chromate	0.02
Barium Chromate	0.001
Lead Chromate	0.00005

Another blister forming process is that of electro-osmosis. In this process moisture vapor or molecular water is forced through the coating by an electrical current in the direction of the electrical pole with the same charge as the coating. Most coatings are negatively charged, and if the underlying metal surface is cathodic, or has a source of negative electrons, moisture is then drawn through the coating towards the negative pole. Under these conditions, if there are areas of poor adhesion, blisters form readily. Incidentally, this process has caused coatings on structures subject to excessive cathodic protection to blister away from the surface. Cathodic potentials in



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excess of 1.0 volt cause many coatings to blister and lose adhesion. Coated pipelines in wet soil conditions have often shown this type of failure.

Blistering most often results from poor surface preparation or applying a coating over a dirty, greasy, moist or contaminated surface. Such a surface is the cause; osmosis or electro-endosmosis is the process that makes it take place.

A coating can also blister when it is used as a lining and is subject to a warm water solution, with the steel substrate being considerably cooler than the liquid (for example, an uninsulated tank containing liquid at a higher temperature than the outside air). In this case, the moisture passes through the film, and because the steel surface is cooler than the vapor, it condenses underneath the coating causing blistering.

Another cause of blistering is entrapped solvents. These are solvents that remain in the coating for some period of time, usually by solution in the coating resin. If the temperature of the coating system is raised and the rate of diffusion of the solvent vapor through the film is slower than the rate of formation of the vapor, then blistering will take place.

Many coatings that dry rapidly on the surface are subject to this type of blistering, particularly where applied in the sun or on a heated surface. When the pressure exerted by the solvent vapor becomes greater than the adhesion of the paint, blisters will be formed and will increase in size until equilibrium between the pressure and the strength of the film is established. If the pressure becomes greater than the cohesive strength of the film,

the blisters will break.

Blistering due to entrapped solvents is common when baked finishes are used. It can be avoided if the coating is prebaked at a temperature high enough to drive out all the solvent but not high enough to cure the surface of the paint before the solvent is removed. After most of the solvent has evaporated, the baking temperature can be increased to cure the paint completely.

Blistering can be caused also by hydrogen absorbed in the surface of the steel during pickling, that is, during the process of removing rust and mill scale before the surface is coated. If, after the coating has been applied, the temperature of the coated object is raised, this hydrogen will leave the metal; and, if the rate of hydrogen evolution is more rapid than the rate of diffusion of the gas through the paint, pressure areas will be formed at the metal-paint interface. When the pressure of the gas under the coating exceeds the force of adhesion between the two surfaces, the paint will be lifted off the metal in blisters. After pickling steel plate or shapes, hydrogen can be eliminated by heating the steel prior to applying the coating. Preferably the coating should be applied while the steel is still warm. There is a strong tendency for some coating materials to blister on cast iron. Cast iron is much more porous than steel and contains gases that expand, particularly when heated. Coatings applied even to clean, sand blasted cast iron, when it is cold, often blister as the temperature increases. If the cast iron is heated sufficiently to release the gases and the coating is applied to the cast iron while it is still warm, blistering will not occur.

Chemical exposure often causes blistering and loss of adhesion of coatings, particularly where a coating may be subject to volatile acids such as acetic acid, hydrochloric acid or nitric acid. These volatile materials can penetrate

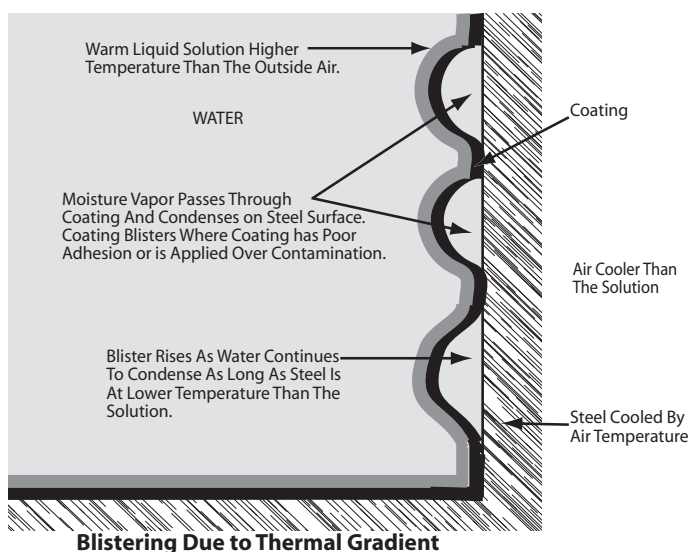


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the coating and react with the underlying metal surface. With moisture vapor always present, a strong acid solution is formed that not only has a strong osmotic pressure, but also is strongly reactive with the metal surface, creating hydrogen gas. Acetic acid is a good solvent for many coating materials, but its presence increases the probability of blistering.

Blistering conditions can best be prevented by using a coating with very strong adhesion characteristics and a low moisture-vapor transmission rate and applying the coating over a perfectly clean surface. The best surface is perfectly clean and white-metal blasted (SSPC-SP 5). It has been proven by many tests and hundreds of actual coating applications that (with all exposure conditions being equal) proper surface preparation can reduce blistering to a minimum or completely prevent it. ASTM Standard D 714 provides a good method of describing the degree of blistering of paints.



2. Peeling

Peeling is a coating failure usually caused by a coating having a tensile strength greater than its bond strength to the surfaces. This was a common early-day cause of vinyl coating failure. It has been overcome by vinyl primers now having superior bond strength when they are applied to clean - preferably abrasive blasted - surfaces. Any coating will peel or pull from the surface if it has less adhesion to the substrate than it has tensile strength, or if it reacts adversely with the substrate over a period of time, thus substantially reducing the adhesion.

3. Flaking and Scaling

These two types of failure are adhesion-related. Flaking is a term describing a condition where small pieces of coating detach themselves from the surface of the substrate. Its edges are generally raised up from the surface and the small pieces can be rather easily removed, leaving the bare substrate.

Flaking is quite common on wooden surfaces and tends to occur after oil paints have oxidized for a period of years. It is a common sight on fences and old wooden buildings. Flaking also occurs on metal surfaces, particularly those which have been galvanized. Alkyds or oil type paints applied to galvanized surfaces eventually age and oxidize to the point where the film shrinks sufficiently to pull itself away from the surface. There can also be an interfacial chemical reaction creating a zinc soap between the organic coating and the zinc substrate, which causes loss of adhesion and flaking.

Scaling is similar to flaking, except that the pieces that break away from the surface are much larger. This is a common type of failure on coated, galvanized surfaces. Pieces of coating several inches in diameter may crack due to aging stresses, curl and come off in large flakes. Scaling can also occur where a new coat is applied over



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a very old, well oxidized coating. The adhesion between the two surfaces, where surface preparation is poor, is low and the top coating on aging will tend to curl and to scale.

The prevention of flaking and scaling is primarily one of surface preparation. Clean surfaces, with a good anchor pattern, combined with a coating that has strong adhesion and good aging characteristics will prevent this problem. ASTM Standard D 772-47 (reapproved 1975) is a standard method for the evaluation of the degree of flaking and scaling of exterior paints.

4. Intercoat Delamination

This is the failure of one coat to adhere to an underlying coat, whether applied as one coat following the other or where the top coat is applied as a maintenance coating after some period of time. The cause is generally within the coating itself. Air-reactive coatings, either those that require oxygen or moisture for cure, or coatings that react internally by the action of catalysts or reactive resins are subject to this type of failure. Compatibility of one type of coating to another is essential.

In the case of air-reactive coatings, either by the absorption of oxygen or water, the surface becomes rapidly insoluble and dense. In the case of internally reactive coatings, the entire coating becomes insoluble and dense. In both cases, the coatings are insoluble in the original solvents in the liquid coating. Solventless coatings are also subject to intercoat delamination. The second coat should be applied over the first after the initial set of the first coating, but before that coating has been completely cured either by internal or exterior forces.

The temperature of application is also critical. Since the curing reactions are temperature-dependent, the higher the temperature, the more rapidly the second coat should be applied over the first. Manufacturer's instructions should be closely followed where internally or externally cured coatings are used. Polyurethanes, epoxies, coal tar epoxies and oxidizing coatings are subject to this type of failure. Where catalyzed epoxy is applied at low temperatures, an exudate may remain on the surface causing incompatibility with subsequent top coats.

Coal tar epoxy coatings have special problems of intercoat delamination. In addition to the normal internal curing of the coating, external forces also create intercoat delamination. Even though the curing of the coating has not progressed to the point of insolubility, if the coating is subject to condensation, rain, or moisture prior to the application of the second coat, intercoat delamination is probable. Also, if the coal tar epoxy coating is applied in the sunlight, even though the coating has not reacted to the point of insolubility, intercoat delamination may occur due to the heat and actinic rays of the sun, causing the surface to cure beyond the point where good adhesion between the two coats can result. Whenever any of the above phenomena occur and the second coat is applied over an insoluble coat, there is a positive interface between the coats. When water or moisture penetrates to the interface, any apparent adhesion between the two coats is lost, causing delamination to occur.

Lacquer-type coatings, such as vinyls, acrylics or chlorinated rubbers are not as subject to this type of failure as are the reactive type coatings. Lacquer-type coatings are permanently soluble in their own solvents, thus allowing the second coat to dissolve into the first coating, reducing the chance of any interface forming between the two coats.



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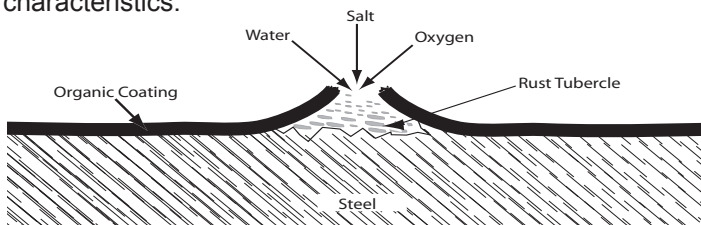
An additional major cause of intercoat delamination is the contamination of the first coat before the application of the second. Moisture, dust, fumes, chemical fall-out, oil and grease all can cause this result. The method of prevention is obvious: prevent the contamination from reaching the coating during application. Where this is impossible, particularly when applying coatings to structures or tanks subject to fallout from adjacent plants or adjacent operations, very fast drying lacquer coatings, vinyls or acrylics, if applicable from a corrosion standpoint, should be used. The second coat should be applied as rapidly as possible following the first to provide good results.

One of the preferred methods of preventing undercutting on steel surfaces is the application of an inorganic zinc coating as a permanent primer before the organic coating is applied. The inorganic binder reacts chemically with the steel, providing very tight adhesion and preventing the undercutting which is characteristic of most organic paints or coatings. This coating system has been successful on hundreds of millions of square feet of surface exposed to extreme marine or industrial conditions.

5. Undercutting

Undercutting is another type of adhesion failure that involves the gradual penetration of corrosion underneath the coating from a break or pinhole in the film or from unprotected edges.

Undercutting often occurs when a coating has been applied over mill scale. Moisture and oxygen penetrate the coating and react with the scale causing it to lose adhesion and thus form progressive corrosion beneath the coating. The application of coatings over a very smooth, dense surface where adhesion is critical also creates a condition inviting this type of failure. Most of these undercutting failures can be substantially reduced by proper surface preparation prior to the application of the coating and the use of a coating with strong adhesion characteristics.





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TABLE 4
SUMMARY OF ADHESION – RELATED FAILURES

COATING FAILURES	FAILURE APPEARANCE	CAUSE OF FAILURE	REMEDY
1. Blistering	Minute ($1/32$ ") to large (1"+) hemispherical bubbles in coating containing gas or liquid. May range from 1 per square foot to several hundred per square foot. See ASTM std D 714-56 (revised 74)	Blistered coatings have adhesion problems due to poor surface preparation, internal soluble materials or poor wetting of substrate. Osmosis, electroendosmosis, gases absorbed into the metal surface or solvent entrapment cause blisters to form.	Select a coating with very strong adhesion characteristics and a low moisture-vapor transfer rate. Apply to a clean, abrasive blasted surface with care.
2. Peeling	Coating may be smooth and lying on surface or it may be hanging in shreds. Little or no adhesion is evident.	Adherence is less than the tensile strength of the coating. When broken the coating can easily be pulled from the surface leaving the original surface of the substrate. Coating may react with substrate and lose adhesion. Coating usually flexible.	Select a coating as outlined under blistering.
3. Flaking or Scaling	Small ($1/16$ ") to large (1"+) pieces of coating, curling at the edges-easily removed from the surface leaving bare substrate.	Coating usually brittle with internal shrinkage characteristics in addition to marginal adhesion. Oil type coatings may scale or flake from a galvanized surface.	Select a coating as outlined under blistering. For galvanizing use a primer compatible with zinc.
4. Intercoat delamination	The top coat does not adhere to the undercoat. It may lie on surface, blister, flake or peel.	The top coat is not compatible with the undercoat; the surface of the undercoat may be contaminated; the undercoat may be over-cured to complete insolubility.	Select coatings with good compatibility and adhesion between coats. Make certain undercoat is clean before application of the second coat. Do not expose coal tar epoxy coatings to water or excessive sunlight before overcoating.
5. Undercutting	Corrosion tends to build up under coating, at breaks, edges or holidays; corrosion is progressive under the coating.	Poor adhesion due to surface contamination, a very smooth surface or lack of compatibility with the surface.	Select a coating with very high adhesion. Apply over a clean, abrasive blasted surface. Using inorganic zinc coatings as a first coat reduces undercutting.



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IV. FAILURE DUE TO THE SUBSTRATE

The substrate is not often considered as being a major factor in the failure of protective coatings, but it is extremely important. The common surfaces that need to be considered are steel, aluminum, zinc, copper, concrete and wood. Each of these have a very different effect on the coating. One coating may be very effective over one surface and completely ineffective over another.

An example of this is the coating of steel surfaces for exposure to sodium hypochlorite. Even though the coating applied may be completely pinhole free, because of the breakdown reaction of the sodium hypochlorite on aging into nascent oxygen and sodium chloride, coatings applied over a steel surface generally last only a very short period of time. Nascent oxygen will penetrate the coating and react with the surface underneath the coating. Tubercles are formed which break the coating, allowing corrosion to proceed very rapidly. On the other hand, if the same coating were applied over concrete, long life could be expected because the concrete itself is unaffected by the nascent oxygen. While this is rather an extreme example, it nevertheless demonstrates the importance of the substrate to the life of the coating.

Steel may be the best and the easiest surface over which to apply a coating. It is a very dense, and essentially non-porous material; therefore, a coating can be applied over it as a continuous film with relative ease. While the steel surface is reactive, it is less so than many other surfaces over which coatings are applied, and most coatings or paints adhere reasonably well over a clean dry steel substrate.

Coating compatibility with the steel is not as critical as it can be with other materials.

To assure consistently good coating life, abrasive blasting of steel is recommended to remove all contamination and oxidation and to increase the surface area for maximum coating adhesion. SSPC-Vis 2 provides a standard for evaluating the degree of rusting on painted steel surfaces. This standard is also available as ASTM-D 610.

Concrete, on the other hand, is a chemically active, non-uniform, porous surface filled with water and air pockets, thus making a surface that is very difficult to a paint properly with a continuous coating. In addition to a very variable surface, it is sensitive to moisture, and when the moisture is confined under a coating, a pH of up to 13 may be encountered. Only a very inert, highly alkali-resistant and penetrating coating can be expected to perform satisfactorily.

The problems of coating a concrete substrate to obtain a failure-free coating are primarily physical. The surface is variable with the most consistent concrete being a hard, steel-troweled surface (sidewalk finish). This surface is preferred for coating. However, because it is often glazed due to the troweling action, the glaze must be removed by acid etching (1 part commercial hydrochloric acid and 5 parts water followed by a clean water wash) or a light brush blast for consistent coating adhesion. A poured concrete surface is the most difficult of all surfaces over which to apply a consistent, uniform, pore-free coating. All surface imperfections, air pockets and pinholes must be eliminated. The surface must receive a coat of cement plaster, hard troweled as described above, or a resinous concrete surfacer must be applied which will fill all the concrete surface imperfections, have some penetration into the concrete for maximum adhesion and provide a smooth, pore-free base for the subsequent coatings. Both of the above methods are applicable for the best coating service under difficult conditions. Where concrete or stucco



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surfaces are coated for decoration only, such surface treatments may not be required.

Aluminum generally has a dense, smooth surface with a tight aluminum oxide coating on the surface. While this surface is relatively stable, it can cause adhesion problems for some coatings. Where there are breaks, particularly under alkaline conditions, undercutting and even perforation of the metal may occur.

Copper provides a dense surface with a copper oxide film over it. Many coatings fail to obtain proper adhesion to this surface. In many ways, it is similar to aluminum, although it is not as reactive a surface so that coating failure is not as prevalent. The failure of many effective coatings is caused by these types of smooth, dense surfaces. A light dust blasting with used sand or very fine sand and low pressure air will break up the surface, increase the surface area and allow adhesion that cannot be obtained by any other means on either of these two types of surfaces.

Zinc is a more reactive metal than aluminum, which is the reason for its use as a galvanic coating. Galvanizing and inorganic zinc coatings have proven to have a very long life in many atmospheres. In spite of this, under certain marine or highly humid conditions, when used as a base coat, zinc may react under the top coat producing a voluminous white corrosion product. This causes coating failure by white salts of zinc corrosion that completely undercut the coating and lift it from the surface.

There are also coatings that react with the various alkaline zinc hydroxides to form zinc soaps. These are oil paints or alkyd coatings and are not recommended for direct application over galvanizing or inorganic zinc. Top coats for zinc surfaces should be inert, thoroughly compatible

with zinc, have high adhesion and a low MVT rate. Certain vinyls, epoxies and chlorinated rubbers work well. Zinc also has a smooth surface; however, once it is oxidized by exposure to the atmosphere for a period of several weeks or months, the smooth surface tends to disappear, providing much better adhesion. If a new galvanized surface must be coated, it should be lightly dust blasted, as indicated for the aluminum or copper surfaces, or it should be chemically treated with a zinc surface treatment (commercially available) prior to coating.

Wood has its own inherent characteristics which cause coating failures. It is very moisture sensitive and will swell during times of high humidity and shrink when conditions are dry. This dimensional change can take place on a daily cycle, in addition to climatic changes which occur over longer periods. Wood has two types of surfaces: that provided by very dense winter grain and the rather porous, soft summer grain. This is very characteristic of woods such as Oregon pine, cedar, ash and many other open-grained woods. Maple, birch and woods which are very dense are somewhat less of a problem, although both types of surface, i.e., summer and winter grain, are present. These grains tend to expand and contract at a different rate due to varying humidity and temperature, and any coating which is applied over these surfaces and which will not expand and contract with them, will tend to fail rather quickly along the grain boundaries.

Any coating which is applied over a surface must be thoroughly compatible with that surface, must have strong permanent adhesion to it and must not chemically react with it. Unless the coating has these capabilities, failure is inevitable.

The failure of a coating over a used surface is much more probable than when applied over a perfectly new, original surface. This has been proven many times. As an example, tanks in the west Texas oil fields, where sulfides



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are a problem, have been repaired by the use of new steel sheets. The entire surface of the tank was then sand blasted to white metal and the coating applied with equal care over the new and the old surface. In a matter of just a few months, the coating applied over the old surface failed, while it was still completely effective over the new steel.

This same phenomenon occurs aboard ships where corrosion has taken place on steel plates. It occurs in chemical tanks and on the exterior of structural steel bridges. This problem occurs to the greatest extent on steel surfaces and in areas where severe corrosion conditions exist. The previous use of the steel must be taken into consideration in order for the coating to be effective. The problem is the retention of very minute quantities of corrosion product in the rough corroded areas of the steel, and when the contamination is not completely removed, they continue to react with the moisture vapor which can penetrate the coating, causing early failure in the previously corroded area.

There are two methods that can be used to improve this situation. 1) After the original blasting, react the surface with a dilute phosphoric acid solution (5%), allow it to dry, and then re-blast the surface. This procedure produces a reaction that allows the minute amounts of corrosion product to be removed on the second blasting. 2) The second procedure, where an inorganic zinc coating can be used as a permanent primer, is a very satisfactory one. The inorganic zinc coating tends to react with the minute amount of corrosion product on the surface, eliminating its corrosive tendency, and at the same time to react with the steel surface to provide a very strong chemical bond. Following the application and cure of

the inorganic zinc, the required top coating can then be applied.

Do not underestimate the problems involved with used steel surfaces. Untold failures of coating have occurred because this problem of prior use was not recognized. Used aluminum and zinc surfaces are less of a problem. However, care should be taken whenever a surface has been subjected to serious corrosion.

Wood and concrete are definitely affected by previous use. Both can absorb and retain soluble or reactive materials, which if not removed prior to the application of the coating, will cause blistering, lack of adhesion and coating failure. The density or smoothness of a surface over which a coating is applied is extremely important. As an example, cold rolled steel is much more difficult to coat than hot rolled steel with the mill scale removed. Cold rolled steel has an extremely dense, smooth surface, and it has proven in the laboratory many times that a coating applied over such a surface compared to a coating applied over a sand blasted, cold rolled surface will fail much faster when both are subject to the same conditions. The problem, of course, is that the very dense, smooth surface does not allow the same quality of adhesion of the coating as does the one that has been roughened and that allows mechanical adhesion in addition to normal wetting of the surface.

Cleanliness of the surface is vitally important, of course to the life of any coating. It is a rule of thumb that any coating applied over a perfectly clean surface will last longer and be more effective than the same coating applied over a lesser surface. This applies to metals, concrete and wood to the same degree. It also applies to the repair and maintenance of coatings as well as to original coating installations.



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TABLE 5
SUMMARY OF SUBSTRATE – RELATED FAILURES

COATING FAILURES	FAILURE APPEARANCE	CAUSE OF FAILURE	REMEDY
1. On Previously Used Steel	Blistering, rust, tubercles, loss of adhesion in areas where steel was previously exposed to corrosive conditions.	Retention of minute amounts of corrosion product or contaminant on the steel surface, even though blasted to white metal.	Wash blast surface with water or dilute phosphoric acid solution and reblast. Apply an anticorrosive primer with strong adhesion. Where applicable, and inorganic zinc primer may react with the minute surface corrosion after first blasting and provide a base coat.
2. On Galvanized or Metallic Zinc Surfaces	White zinc corrosion product forming under the coating or actually breaking through the coating.	Formation of zinc salts (oxide, sulfide, oxychloride, zinc soap), underneath coating.	Brush blast zinc surface or treat with commercial zinc treatment. Apply a non-oil base, inert strongly adherent primer.
3. On Aluminum	White corrosion product causing pinpoint failure in coating- loss of adhesion because of very smooth surface. Possible blistering.	The very smooth aluminum oxide surface. No physical adhesion.	Very lightly dust blast the aluminum surface, or where applicable, treat with commercial aluminum treatment. Apply a primer with known compatibility and strong adhesion to aluminum surface.
4. On Copper	Grey-green corrosion product, loss of adhesion, blistering.	Very smooth copper oxide surface. No physical adhesion.	Brush blast copper surface or etch with commercial copper treatment. Apply a primer with known high adhesion to copper.
5. On Wood	Checking and cracking of coating. Flaking from hard winter grain. Blistering of dense coatings with a low MVT rate due to absorption and evaporation of moisture from the wood.	Expansion and contraction of wood due to varying temperature and humidity. Differential expansion of the grain. Very hard dense winter grain combined with soft porous grain, causing a variation in coating adhesion.	Start with clean, newly sanded wood surface. Apply low molecular weight, highly penetrating paint, preferably oil base, with sufficient elasticity to expand and contract with the wood surface. Paint should have relatively high moisture porosity to allow wood to breathe.
6. On Concrete	Blistering of coating. Formation of calcium salts under coating, forcing coating from the surface. Loss of adhesion and peeling.	The chemical reactivity and moisture content of concrete. Its non-homogeneous, very porous structure. Pinholes, water and air pockets in poured concrete surfaces.	The concrete should be clean and the surface dry. It may be acid etched or lightly blasted to obtain proper surface condition. Use a low molecular weight, highly penetrating primer with strong alkali resistance (liquid epoxy). Primer should be heavy body and thixotropic to fill imperfections in concrete surface.