Painting Over Soluble Salts: A Perspective

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One of the most important goals of coating and corrosion protection programs is to provide the most economical protection of structures. Numerous surveys and statistics have depicted the consequences of neglecting or scrimping on surface preparation, coatings application, materials, or inspection. It is, however, equally evident that we cannot afford “gold-plated” corrosion protection and coating projects. For example, the commonly used term “cadillac system” may be a poor description for the inorganic zinc-rich/epoxy/urethane system, because it conveys the impression that this is the best system money can buy rather than one of the most economical long-term protection systems.

As we gain a better understanding of corrosion processes and the influence of coatings, we learn how to use resources more effectively. For example, over the past 10 to 20 years, there has been a general recognition of the overriding importance of proper surface preparation for long-term durability. Continuing research, though, has led to refinement of some of the concepts regarding surface preparation. The “best” surface preparation is not necessarily the most desirable. For example, careful studies have demonstrated that white metal blasting (SSPC-SP 5) is not always the preferred method, but that commercial (SSPC-SP 6) and near-white metal (SSPC-SP 10) may give equivalent performance at a much lower unit cost. Another area where earlier approaches have been modified is in specifying surface profile. Most coatings specialists now recognize that lower profile (on the order of 1 to 2.5 mils) is entirely acceptable for most coatings systems. The old rule of thumb, that a profile of 1/3 the total thickness of the coating system was needed to “anchor” the coating, has been displaced.

Thus, as our knowledge base grows, we are better able to focus our attention and our resources on factors that count the most. Other examples of areas in which additional investment has proven worthwhile are better defining of inspection requirements and improved training of inspectors, now available through NAACO and other sources.

Background on Soluble Salts

In recent years, many specialists have called attention to the subject of nonviable contaminants on steel. Of most concern are water-soluble salts such as chlorides, sulfates, and nitrates, which are deposited on the steel surface by acid rain, marine spray, and chemical splash and spillage.
Recall that the definition of blast-cleaned surfaces (e.g., SSPC-SP 5, 6 or 10) includes the phrase “surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, millscale, rust, paint, oxides, corrosion products, and other matter.” Thus, these standards do not address the non-visible contaminants described above. In fact, results have shown that abrasive blast cleaning, even to white metal, will not necessarily remove these contaminants from the surface.

It has also been well documented that soluble salts, particularly chlorides and sulfates, initiate and accelerate corrosion of steel, and become deeply embedded within the iron corrosion products. They are also capable of causing breakdown of the coating by the mechanism of osmotic blistering. A large number of basic and empirical studies have been undertaken to gain a better understanding of how these substances are deposited on the steel, how they catalyze and effect the corrosion process, and how they interact with coatings.

For those individuals concerned with the practical side of the technology (e.g., end-users, contractors, specifiers, and inspectors), however, the crucial question is “How do these salts affect the performance and economics of commonly used corrosion-protective coatings systems?”

In this article, we will address this general question by considering the following related questions.

- What is the evidence of the effects and impact of soluble salts? Are they, in fact, a significant factor for the protection of steel?
- What techniques are available for detecting and identifying these contaminants?
- What techniques are available to remove them or negate their effects?
- What levels of soluble salts are permissible on steel to be coated?

The article is intended to be a general review of the technology, not a comprehensive survey of all the data and techniques. As will be seen, there are gaps and uncertainties in our knowledge in each of the four areas above. Thus, another purpose of this article is to identify areas requiring additional research, development, and evaluation, and to encourage various organizations to conduct such investigations.

**Evidence for Detrimental Effects of Soluble Salts**

This section describes the various types of general evidence that water-soluble salts are an important factor in the degradation of protective coatings on steel.

Protection of steel is already an extremely demanding, difficult, and expensive operation. The introduction of another variable that must be controlled, monitored, and specified will add to the burden of those responsible for protection. SSPC, NAACO, and other organizations must therefore develop strong evidence and documentation that such measures are warranted and cost-effective.
The argument that soluble salts are a major problem rests on three premises, as follows.

- Water soluble salts are deposited on structural steel surfaces.
- Residual levels of these salts cause corrosion and paint degradation.
- These salts are not adequately removed by standard surface cleaning techniques.

**Deposition of Salts on Surfaces**

The evidence for these salts being deposited on structures is hard to contest. Polluted air containing oxides of sulfur and nitrogen have been causing problems in this country for decades. Increased acidity (lower pH) of rainfall has been recorded in almost every city and county in the US; and, in fact, the Environmental Protection Agency (EPA) is sponsoring a special research program to investigate the impact of acid rain on painted metals, which is considered one of the most serious economic consequences of acid rain. Another contaminant that will be characterized, sodium chloride, is obviously present in marine atmospheres and deposited on bridges and vehicles as a result of de-icing salt.

A comprehensive study has identified and quantified a number of species, including sulfates, chlorides, phosphates, nitrates, sulfides, and a variety of metallic ions. Research sponsored by the Federal Highway Administration demonstrated that test panels exposed in industrial and marine sites accumulated substantial surface deposits of sulfates and chlorides, respectively, in less than 6 months.

**Effect of Salts on Corrosion and Coatings**

These salts can affect the performance of coatings systems on steel in two different manners: by accelerating the corrosion of the steel, and by promoting blistering and loss of adhesion of the coating.

The reactions of steel with chlorides and sulfates have been recognized for many years. In fact, the categorization of atmospheres is based largely on the amounts of these two atmospheric constituents; industrial environments are characterized by pollution composed mainly of sulfur dioxide and other sulfur compounds, whereas a marine atmosphere is one characterized by fine particles of sea salt in droplets carried by the wind to settle on exposed surfaces.

Numerous studies have shown the pronounced effect of sulfur dioxide pollution and chlorides on corrosion rates of steel. One study showed that the presence of both chlorides and sulfates caused increased weight loss of steel, which was proportional to the amount of chloride or sulfate present. Further studies have demonstrated that sulfate and chloride participate directly in the corrosion reactions of steel. A detailed discussion of the reactions and mechanisms is, however, beyond the scope of this article.
Chlorides and sulfates are not the only salts that affect corrosion. Most salts also have the effect of increasing the rate of absorption of moisture from the atmosphere by lowering the threshold relative humidity for condensation. In addition, any soluble salt, together with condensed water will form an electrolyte, which furnishes the medium for completing the electrical circuit in the corrosion of steel. Soluble salts under coatings have been shown to promote blistering in various theoretical and experimental studies. A coating behaves as an impermeable membrane; thus, it allows moisture but not salts to penetrate. This produces exactly the conditions required for osmotic blistering; the water, passing through the coating, attempts to dilute the soluble salts so that the concentrations at the interface (location of soluble salt) and the coating outer surface (which has little or no salt) are equal. Numerous other studies have shown that the growth of blisters is directly related to the concentration of salt on the surface.

There is also a vast amount of empirical and practical evidence to support the laboratory and theoretical studies cited above. Numerous corrosion and coating authorities have observed and reported on early failures and reduced lifetimes of coatings applied over previously rusted steel. This effect is acknowledged to result from the reactions of the soluble salts, primarily chloride and sulfate. The phenomenon of “rust-back” of a freshly blasted surface in a moderate to high humidity environment has been universally observed. Cathcart reported approximately a 50 percent decrease in repaint lifetime of lining systems; he attributes this primarily to surface contamination by soluble salts that are not removed by blast cleaning. Munger has reported that chloride contamination of steel surfaces has caused untold coating failures around the world “and is one of the reasons why corroded areas in the marine industry are so difficult to recoat.” McKelvie has noted that iron chlorides and sulfates are prevalent in maintenance situations whenever substantial rusting of the substrate has taken place.

Thus, it is clearly established that soluble salts deposited on the surface can increase both the corrosion rate and the paint breakdown rates for many systems currently in use.

The third question, whether the conventional cleaning methods will adequately remove these soluble salts, is addressed in the next section.

**Methods for Removing Soluble Salts**

A variety of methods has been used over the years to prepare steel for painting. These have generally been judged on their ability to remove corrosion products, produce a profile, and to create a **visually clean** surface.

The presence of soluble salts (i.e., the chemical cleanliness) has not been addressed by most owners or specifiers, nor has it yet been included in industry surface preparation standards.
The International Standards Organization (ISO) is currently developing a method for detecting soluble salts.\textsuperscript{24} The NAACO has published a state-of-the-art report.\textsuperscript{25} SSPC has evaluated numerous techniques for detecting soluble salts, and it is anticipated that in the near future there will be both a US and an international standard.

Commonly used surface cleaning techniques differ widely in their effectiveness in removing soluble salts from the surface. A brief overview of these techniques and their expected success in removing soluble salts is given below. A more thorough discussion, including review of some recent detailed evaluations, will be published in a forthcoming issue. A partial review of removal techniques was given by Morcillo\textsuperscript{26} and the NAACO report.\textsuperscript{25}

**Solvent Cleaning**

The use of organic solvents will not ordinarily remove water-soluble contaminants. However, as described in the SSPC Surface Preparation Commentary (SSPC-SP Com, November 1, 1982),\textsuperscript{27} solvent cleaning also encompasses use of alkaline cleaners, emulsion cleaners, and steam cleaning. Each of these includes water as one of the cleansing agents, and therefore is capable of removing substantial quantities of the water-soluble salt. As noted earlier, in order to dissolve the salt, the water or steam must penetrate and wet the surface containing these salts. Otherwise, the procedure will simply remove the soluble salts on the surface of the rust layer and not the salts embedded in the rust. There may well be some benefits from even this surface rinsing, but the long-term properties have not yet been determined. Alkaline, emulsion, or steam cleaning over blast-cleaned steel would be expected to have some beneficial effect in removing soluble salts.\textsuperscript{28}

**Hand Tool Cleaning**

Morcillo\textsuperscript{26} and Yannas\textsuperscript{28} have shown experimental evidence that hand tool cleaning is very ineffective in removing soluble salts, even from the surface layer of rust and scale.

**Power Tool Cleaning**

Conventional power tool cleaning (power wire brushes, disc sanders) is probably not much more effective than hand tool cleaning in removing soluble salts. These tools provide only mechanical cleaning, and any rust or scale remaining after cleaning is likely to retain soluble salts deposited during the formation of the rust.

The recently developed profiling type power tools (see article on page 84) are certainly more efficient in removing the corrosion products than the conventional tools. There is some evidence\textsuperscript{29} that some of the non-woven discs are capable of producing a chemically clean surface; however, further evaluation of this technique, using the procedures described above, is needed to corroborate this effect.
**Dry Abrasive Blast Cleaning**

Blast cleaning is a mechanical removal technique that is not designed to remove the small micro-crystalline salt particles deposited on steel. Numerous instances have been cited where contamination remaining in the steel after blast cleaning quickly darken, and within a short period, start to re-rust.\(^\text{30}\) Repeated and continual dry blasting will eventually erode the steel to the point where the corrosion products are removed from the pits, but this can add appreciably to the cost of cleaning a surface, particularly if such pits are prevalent.\(^\text{23}\)

**Effect of Abrasives**

It has been claimed that use of smaller sized abrasives would be more effective in reaching and cleaning out narrow pits in steel. One study\(^\text{31}\) showed that fine grit (240 micron diameter) left 20 micrograms per square centimeter of ferrous sulfate on the surface, compared to 120 micrograms per square centimeter for a coarse grit (1 mm diameter). Again, additional experimental verification of such effects is needed before this technique can be recommended.

In some instances, abrasives themselves may contain water-soluble contaminants that can be embedded or deposited onto the surface being blast-cleaned.\(^\text{32}\) This can result from exposure to the atmosphere, or in the case of slag abrasives, from quenching in salt water. The ASTM and SSPC are currently working on simple tests to evaluate the water-soluble salts on abrasives.\(^\text{33}\)

**Addition of Water**

Rinsing the surface with low-pressure water after dry blasting does remove a proportion of the soluble salts.\(^\text{31}\) It is a possible alternative to the wet and water blasting techniques described below.

**Wet Abrasive Blasting**

The technique of adding water to air abrasive blasting has been claimed to provide improved removal of soluble salts.\(^\text{34}\) The action of the water would certainly seem to have the capability of dissolving salts that would otherwise be unaffected by the dry blast. Some preliminary work by SSPC has shown that wet blasting can significantly reduce the level of soluble salt on blast-cleaned surfaces.\(^\text{35}\) How these reduced levels affect coatings performance has not yet been verified.

**Pressurized Water Blasting**

Use of medium to high-pressure water jetting (3,000-10,000 psi) is also claimed to remove substantial portions of the soluble salts.\(^\text{34,36}\) In many cases, however, pressurized water by itself does not remove tight rust and millscale, and thus the salts that are embedded in the under layers of the corrosion and within the pits of the steel will not be removed.
Ultra high pressure water jets (20,000-40,000 psi) offer great promise for removing soluble salts from steel surfaces because of the increased capacity to first remove the tightly adhering rust and mill scale layer.

The introduction of abrasives into the pressurized water stream facilitates the removal of tight rust and millscale and can produce commercial, near-white, or white metal surfaces. This technique is also expected to be superior to dry blasting in removing soluble salts; but again, the quantitative data on the completeness of removal and the effects on subsequent coating performance are not yet available.

The above evidence strongly suggests that commonly used surface preparation techniques do not eliminate potentially detrimental soluble salts from surfaces to be coated. It is also evident that additional laboratory and field evaluations are needed to determine the effectiveness of conventional and new techniques and materials in removing the contaminants from the various types of surfaces encountered.

In order to assess these various surface treatments, a means is needed to evaluate the cleanliness of the surface attained.

**Techniques for Identifying and Detecting Soluble Salts**

This section reviews the procedures for identifying and detecting soluble salts on surfaces. These materials are normally deposited in quantities too small to be detected with the unaided eye. A British Maritime study\(^{19}\) has noted that at levels exceeding 0.75 milligrams per centimeter squared, crystalline deposits can be noticed, but this quantity is so high as not to be appropriate for practical situations.

In order to establish an analytical procedure, it is first necessary to determine precisely what chemical species are of concern. The two substances receiving the most attention have been chlorides and sulfates. Gross\(^{15}\) has identified additional species that were deposited on bridges throughout West Germany.

Over the last 15-20 years there have been major efforts directed at developing both laboratory and field techniques for detecting and quantifying the amount of the following salts on bare steel or on coated surfaces:

- soluble chlorides,
- soluble sulfates,
- soluble ferrous salts, and
- total soluble salts by conductivity.

The question is not simply one of removing or extracting the surface layer, or of cutting out a section of steel and analyzing it. One must also be concerned with the location and distribution of the chemical species within the oxide layer, the pits, and the steel matrix. Thus, how to sample the
surface becomes an important question. Sampling procedures will be
discussed subsequently.

**Soluble Chlorides**

Several specific techniques have been developed for analyzing chloride
ions, some of which can be accomplished in the field. One technique, which
has been used primarily as a laboratory reference method, is the selective
ion electrode. The technique also requires a specific ion analyzer and
calibration against known standards. This method is capable of measuring
chloride concentrations down to about 1 ppm. The equipment is sufficiently
portable for field use; however, the delicacy of the equipment, the need for
stable conditions, and the expense would tend to limit its use in this area.

A semi-quantitative field technique involving use of paper chromatography
has also been developed and implemented by several organizations. The
chromatography strips are normally dipped into a solution containing the
unknown chloride. In one case (Quantabs) the level of chloride is
determined by the degree of elution (wicking) on the paper strips. The
Quantab strips are sensitive only down to 40 ppm chloride. In the
Aquaquant method, one compares the color with a standard color chart to
establish concentration. The former technique has proven to be more
practical and reproducible and is the basis for a commercially available test
kit. Recent work has focused on evaluating a reportedly more sensitive
test strip. Chloride can also be detected using silver nitrate or silver
chromate. This is a very sensitive reaction and is the basis for the Saltesmo
test papers.

**Soluble Sulfates**

As with other chemical species, a number of analytical techniques have
been developed for detecting sulfate in the laboratory. These involve
measurements of quantities such as scattering or turbidity and would not be
very suitable for routine evaluations of field specimens. The South African
Bureau of Standards (SABS) has developed a test method for qualitative
detection of soluble sulfate. The filter paper is soaked in barium chloride
solution and pressed onto the steel surface in the presence of potassium
permanganate solution. Pink spots on the barium chloride paper indicate
the presence of soluble sulfates. This technique is reported sensitive to less
than 1 microgram/sq cm, but is difficult to quantify. Starr and McKelvie
have described alternate tests using barium complexes, but little further
work on these methods has been reported.

**Soluble Ferrous Salts**

As noted previously, sulfates and chlorides not only act as electrolytes, but
also react with steel to form ferrous sulfate and ferrous chloride,
respectively. These ferrous salts are concentrated at the bottom of pits and
become responsible for the localized “rust-back” that occurs on blast-
cleaned, pitted steel exposed to atmospheric moisture.
Thus, it is of great interest and importance to detect the presence of ferrous salts in steel to be painted, as they represent points at which accelerated corrosion and premature coating failures may occur.

**Rust-Back Test**

Ferrous salts in pits of steel will readily absorb moisture from the atmosphere and cause a localized darkening of a blast-cleaned steel surface. Thus, one indication of these salts is the occurrence of rust-back within a short time after blast cleaning. This criterion is currently used by many specifications, which stipulate that paint must be applied before any rust-back occurs. However, the general remedy applied if there is any rust-back is to re-blast the surface, which may not remove the salts. Consequently, applying the paints before rust-back occurs will not correct the problem if ferrous ions are in the pits. Thus, a more reliable means of detecting these contaminants may be required.

**Indicator Paint Test**

One technique involves applying a specially formulated white emulsion paint over small spots on the surface. When the paint dries, rust spots are revealed, coinciding with the soluble salts in the pits.24

An instantaneous assessment of the surface may also be obtained by spraying a light mist of water on the steel and/or exposing it to high humidity (for laboratory evaluations).

**Potassium Ferricyanide**

Potassium ferricyanide in the presence of ferrous iron will undergo a reaction to produce potassium ferrocyanide, which produces a color change (dark blue). A solution can be applied directly onto the steel, or paper strips can be tested in a solution obtained from rinsings. It can be used as a go/no-go test, or analyzed further for quantification; but according to Starr it is not sufficiently sensitive to indicate ferrous ion unless the surface is visibly corroded.40

In another variation of this test, the ferrous ion concentration is determined by comparing the color developed on the strip with standard color charts provided. An example of a commercially available method is based on use of Merckoquant strips.39 There is little evidence that these strips are being widely used in the field.

**Dipryridyl Reaction**

Another technique for detecting ferrous ion is based on its reaction with a dipryridyl, which forms a red complex. The method can detect levels of ferrous ion to about 2 micrograms/sq cm but does not give quantitative results.40
Other Water-Soluble Ions

Although laboratory tests are available for detecting species such as sulfide, ammonium ions, and nitrate, we are not aware of any specific field techniques.

Total Salt Concentration by Conductivity

As an alternative to measuring the concentration of specific ions, several groups have chosen to look at the conductivity of solutions of these species. This approach may be justified as follows:

- The presence of any soluble salt is detrimental to paint performance because of the formation of electrolyte and the possibility of osmotic blistering.
- In many cases, the major contaminating species is known or assumed (e.g., sulfate in industrial environments or chloride in marine environments). The primary question for users is the quantity of these contaminants.
- A single test is easier and more practical for field use; it may be possible to establish an upper limit based on the conductivity (i.e., go/no-go test). Alternatively, conductivity may be used as a screening test to determine the need for more specific analyses.

Conductivity of solutions can be measured quite reliably with a small, portable conductivity meter. In the field, these require a source of deionized water, gloves, and other precautions to avoid sample contamination. A field procedure is currently being developed by SSPC as part of a project sponsored by the Federal Highway Administration.35

Sampling Procedures

For any analytical or measuring method, without an accurate and valid sampling procedure, the value of the results may be greatly diminished. In sampling and testing of soluble salts, it is necessary to determine exactly what information is required and how it will be used.

There are several zones within a steel substrate that must be considered. These include the following:

- oxide/scale surface (the outer layer, exposed to the atmosphere, of incompletely removed rust and scale);
- steel surface (the surface of the steel after oxide layers have been removed -often called “bright metal” but containing very thin oxide layer);
- oxide/scale bulk (the aggregate of the incompletely removed scale and oxides); and
- sub-surface steel (pits and other inclusions in the steel)

The specific zone that is sampled and analyzed will depend on the method of sampling. The major procedures of sampling for soluble salts are direct surface treatment, surface rinsing, chemical treatment, grinding and cutting of steel, scraping.
**Direct Surface Treatment**

These methods refer to the application of a solution directly onto the surface to observe or detect certain properties. Examples include the following:

- brushing with a solution of indicator (e.g., potassium ferrocyanide); blue spots indicate the presence of soluble ferrous ion;
- placing an indicator strip (e.g., for chloride or for pH) directly onto the wetted surface to observe a color change; and
- using limpet cells -designed to hold water onto the surface (must be watertight) to allow direct analysis of the solution for conductivity, chloride, or other properties. Several versions have been proposed, but none has yet been demonstrated suitable or made available commercially.

**Surface Rinsing**

This technique consists of marking an area followed by swabbing by a sponge or absorbent wool saturated with deionized water to extract water-soluble materials. Several standard procedures have been developed based on this method.\textsuperscript{24,35,40}

This procedure requires precise definition of the techniques for swabbing, measuring, and handling, and for avoiding contamination.

The solution obtained may be analyzed on the spot (using conductivity meter, chloride strips) or retained for future laboratory or other analysis. For the latter, the possibility of chemical changes, sample contamination, damage, and other changes must be considered.

It is important to recognize that these procedures will extract material only from the exposed outer surface. The water will not penetrate rust or millscale; thus, if there is a substantial layer of corrosion remaining on the steel, the underlying steel surface will not be sampled. Even for blast cleaned steel, the water may not penetrate the bottoms of pits if there is rust in the pits.

**Chemical Treatment**

Sometimes a treatment more powerful than water rinsing may be desired to react with or dislodge soluble salts or their derivatives. A number of such treatments have been evaluated in the laboratory for their ability to remove contaminants from the surface. Examples include application of electric current (to release anodic species), heat treatment (to drive away high-boiling substances such as ferric chloride), and boiling in water (to take advantage of increased solubility and mobility at high temperatures). These techniques, particularly the boiling procedure, may be useful as laboratory reference methods to determine the efficiency and reproducibility of field tests.
Grinding and Cutting of Steel

In some cases it may be desirable to obtain a small specimen of the steel for special investigations. These can be used for laboratory tests such as boiling, chemical treatment, or scanning electron microscopy examination to be conducted on actual field specimens. Cutting of field specimens will generally require a welding torch or similar equipment. Smaller specimens can be obtained by shearing or band sawing. Caution must be exercised to avoid contaminating the surface of interest with cutting oils, fingerprints, or debris.

Scraping

Scraping is used to obtain data on the soluble salt content of bulk corrosion products. In scraping of field specimens, special procedures are needed to prevent loss of the scrapings. One approach is to tape a large polyethylene bag around the area to be scraped, allowing just enough room to insert a hand and scraper. The tool to be used for scraping depends on the thickness and hardness of the scale. Chipping hammers, files, putty knives, and wire brushes have all been used for various applications. Scraping is not a very satisfactory method for obtaining quantitative results, because of the difficulty of removing all the scale in a given area.

For qualitative detection of soluble species, it may be adequate to place the scale samples in deionized water and measure for chloride content, conductivity, or soluble ferrous ion as previously described. However, for any reasonably quantitative data, it is necessary to pulverize the samples, and stir or otherwise agitate the mixture. This will provide rough quantitative estimates of the species of interest.

Progress Realized

As a result of problem-oriented efforts by groups around the world, and the coordinating actions of the International Standards Organization, it appears that suitable techniques are being developed and standardized for quantifying the levels of soluble salts on surfaces. Presently these and other groups are working to establish practical, reliable, reproducible, and inexpensive field techniques. Suitable international and national standards based on these methods are expected to be available in about a year.

Permissible Levels of Soluble Salts

The availability of these techniques makes it possible to evaluate the performance of various coatings applied over differing levels of the soluble salts. This is the crucial information needed by specifiers and owners to design their coating systems. The use of wet abrasive blasting or multi-step cleaning operations may indeed be capable of greatly reducing the level of soluble salts; but is it worth the extra cost and time to achieve that level of cleanliness?
In some cases, painting over contaminated surfaces is unavoidable because of lack of accessibility of cleaning equipment or contamination resulting from the cleaning itself. How severe a penalty must be paid? Will the paint life be reduced by 30 percent, 50 percent, 75 percent? Also unknown are how different generic paint types are affected by these conditions. Certain coatings are claimed to be “surface-tolerant.” Does this tolerance extend to applications over steel with chloride or sulfate corrosion cells embedded in the steel?

Unfortunately, however, hard, quantitative data on these effects are not generally available. Nevertheless, it is instructive to review recent literature describing some of the experiments that have been done to establish performance trends.

Igetoft has reviewed several earlier studies relating corrosion rates and coating life to time and location of exposure. One study showed that the lifetime of an oil-alkyd red lead over steel cleaned to SSPC-SP 5 depended on the initial steel grade (per SSPC VIS-I) as follows: Grade A - 16 years, Grade B - 14 years, Grade C - 8 years, Grade D - 7 years. Similar behavior was observed for a zinc-chromate system. Additional details, including results over hand-cleaned steel, may be found in the original paper. No measurements of soluble salt levels were taken in this experiment.

Igetoft described another set of experiments being undertaken by the Swedish Corrosion Institute. Based on preliminary findings, he recommends that after surface cleaning, chloride levels not exceed 1-2 micrograms/square centimeter and soluble ferrous ion levels not exceed 10 micrograms/square centimeter.

The performance of paints will depend not only on the level of soluble salt remaining on the steel, but also on its location (i.e., in pits or on surfaces) and how tightly bound up it is chemically. Thus, there may be a significant difference in the effect of soluble salts that are evenly distributed on the surface of blast cleaned steel (e.g., from contaminated abrasives) versus iron chloride or iron sulfate complexes that are concentrated at the bottoms of pits.

The major detrimental effect of the uniformly deposited salt particles (surface salts) may be the promotion of osmotic blistering. Early paint failure due to rust breakthrough and undercutting, on the other hand, may well result from corrosion cells arising from salt contaminants in pits.

Coatings Over Artificially “Doped” Surfaces

A few laboratory and test panel evaluations have been conducted by various agencies giving some indication of the magnitude of these effects and factors. Most of the evaluations have primarily addressed the effect of coatings applied over artificially contaminated surfaces. For example, Weldon and Morcillo have evaluated the effects of coatings applied over surfaces containing known quantities of soluble salts added after the blast cleaning. In each of these studies, the primary method of degradation was found to be blistering, presumably caused by osmosis of water through the...
coating membrane. The levels of contaminants used in these studies would provide an indication of the threshold for preventing osmotic blistering.

The levels of chloride and sulfate found by Weldon to produce blistering in vinyl and epoxy coated panels after 4 weeks in a condensing cabinet was about twice the level recommended by Igetoft.

The British Maritime conducted a series of experiments to relate blistering in a series of accelerated and immersion tests to the type and thickness of coating and the level of surface contamination. This method of doping consisted of adding small drops of contaminant onto a very localized area, rather than spreading contaminant solution uniformly across the surface. They found that for full systems of 10 mils or more, no blistering was observed for chloride or sulfate levels up to 50 micrograms per square centimeter. For thin films some blistering occurred at a chloride concentration of 7 micrograms per square centimeter and a sulfate concentration of 16 micrograms per square centimeter.

**Coatings over Naturally Contaminated Surfaces**

Applying coatings over surfaces containing “natural contamination” (e.g., pits) is more difficult experimentally. It is much harder to obtain uniform surfaces and more difficult to determine the level of contamination on the surface. It is first necessary to produce the required contaminated surfaces. For laboratory evaluations, this means exposing the test specimens to an aggressive environment that will produce the required degree of corrosion and pitting.

A study has been reported by Frondistou-Yannas in which small test panels were exposed for about six months in industrial and marine environments. Several experimental coatings were applied over these surfaces following hand tool cleaning and the panels were re-exposed at the original sites. The results showed rapid degradation of almost all the coatings, which was attributed to the soluble salts in the corrosion layer and embedded in the steel.

In some ongoing work by SSPC, contaminated weathering steel (ASTM A588) was obtained from long-term field exposures (i.e., actual bridge specimens) and from accelerated laboratory corrosion simulation testing. The results on the levels of soluble salts measured and the ultimate performance of the coatings applied over these surfaces will be reported at a later date.

**Summary and Conclusion**

The above data demonstrates the complexity of the task of determining specific effects of soluble salts on paint performance. There are a number of important variables, including the method of producing the contamination, the method of detecting the contaminants, the type of contaminant property analyzed, the type and thickness of the coatings applied, the type of exposure environment, and the method of evaluation.
The data presented do not allow us to establish any definitive levels for specific contaminants, but they do provide firmer evidence that these materials are detrimental for coating performance. We can derive some conclusions from the above discussions and define areas where additional knowledge must be sought.

The principal conclusions are as follows.

- Atmospheric chlorides, sulfates (or sulfur oxides), and similar gases or particulates will be deposited on exposed steel.
- All water-soluble salts not removed from steel during surface preparations can produce osmotic blistering of the coating. The extent of blistering depends on the concentration of the salt, the thickness of the coating, and the chemical nature of the coating, as well as the specific exposure environment.
- Chlorides and sulfates react chemically with steel and form corrosion nests or cells that concentrate in the pits of steel.
- These corrosion nests can cause accelerated degradation of the coating system.
- Conventional cleaning techniques, including abrasive blasting, do not remove all these embedded contaminants.
- There are a number of suitable techniques for detecting the levels of the most important soluble contaminants. Standard methods are expected to be forthcoming within the next year or so.
- Alternate surface preparation techniques, principally wet abrasive blasting and pressurized water blasting with abrasives, have shown some capability of removing soluble salts that would be left by dry blasting. Even wet blasting, however, may leave residual salts on the surface. The effect of this improved efficiency of removal on paint performance lifetime has not yet been demonstrated.
- Chloride and sulfate levels of several micrograms per sq centimeter are sufficient to induce blistering in certain types of coatings. These are only very rough guides. Under certain circumstances much higher levels of those contaminants may be tolerated.
- Very little experimental work has been undertaken on performance of coatings applied over naturally corroded and contaminated steel.

**Recommendations**

How do the above findings pertain to the owner or specifier who must decide on the type of surface preparation and coating material for specific types of jobs? Ideally, he would like to know which surface preparation techniques or which coatings can be used to eliminate the problem without further consideration. As a second choice, he would like to know what levels of contamination are detrimental to performance of specific coatings and thus require special treatment. Presently, there is insufficient information to satisfactorily answer either of these questions.

In order to provide answers, the industry must undertake some comprehensive, carefully planned experimental evaluations of the factors mentioned above. Several US government agencies have ongoing or
planned tests to address these issues. These include research projects by the US Navy, the Federal Highway Administration, and the US Maritime Administration. There have also been some special investigations by private industry, many of which, unfortunately, are not published or widely disseminated. Important work is also being undertaken by the International Standards Organization and research agencies in other countries.

The issue of soluble salts is one that no longer can be considered a research curiosity or a specialized occurrence. Soluble salts have a significant effect on the lifetime and hence the cost of coating systems and corrosion protection.

Because of the economic consequences, there is strong motivation for facility owners, coatings manufacturers, and technical organizations to address these issues in a comprehensive, coordinated fashion.

References

38. Quantabs (available from Ames Division, Miles Laboratory, Inc.) have been found suitable for this purpose.
41. Additional information on these products is available from KTA-Tator, Pittsburgh, PA.

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