



## **PAINTING OVER FLASH RUST AND OTHER SURFACE CONTAMINANTS**

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### **ABSTRACT**

It is often said in the coatings industry that surface preparation is the most important part of the job. However, as a practical matter some level of surface contamination is usually present under industrial coatings. It simply isn't cost effective to perform extremely high levels of cleaning in most industrial environments. Identifying the acceptable level of surface contamination is a critical element of any coating specification. It is one of the key cost-benefit decisions an owner can make. Unfortunately there is little good data regarding the service life sacrifices associated with applying coatings over contaminated surfaces. Flash rust, rustback, embedded abrasive, soluble salts, and many other contaminants will interact uniquely depending on the applied coating, service environment, and substrate. This paper will explore the types of contaminants, methods for reducing them, and their impact on coating service life.

Key Words: Surface Preparation, Surface Contaminants, Flash Rust, Coating Performance, Surface Cleanliness

### **INTRODUCTION**

It is often said in the coatings industry that surface preparation is the most important part of the job. Furthermore, it is generally agreed that a cleaner surface will result in better coating performance. While that generalization may be true, there needs to be some consideration of the cost-benefit trade-offs associated with surface preparation. Typically such decisions are based simply on what level of surface preparation an owner can afford rather than a cost-benefit analysis. Unfortunately there is little data on which to base such an analysis.

This paper will primarily concern itself with the performance of industrial coatings applied to steel substrates. No distinction is made between maintenance and new construction. As a practical matter, the type of work and other factors will impact the analysis. The following data has been pulled from studies in published literature where coating performance over varying levels of surface preparation has been studied.

The literature generally provides summarized measures of coating performance relative to the variable of interest. Assuming that the observations follow a normal distribution, an average value may be useful in making generalizations concerning relative coating performance at the time of inspection. However from an engineering standpoint, describing the lifetime afforded by the alternative materials is of more interest. Knowing the average performance rating for 10 test panels does not address this issue. Furthermore, experience tells us that a coating does not completely fail at the same time. Maximum and minimum times to failure may differ significantly from the average.

Lifetime analysis of engineering data is typically modeled using exponential, Weibull, or gamma distributions, to name but a few of the common models. Data are gathered concerning the time-to-failure for specific trials. Failure can be defined using various measured parameters. An analogy might be the medical analysis of a drug treatment in which failure may be defined as anything from inefficacy of the drug to death of the patient. In our corrosion analysis, failure may be defined by any critical parameter of interest, such as cumulative corrosion rust-through, blistering, cutback or deviation in color/gloss. Literature reporting time-to-failure vs. specific criteria is ideal for these analyses. Alternatively, literature providing performance ratings at various time intervals can be used if we apply our own definition of failure.

The paper will address four areas of surface contamination – surface cleanliness, soluble salts, dust and embedded grit, and flash rusting after ultrahigh pressure waterjetting. Where possible, lifetime analysis of the data will be used to attempt to quantify the impact of these surface preparation variables on coating service life.

### SURFACE CLEANLINESS

Surface preparation is commonly specified using one of a series of standards published by SSPC,<sup>1</sup> NACE and ISO which describe various levels of “cleaning.” Key elements of the standards are the surface preparation method identified (hand tool, power tool, abrasive blast) and the allowable remaining material on the substrate. The material remaining on the substrate may be characterized by adhesion (tight versus loosely adherent material), type of material (rust, paint, mill scale) and extent (percent coverage, distribution).

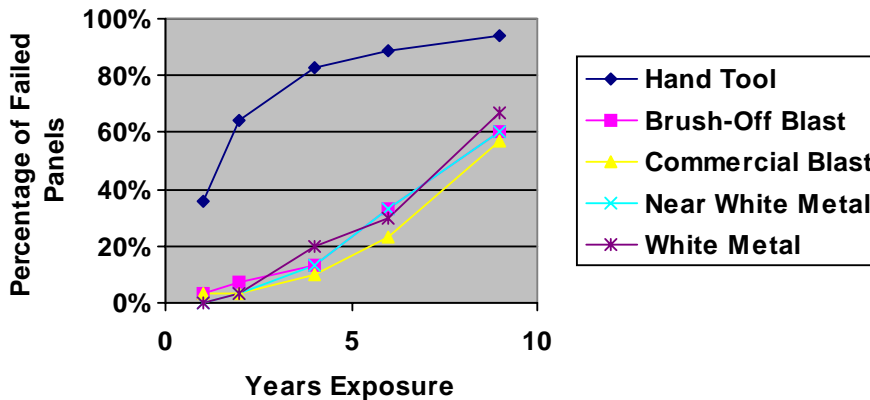


FIGURE 1 shows the probability of failure for five different surface preparations, SSPC SP-2 (Hand-Tool Cleaned), SP-7 (Brush-off Blast), SP-6 (Commercial Blast), SP-10 (Near-White Metal Blast), and SP-5 (White Metal Blast).<sup>2</sup> Failure was defined as the point in time where the coating exhibited an ASTM D 610 rating of 7 or less. A range of coatings were exposed in different atmospheric exposure environments and the number of panels that had exceeded the failure criteria was recorded as a function of time over a 9-year period. Approximately 30 test

panels form the basis for each data point. All surfaces were covered with mill scale prior to hand tool cleaning or abrasive blasting with G-40 grit.

The SSPC SP-2 (Hand Tool) prepared surfaces failed much quicker than the remaining surfaces. The failure rate of the coatings applied over the SP-2 substrate are about 10 times higher for the first 2 years of exposure and are about 1.5 times higher after 9 years. This magnitude of service life reduction is corroborated by work done for the Federal Highway Administration and the U.S. Navy.<sup>3,4</sup>

The superior performance of blasted surfaces versus hand-tool cleaned surfaces is rather unsurprising. A more interesting observation is the lack of performance difference among the various levels of abrasive blasting. The data suggests no statistically significant difference among the various levels of blast cleaning. Given the increased cost associated with a white metal blast versus a brush-off blast, this is an opportunity for significant cost savings. Readers are cautioned that results may vary depending on the nature of the existing structure condition (the surfaces represented here did not have any corrosion present), coating type and exposure environment (immersion or chemical exposure will be different than atmospheric exposure), and mode of failure (cathodic disbondment, blistering or corrosion undercutting versus rust-through). Clearly, more data on the performance of coatings over “less-than-ideal” surfaces needs to be developed.

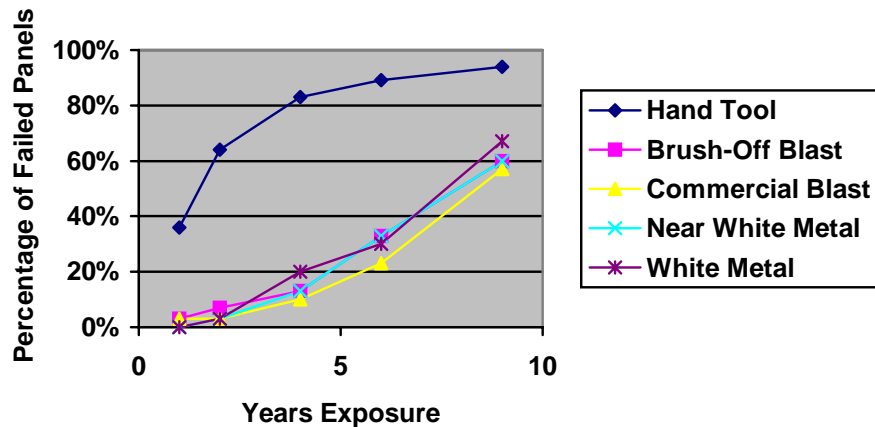


FIGURE 1 - Effect of Surface Cleanliness on Atmospheric Exposure Performance

### SOLUBLE SALTS

It has been long understood that salts on the surface will impact coating performance. Literature in the late 1980's and early 1990's investigated underfilm soluble salts as a major contributor to subsequent coating deterioration. Soluble salts on surfaces may include chlorides, sulfates and nitrates. Generally, such salts are not visually detectable. Various chemical tests are available to detect soluble salts on surfaces prior to painting.

FIGURE 2 lends some insight into the relative effects of various types of surface contamination prior to coating based on Soltz's work<sup>5</sup>. The data demonstrates that surface chlorides have the greatest effect on coating performance. Ferrous sulfate contributed to coating failure, but at a much lower rate than chlorides.

Salts just above the Lower Detection Limit (LDL) of commercially available detection technologies were shown, over-time, to accelerate the blistering and rust-through of coatings under immersion conditions.<sup>6</sup> Based on these findings, about  $3 \mu\text{g}/\text{cm}^2$  NaCl, as Cl<sup>-</sup>, became the U.S. Navy acceptable limit for immersion service. The implementation of these levels was supported by a host of international standards.

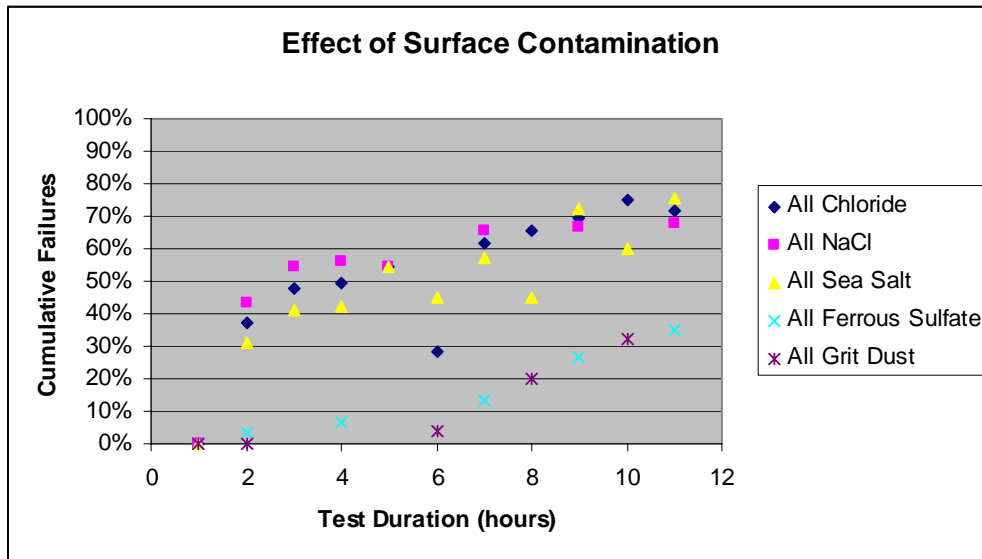


FIGURE 2 - Effects of Various Surface Contaminants on Coating Failure

In the marine industry, most specifications require surface chlorides below  $5 \mu\text{g}/\text{cm}^2$ . NORSOK requires surface chloride levels below  $2 \mu\text{g}/\text{cm}^2$  for all off-shore service conditions.<sup>7</sup> ISO standards<sup>8</sup> recommend limits of  $3 \mu\text{g}/\text{cm}^2$  on surfaces prior to coating. Australian standards<sup>9</sup> state, "For adequate surface life in an outdoor environment, low film build protective coatings of less than  $100 \mu\text{m}$  thickness require a level of chloride deposits not greater than  $50 \text{mg}/\text{cm}^2$  ( $5 \mu\text{m}/\text{cm}^2$ )."

It has been shown that corrosion also occurs under coatings applied over salts in non-immersion service (e.g., splash-type environments and condensing humidity environments). Work by Morcillo<sup>10</sup> identified corrosion rates over 4 mpy when as little as  $2 \mu\text{g}/\text{cm}^2$  of chloride ion was present under the coating on steel in a high humidity atmosphere. Soltz observed "considerable underfilm corrosion" when surface chlorides under an epoxy coating were above  $1 \mu\text{g}/\text{cm}^2$ .

Since the deleterious effects of salts have been recognized and practical field measurement techniques have been developed, coating specifiers have recognized the benefits of requiring cleaned surfaces meet certain soluble salt levels. More than 68% of the 54 coating specifications

from various industries surveyed<sup>11</sup> had surface chloride requirements of 5 µg/cm<sup>2</sup> (~ 30 uS/cm) or below. Generally, higher allowable limits are for non-marine atmospheric exposure.

Studies performed for the Naval Sea Systems Command<sup>12</sup> show the propensity for blistering in hot distilled water (180°F) or in condensing humidity environment is increased drastically by chloride contamination values at or below 5 µg/cm<sup>2</sup>. FIGURE 3 shows the percentage of test panels failing as a function of time. Failing is defined as blistering exceeding ASTM D714 “8M” or rusting exceeding ASTM D610 “8.” Within a two-week period, all of the panels with any measured level of salt contamination had blistered to the failure criteria. For clean steel (e.g., non-detectable levels of salt) the data trend suggests that more than 35 months would be required to reach failure on 100% of the population, assuming a linear deterioration rate. In harsh test environments, surface chlorides may increase the failure rate by a factor of 70.

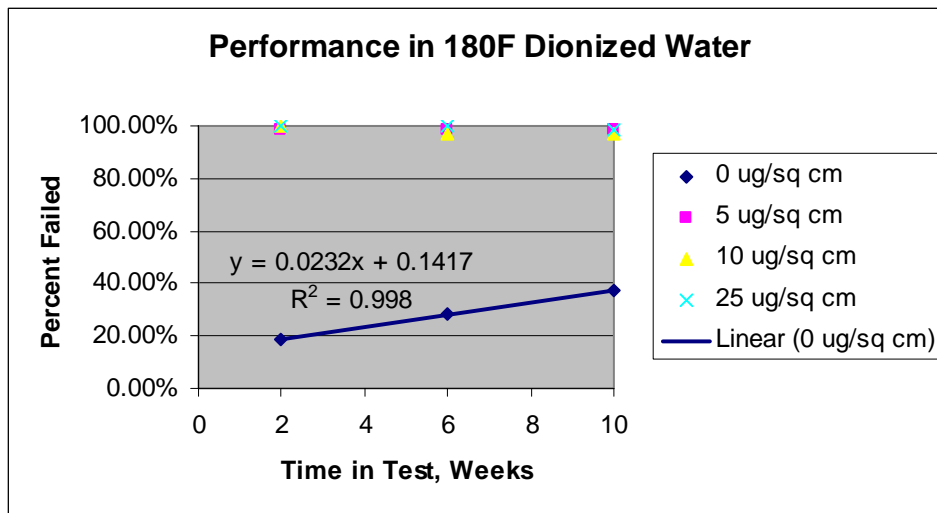
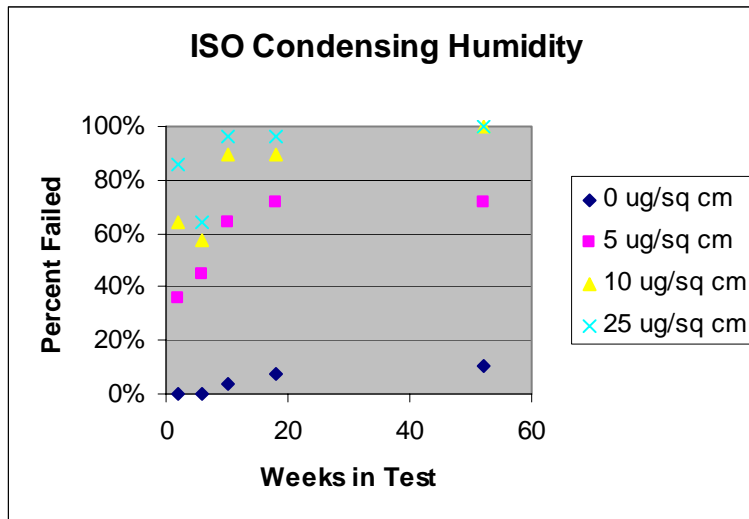


FIGURE 3 - MIL-P-24441 Over Salt in Hot Distilled Water

The same study included test panels of a MIL-P-24441 epoxy coating system exposed in an ISO condensing humidity test (FIGURE 4). This exposure environment is similar to what might be observed on roof of a tank. Under this exposure environment, a successively shorter time-to-failure was observed for each increasing level of salt contamination.



**FIGURE 4 - MIL-P-24441 Over Salt in Condensing Humidity**

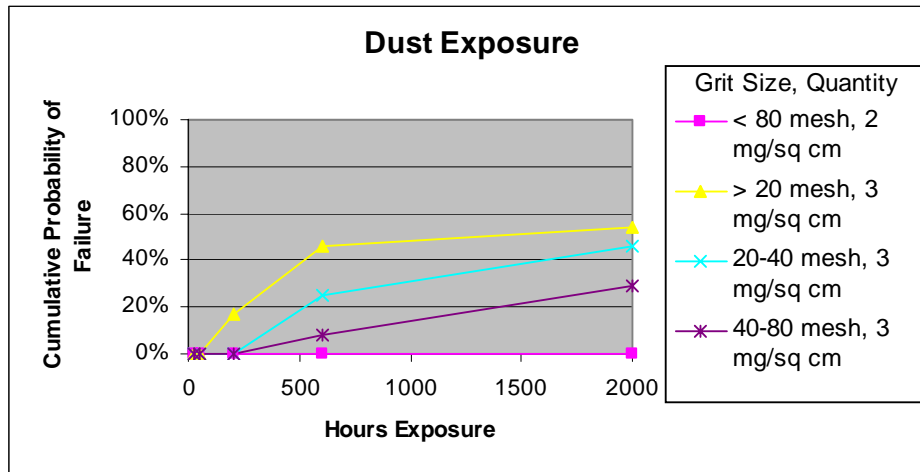
In this test environment, the coating applied over surfaces with  $5 \mu\text{g}/\text{cm}^2$  chlorides experienced a failure rate nearly 7 times those with salt below the detection limit. Increasing chlorides from 5 to  $10 \mu\text{g}/\text{cm}^2$  increases failure propensity on the order of 40% over the lower salt level. Clearly there is a benefit to reducing surface chlorides in the condensing humidity and similar environments.

### **DUST AND EMBEDDED GRIT**

Dust remaining on the surface prior to coating can significantly impact the long-term adhesion of the coating. Surface dust is identified in accordance with ISO 8502-3, which basically requires pressing clear tape onto the surface and observing the tape for dust after removal.

The most abundant potential contaminant for most industrial coating applications may be blasting grit. Soltz investigated the effect of blasting grit left on the surface prior to coating.<sup>13</sup> Steel test panels were contaminated with 2 or  $3 \text{ mg}/\text{cm}^2$  of coal or copper slag grit of varying sizes (larger than 20 mesh, 20 to 40 mesh, 40 to 80 mesh and less than 80 mesh). Three types of epoxy tank coatings were applied to the contaminated panels. Exposure testing was conducted in high-pressure, high-temperature salt water

During testing, rust spots formed at some of the grit particle locations. FIGURE 5 shows the impact on performance of various grit contamination size and quantity combinations. As can be seen, only with the smallest grit at a lower contamination level were no rust failures observed. Furthermore, larger grit contamination led to more frequent failures.



**FIGURE 5 - Impact of Grit Contamination on Coating Performance.**

FIGURE 2 in the previous section includes data on the effect of dust as well as salt contamination. It is important to note that the number of failures observed on the grit contaminated panels was not as significant as the number of failures observed on the chloride contaminated panels. The levels of ferrous sulfate tested had about the same effect as the levels of grit contamination tested.

### **FLASH RUSTING AFTER ULTRAHIGH PRESSURE WATER CLEANING**

Flash rust, in simple terms, is the rapid onset of rust. For purposes of coatings performance, there appears to be a distinction between the flash rust which occurs after hydroblasting versus the “rustback” which occurs after abrasive blasting. The length of time it takes for the flash rust to form depends on the ambient conditions, percent relative humidity, and the level of soluble salts contained on the steel substrate. In the case of waterblasting, humidity would appear to be a greater concern than soluble salts left on the surface. This discussion concerns flash rusting which occurs after preparation of surfaces with hydroblasting. By the definitions provided in SSPC SP-12/NACE No. 5, “any steel surface may show flash rust within 0.5 to 2 hours, or longer depending on environmental conditions, after cleaning by water.”

In a report for the Navy<sup>14</sup>, a study was conducted of several tank and underwater hull coating systems applied over various degrees of flash rusting followed by subsequent exposure to a marine environment or seawater immersion. The study included four levels of flash rusting – less than light (LTL), light (LFR), medium (MFR), and heavy (HFR). Panels were exposed in various immersion tests for eight months.

FIGURE 6 plots the percent failed at the end of testing assuming an ASTM D 610 failure criteria of “8” (corresponding to 0.1% of the surface with corrosion) and a rating of “7” (0.3% surface corrosion). First, observe that the percentage of the test panels which failed varies depending on how failure is defined (i.e., as “7” or “8”).

Consider the data associated with a failure criterion of “8” in FIGURE 6. The data show that flash rust per se, tends to increase rust-through vs. a clean surface. Increased levels of flash rusting correlate with incremental coating failure over conditions ranging from clean steel to medium flash rust. Interestingly, the trend does not seem to hold for the panels with heavy flash rust. This may relate to the somewhat different process used to generate the heavy flash rust on these panels vs. the other grades of rusting observed (a technical detail of the testing which is beyond the scope of this paper).

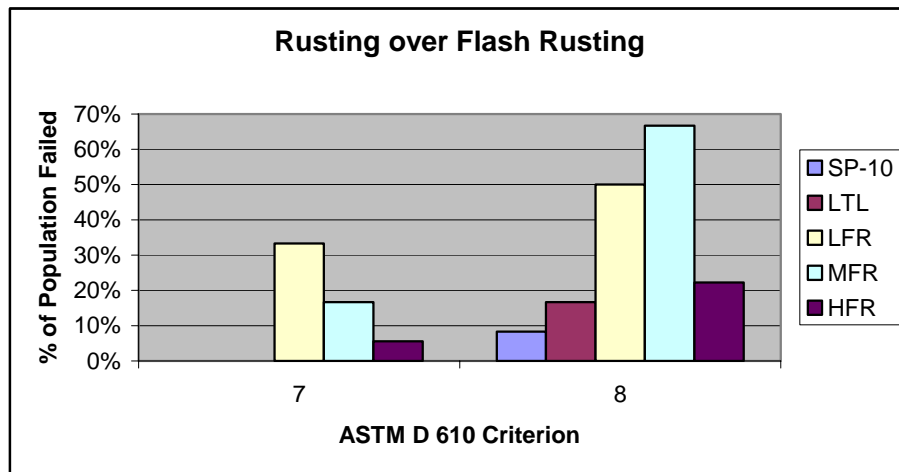


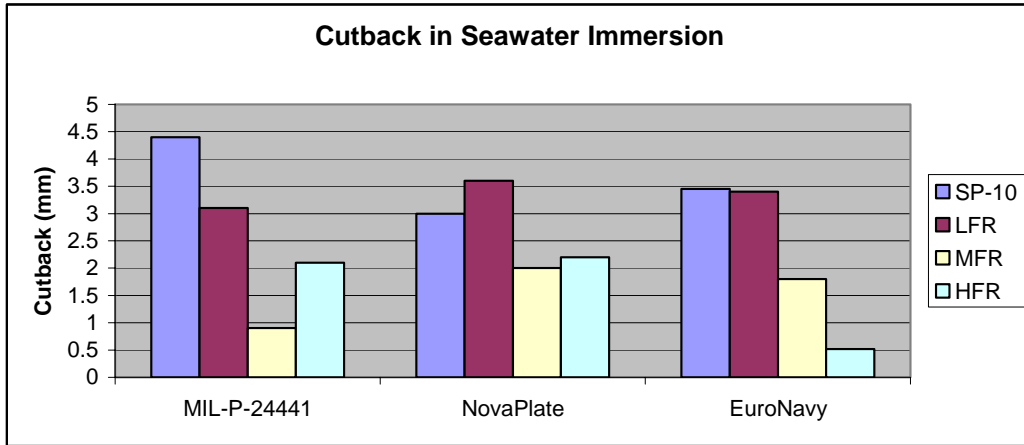
FIGURE 6 - Percent of Population Failing for Different ASTM D 610 Criterion

In follow-on testing<sup>15</sup>, this same behavior was not observed over a period of nine months. In this study, three levels of flash rusting were created, including “light,” “medium,” and “heavy.” A control consisting of a SSPC SP-10 abrasive blasted substrate was included. In this study all flash rusting surfaces were created via a similar water jetting and variable time-of-wetness process. The averages of replicate panels all exhibited between a 9.5 and 10 ASTM D 610 rating. In the previous tests, residual salt levels prior to painting were not confirmed; in the subsequent tests (with less breakdown) they were confirmed to be below the chloride detection limits.

FIGURE 7 shows a plot of the magnitude of cutback from an intentional scribe following 9 months of seawater exposure. This is from the “second” test program where low chloride levels were confirmed. The data show a decreased amount of cutback as the level of flash rusting increases. This data implies that flash rust may not decrease coating performance if the flash rust is free of invisible contaminants (e.g., salts).

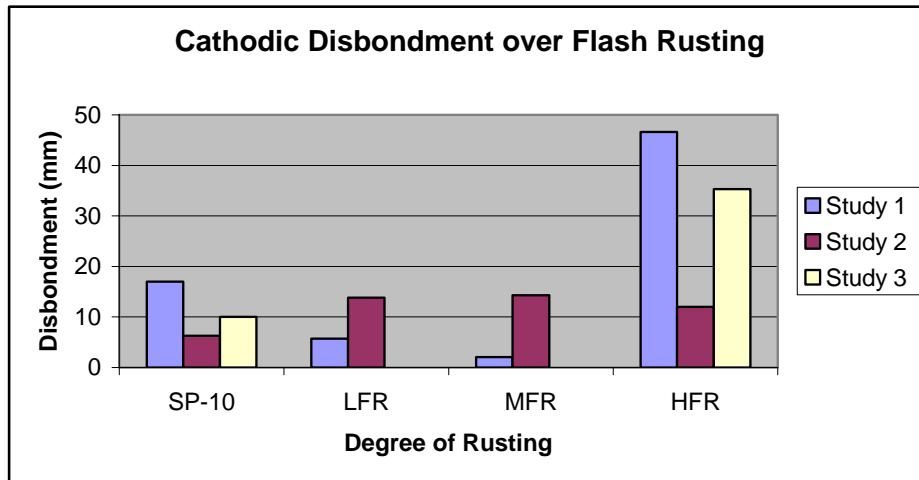
The literature contains conflicting data regarding the impact of flash rusting on coating performance. There are data in the literature from practical experience (i.e., paint vendor shipyard observations or field tests) that suggest caution when painting over flash rust. Unfortunately, many of these studies tend to either neglect to measure or control for the presence of chlorides on the surface. Sometime, they acknowledge that part of the heavy rusting is indeed the result of a delay in painting and subsequent corrosion due to chloride exposure. Understanding levels of contamination in flash rust is critical to determining the impact on coating performance.





**FIGURE 7 - Cutback on Flash-Rusted Panel (Freely Corroding)**

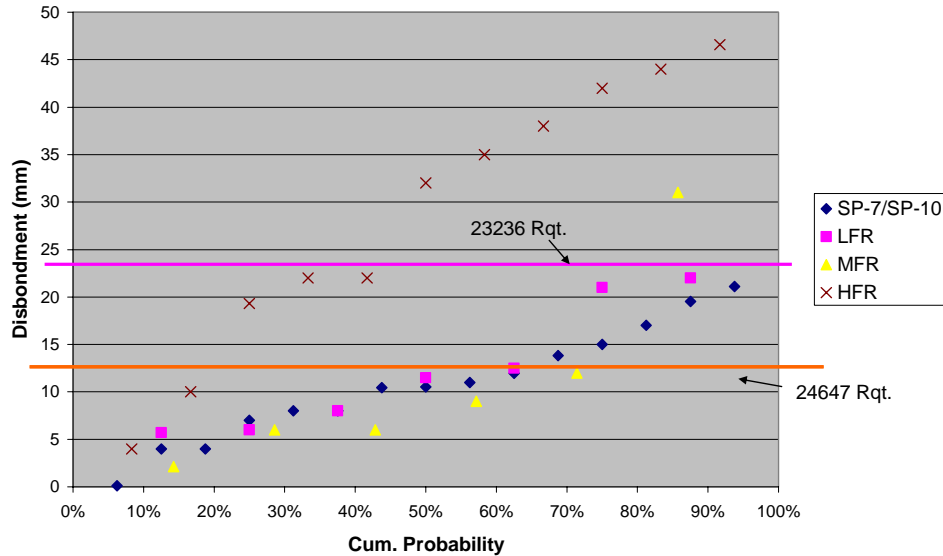
Many immersed surfaces have some form of cathodic protection to provide corrosion control in conjunction with coatings. Thus, cathodic disbondment may be of more concern in an immersion environment as compared to the underfilm cutback for freely corroding steel. FIGURE 8 shows a compilation of cathodic disbondment data for immersion coatings applied over clean steel and flash rusted steel in three studies. The first two studies were previously described. The third study<sup>16</sup> was a trial of panels that were water-jetted in a simulated seawater ballast tank; all of the panels were considered to be either SP-10 or medium/heavy flash rust (the data are plotted as heavy flash rust). In two of the three studies, heavy flash rusting seemed to cause significantly more coating disbondment vs. the SP-10 control surface. The third study showed negligible effect of flash rust on cathodic disbondment.



**FIGURE 8 - Cathodic Disbondment over Flash Rusting**

FIGURE 9 is a probability distribution function for various cathodic disbondment data. This includes data from work performed by the authors and some commercial testing in the literature. The plot shows that cathodic disbondment over “heavy” rusting is more significant than over SP-

10, light, or medium conditions. This finding suggests that painting over heavy levels of flash rusting may be a concern. To place the finding into perspective, the two lines on the plot are requirements from MIL-PRF-23236 (4% of total panel surface area, assumed to be a 6 x 12 panel) and MIL-PRF-24647 (0.5 inch or 12.7 mm of curback). Note that the mathematical mode (probability of 0.5) of the heavy data is approximately 50% higher than the MIL-PRF-23236 requirements. So even in this “discriminating” test, the data do not suggest catastrophic failure of the coating when applied over heavy levels of flash rust.



**FIGURE 9 - Distribution of Cathodic Disbondment Cutback Data from Various Sources**

## CONCLUSIONS

1. The paper presents data in the literature which suggests:
  - The highest levels of blast cleanliness do not offer significant improvements in coating performance in atmospheric performance. More data should be generated in this area as the available data is somewhat limited in scope.
  - There is substantial data documenting the performance benefit from removing soluble chlorides from the substrate prior to coating. The benefit of removing chlorides is applicable for both atmospheric and immersion service. Data on the effects of other soluble salts is limited and less conclusive.
  - There is evidence to suggest that small enough quantities of grit or other dust will not adversely impact coating performance. This data is extremely limited. Furthermore, it is expected that such tolerance would be dependant on the coating type.
  - Data on coating performance over flash rust after high pressure waterjet coating removal suggests that some level of flash rusting will not impact coating performance. The specific level which will not have an impact is subject to debate.

2. More work needs to be done to define the performance sacrifices associated with progressively lower levels of surface preparation to improve our understanding of the relationship between surface preparation and coating performance.
3. More complete cost and performance data is needed to allow specifiers to make the cost-benefit analyses which will optimize industrial coating expenditures.

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