INSPECTION TECHNIQUES FOR FLASH RUST FORMED AFTER WATERJETTING

J. Peter Ault, P.E., PCS
Elzly Technology Corporation
Ocean City, NJ

Abstract: Recent US Navy and NSRP projects have explored alternative inspection techniques for evaluating flash rust on waterjetted surfaces. This paper will summarize investigations into new inspection techniques which have been performed over the past few years.

Introduction

Based on historical experience inspecting flash rusted surfaces, there is variability among industry personnel in their ability to consistently discern different levels of flash rust in accordance with the SSPC SP-12 standards. This was quantified as part of a previous National Shipbuilding Research Program (NSRP) project.(1) The data suggested that industry personnel could clearly establish a break point between the Moderate grades and a Heavy grade of flash rusting as defined by the three-tier SSPC SP-12 standard. Personnel were less able to agree on distinctions between Light and Moderate.

Current industry standards predominately use written descriptions of visual observations and relatively simple physical tests to determine whether the degree of flash rust is acceptable for coating application. Different interpretations arise because the visual standards represent discrete levels of flash rusting, while the field conditions will likely be some intermediate level formed under different circumstances. A number of investigators have worked to develop more quantitative test procedures to reduce disputes. (2,3,4,5) This paper will discuss characterizing flash rusted surfaces using the following techniques:

- Visual Assessment
- Ease of Removal
- Colorimetry
- Electrochemical measurements
- Pull-Off Adhesion

Visual Assessment

One of the concerns with painting over flash rust is that the present surface preparation by waterjetting standards are subject to interpretation. To quantify this concern, an NSRP project (1) included a “round-robin” evaluation of the flash rust descriptions in SSPC SP-12, *Surface Preparation and Cleaning of Steel and Other Hard Materials by High- and Ultrahigh-Pressure Water Jetting Prior to Recoating*.

The round robin evaluation was intended to quantify the variability in the interpretation of the wording in SSPC SP-12 and VIS-4, the dominant US industry standards for rating flash rust. To perform the round-robin test, eight steel test panels were prepared with ultrahigh pressure waterjetting and allowed to flash rust to varying degrees. The panels were each nominally 2-foot square. All eight of the test panels originally contained preconstruction primer. The pre-construction primer was removed from seven of the panels with abrasive blasting. Pre-construction primer was left on the eighth panel to ensure at least one condition with no flash rust. The panels were allowed to weather outdoors near Jacksonville, FL for approximately a week. The test panels were then high pressure waterjet cleaned using a hand lance and allowed to flash either outside or in a covered area (again near Jacksonville, FL). The level of flash rust was varied by adjusting the location of exposure, time of exposure and in some cases adding a remediation step (water wash or solvent wipe).

Volunteers for the round robin were solicited from the 2007 attendees at the Hull Preservation Subcommittee of the NAVSEA Standard Specification for Ship Repair and Alteration Committee (SSRAC). Eighteen of the attendees participated in the round-robin evaluation. The participants equally represented the owner (Navy in this case) and contractor perspectives. Of the participants responding to the question, all had some level of coating inspector training.

Figure 1 shows a summary of the percentage of people rating each panel “light,” “moderate,” or “heavy.” In the figure, the panels are sorted in order from lightest to heaviest based on the average rating received. The data suggest strong consensus on the panel judged to have “heavy” flash rust. All but one of the participants determined that this panel had heavy flash rust (94% agreement). The panels rated “light” or “moderate” had between 88% and 75% consensus with the exception of panel 7. There was significant disagreement over whether panel 7 had moderate (50%) or light (39%) flash rust. Panel 8 was predominately judged to have no flash rust (56%), though it should be pointed out that much of the preconstruction primer remained on this panel after waterjet cleaning. The panel had a dark gray appearance with some pinpoint rusting where the primer was adequately removed.

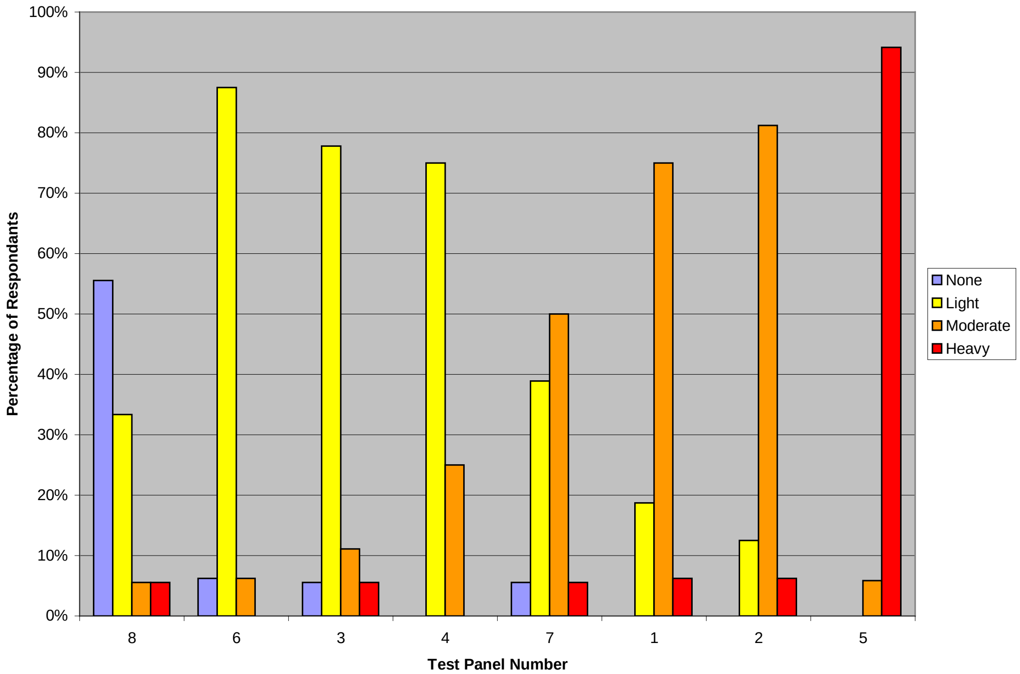

Figure 1. Flash Rust Ratings Provided by Multiple Inspectors during Round Robin

Ease of Removal

There are a number of flash rust evaluation techniques which focus on the ease with which the flash rust can be removed. Two procedures are qualitative tests which involve removing the flash rust with either a white cloth or with standard tape. A third method has been developed to quantify the amount of flash rust removed by the tape test.

White Cloth Test

One of the evaluation criteria for flash rust is the degree to which it can be removed when “lightly wiped” with a cloth. There is neither a standard method for “lightly wiping” nor a standard type of cloth to be used. Cloth wiping is one of the criteria used to determine the level of flash rust on a surface in accordance with SSPC SP-12/NACE No 5.

An NSRP project developed a stand-alone training manual to focus on the fundamentals of inspection for flash rust as found after waterjet or wet abrasive blast cleaning in preparation for painting.(6) Based on that project and other work of the NSRP Surface Preparation and Coatings Panel, a non-mandatory guide was developed to supplement SSPC-VIS 4/NACE VIS 7 and SSPC-SP 12/NACE No. 5 and assist the inspector and customer in determining the level of flash rust on a surface. Within that guide, a more detailed procedure for cloth wiping is provided (the “brush-cloth” method). While not quantitative, the procedure does seem to improve consistency of observations by different inspectors.

As described within the newly developed guide, the brush-cloth method involves lightly wiping the flash rusted surface using a cloth wrapped around a paint brush and evaluating the amount of rust transferred to the cloth. The brush-cloth method uses a standard brush, a standard type of cloth and a standard technique in order to minimize subjectivity. After testing various methods and materials, this method has been identified by the NSRP as reliable and consistent. Figure 2 shows photographs of the test being performed. Following is the procedure:

1. Use a white, lint-free, woven cotton cloth and a standard 4-inch nylon bristle paint brush.
2. Neatly wrap cloth around the paint brush. Hold the cloth in such a manner as to prevent it from slipping.
3. Swipe the cloth across the surface in one motion, using the amount of pressure you would use when applying house paint to a door.
4. Use a consistent length of the swipe. NSRP recommends one pass at 6 inches (15 cm.)
5. Evaluate the amount of rust transferred to the cloth. (Reference photos are provided in the guide.)

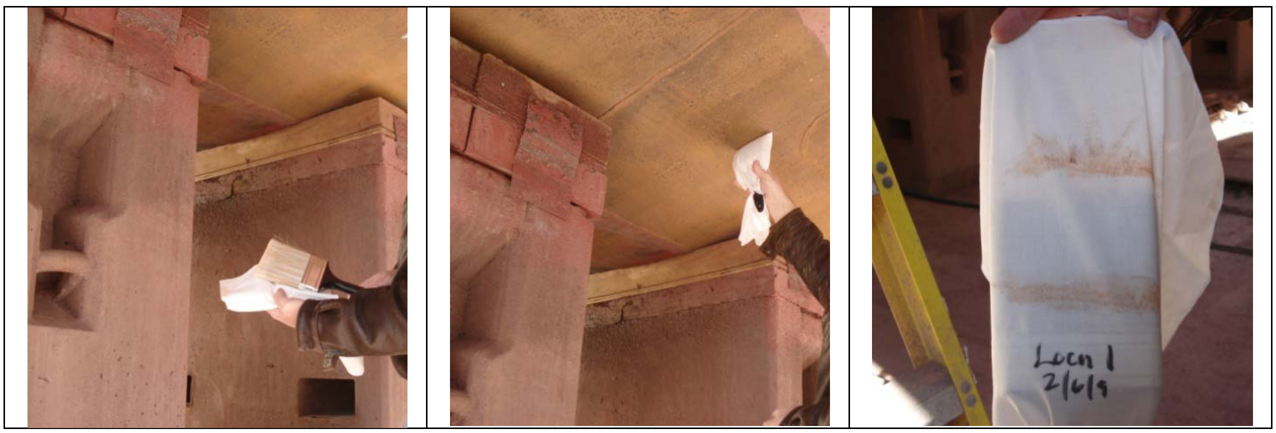

Figure 2. Photographs of the "brush-cloth method."

<u>Ten Tape Test</u>

Hempel describes a test which involves sequential application of multiple tapes to the same location on the steel substrate.(7) The test involves the following steps:

1. Select a spot on which to perform the test.
2. Attach a piece of tape (as specified in ASTM D 3359) of at least 5 cm (2") in length and rub thoroughly with a fintertip –not a nail– to make the tape adhere firmly.
3. Peel off the tape and place it on a piece of white paper for reference.
4. Repeat steps 2 and 3 a total of 9 times on exactly the same spot using a new piece of tape each time.
5. Assess the appearance after the 10th piece of tape using the Hempel rating scheme:

   - FR-1: No rust on the tape. No or only a slight change of the test spot.
   - FR-2: Slight localized red-brown rust on the tape. A significant change of the test-spot; possibly showing localized areas of black rust.

- FR-3: Significant, uniform red-brown rust on the tape, also showing grains of black rust. A significant change of the test-spot, also showing localized areas of black rust.

The test can be somewhat tedious to perform. Difficulties include applying the series of tapes in the same spot and avoiding fingerprints on the tape. While the results would seem easy to interpret, the test still does not provide a quantitative measure. Some inspectors have commented that the trends in relative performance can be observed prior to the tenth tape.

Tape Transmittance Test

In an effort to simplify the “ten tape” test and make it more quantitative, the Navy developed a technique wherein the first tape pulled off the flash rusted surface is quantitatively analyzed using a light transmittance meter. A test sample is prepared by applying a 4-5 inch length of ISO 8502-3 dust tape to the flash rusted surface. The inspector rubs the tape onto the steel with his/her thumb or other finger, pressing as hard as possible over the central 3-inches of the tape without damaging it. The tape is then applied to a clear microscope slide. The light transmittance through the tape/microscope-slide assembly is measured using a transmittance meter. The difference in average transmittance of the test sample (i.e., sample with flash rust) and the average transmittance of a control sample (i.e., tape/microscope-slide assembly without flash rust) constitutes one transmittance reading.

Based on a 2009 round-robin evaluation of test panels by eight inspectors from Navy and Industry, the following criteria were developed:

- SSPC-SP-12/VIS-4 "high" level of flash rust will exhibit a difference in transmittance reading in excess of 20%
- SSPC-SP-12/VIS-4 “moderate” level of flash rust will exhibit a difference in transmittance reading between 10% and 20%
- SSPC-SP-12/VIS-4 “low” level of flash rust will exhibit a difference in transmittance reading below 10%

Preliminary feedback from a number of shipyards and waterjetting contractors is that the proposed criteria correlate well with current flash rust descriptions. It is important to remember that this tape test is a quantifiable extension of the cloth wipe test in that it evaluates the degree of loosely adherent dust. The remaining criteria within the SSPC SP-12/NACE No 5 definitions of flash rust must be met as well.

Colorimetry

A number of attempts to quantitatively measure flash rust have involved using a commercial colorimeter to measure the color of the flash rust. This technique has shown promise in a few tests. Figure 3 shows data collected during two NSRP efforts (“data set 1” and “data set 2”) as well as bands which were proposed by one investigator.(2) The chart shows the “b-value” of color in the Lab color space. This is one dimension of color which has been observed to correlate with the degree of flash rust. While the measurement technique shows promise, it requires further testing on a wider range of samples.

A colorimeter is a relatively expensive piece of sensitive equipment. To avoid bring such equipment into an industrial environment where it might be damaged, investigators have attempted to measure the color of flash rust in photographs taken under standard lighting or measure the color of tape used to remove loose flash rust. While these methods have shown some promise, none have been fully developed.

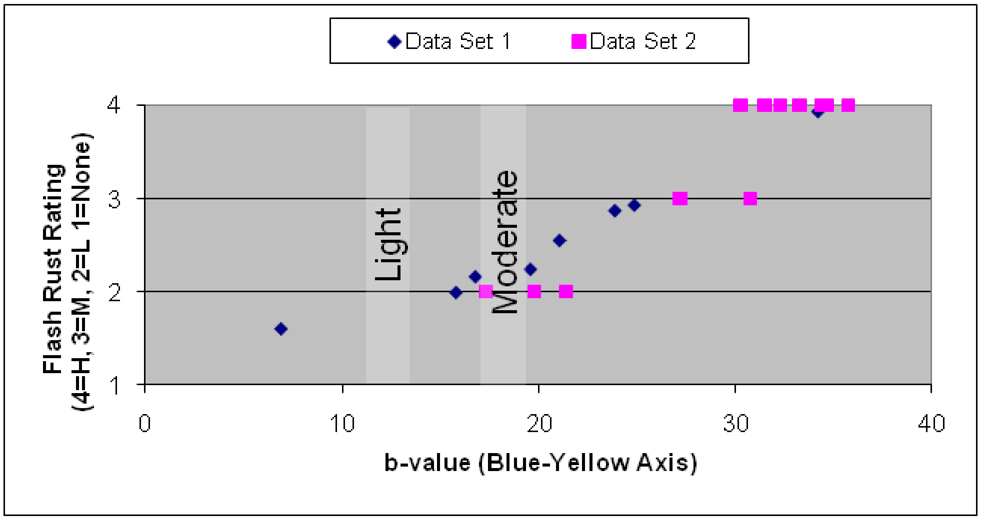

Figure 3. Colorimeter data from varying flash rust panels.

Electrochemical Measurements

In terms of failure, flash rust is likely to cause coating failure for one of three reasons: initiation of underfilm corrosion, mechanical interference with coating adhesion, or as a driver behind osmotic blistering. Conceptually, electrochemical measurements might be expected to indicate the likelihood that flash rust would promote underfilm corrosion.

Initial work with the technique was reported in 2006.(2) The work recommended further investigation of corrosion potential measurements, and linear polarization resistance (LPR). Further work on the electrochemical potential measurements has been informally reported.(8)

Electrochemical Potential

A metal or an alloy develops a characteristic electrochemical potential (or voltage) when exposed to an electrolyte due to the formation of reaction products on the surface. This voltage (commonly referred to as the corrosion potential or equilibrium potential) can be measured with the help of a suitable reference electrode (e.g. calomel, silver/silver chloride, copper/copper sulfate, etc.) and a high impedance voltmeter. Since the surface films encountered with different grades of flash rust have different characteristics it is reasonable that the electrochemical potential (voltage) response of these surfaces would be different. Thus, the measurement of the corrosion potential of the different grades of flash rust (as a function of time) should yield a distinct relationship.

To measure corrosion potential, the flash rusted surface needs to be exposed to an electrolyte (i.e. aqueous solution). However, exposure to water may alter the surface characteristics of the initial flash rusted surface. Commercially available EKG patch electrodes consist of a thin sheet of solid-state Ag-AgCl reference electrode attached to a conductive adhesive gel. The gel "electrolyte" of some of these electrodes has been determined to have negligible short-term impact on the flash rust for purposes of this measurement.

Previously referenced work has shown that surfaces having lower levels of flash rust generally display more active (electronegative) potentials. Figure 4 shows the potential versus time from reference 2. Figure 5 show the potential versus time from Reference 8. Note that the potentials in Figure 4 range between -230 and -150 mV while those in Figure 5 range from -510 to -400 mV. The observed differences between varying levels of flash rust do not correlate among the two studies. There were differences in the measurement procedures used for the two studies. In order to establish a robust measurement procedure, the exact reasons for these differences would need to be understood.

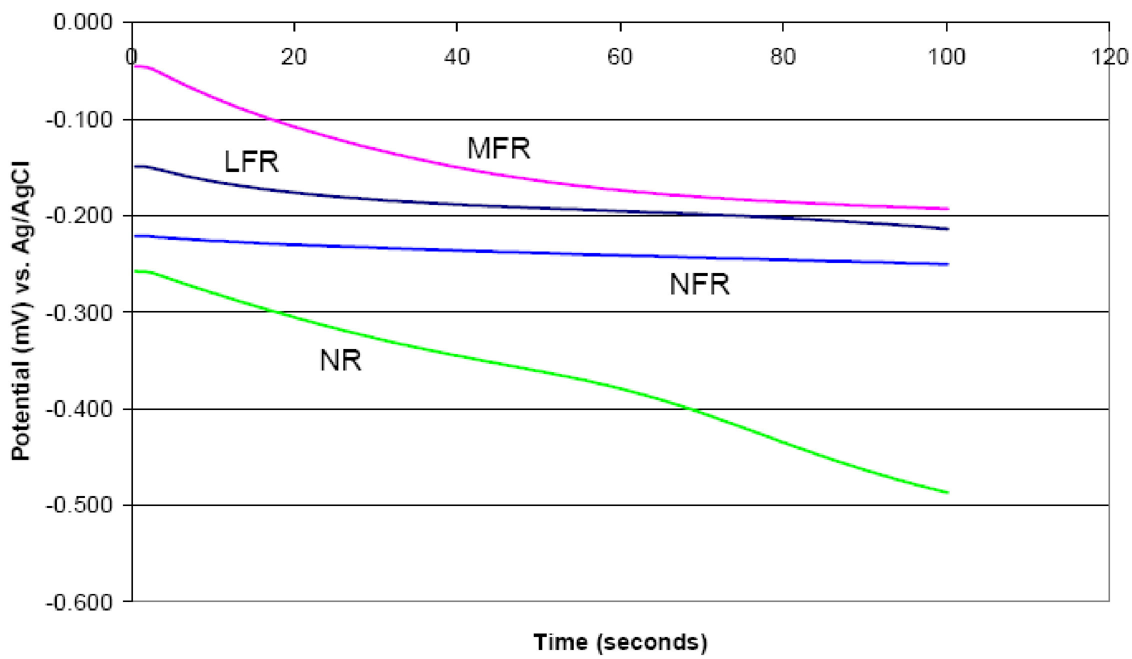

Figure 4. Potential vs time relationship of flash rusted panels from Reference ii. NR = No Rust (mechanically abraded); NFR = No Flash Rust; LFR = Light Flash Rust; MFR = Moderate Flash Rust.

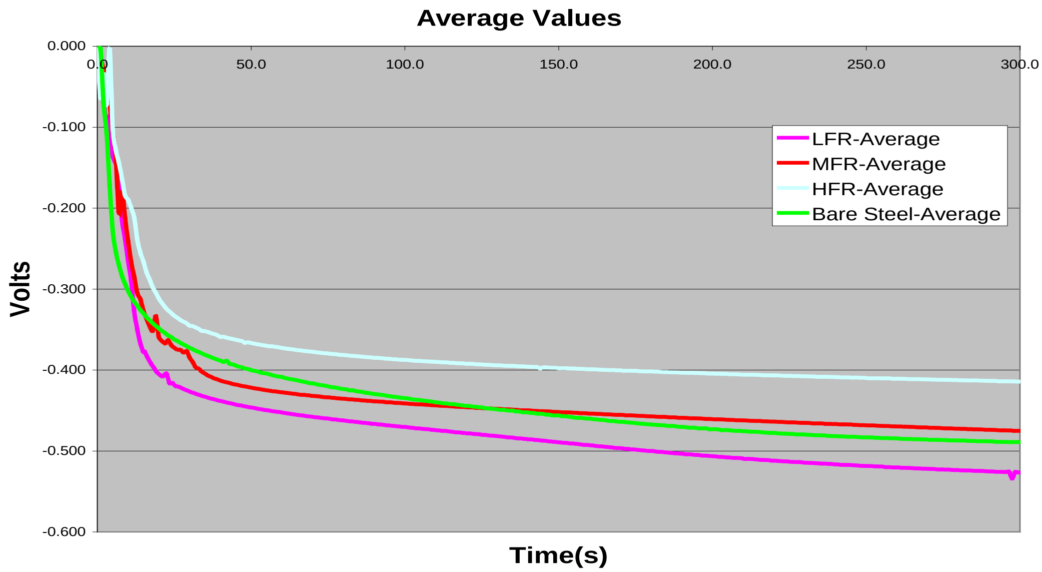

Figure 5. Potential vs time relationship of flash rusted panels from Reference viii.

During the NSRP round robin evaluation, we measured the electrochemical potential of the flash rusted surfaces. For each test, a 3M™ 2360 Resting EKG Electrode was attached to the test panel. The potential-time response was monitored with a high impedance digital voltmeter for approximately 5 minutes.

Ideally, the electrochemical potential of the various levels of flash rust would be distinct and stable over time. The graph shows that the electrochemical potential tend to shift with time. This is expected and is the result of the interaction of the flash rusted surface with the gel electrode. Knowing that the potentials will shift with time, we could specify a point in time after attaching the electrode to make the measurement. For practical purposes the measurement timeframe should be as short as possible (e.g., minutes, not hours). Figure 6 shows the potential versus time trends for seven test panels. The line colors correspond to the flash rust condition: red = heavy, orange = moderate, yellow = light. While the light and moderate potentials seem to distinguish themselves throughout the five minute timeframe, the potential of the heavy test panel is indistinguishable from the light flash rust panels.

It is also worth noting that the potentials measured on these test panels do not correlate with those shown in Figure 4 and Figure 5. The measurement procedures were quite similar to those used to develop the data in Figure 5. However, the steel substrate and environment where the flash rust was developed was different among the two studies.

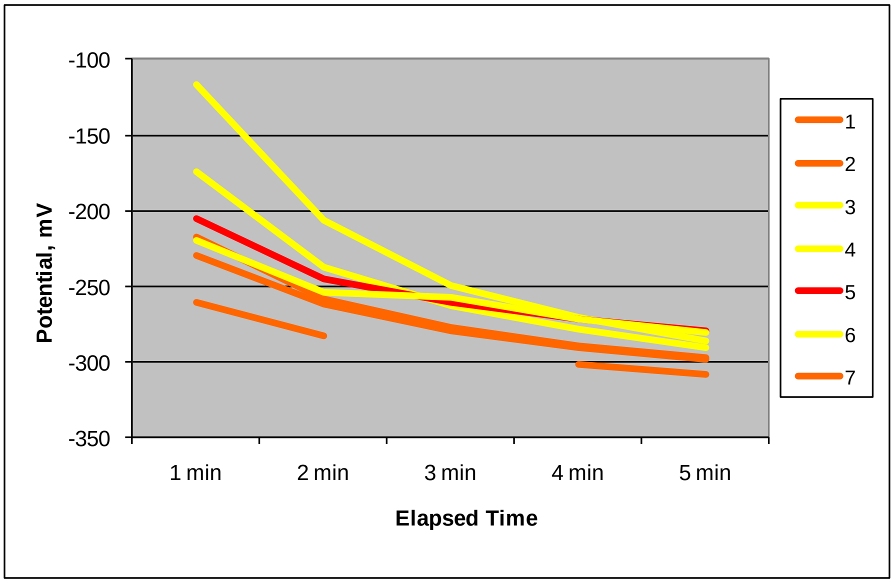

Figure 6. Potential vs time relationship of flash rusted panels from NSRP study. The line colors correspond to the flash rust condition: red = heavy, orange = moderate, yellow = light.

Electrochemical Polarization

Previous work has investigated the polarization resistance of flash rusted substrates.(2) While laying the groundwork for technology advancement, these techniques are limited by inconsistent absolute potential behavior and rapid time-polarization of the substrates. The present measurements were made with a passive instrument specially designed to indicate the potential and electro-chemical significance of flash-rusting on steel surfaces and its potential to impact coating system life, especially for immersion service.

The principle identified is the difference in corrosion potential exhibited by flash-rust coated areas vs. areas "suitably" prepared. Suitably prepared areas may be areas of white-metal on the surface or areas of less flash rust—at the discretion of the coating specifier. In this case, the "suitable" reference surface was a portion of the test panel where the flash rust was removed with abrasive paper.

Figure 7 shows the galvanic current created between various flash rusted surfaces and the reference surface under the test conditions. It is expected that heavier flash rust will result in greater current flow. Figure 8 shows the correlation between the galvanic current flow and the average flash rust ratings provided in the round robin. While there is not perfect agreement, the r-squared value of 0.85 indicates a reasonable fit. Further data would need to be collected to confirm the usefulness of this technique. Ideally, such data would be correlated to coating performance rather than visual ratings provided in accordance with SP-12. However, more work is needed to fully develop this technique.

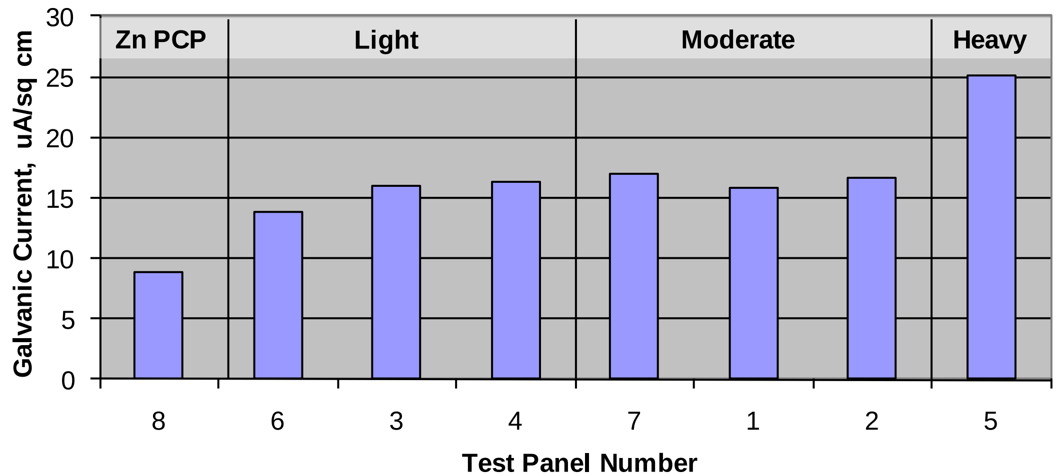

Figure 7. Galvanic Current Density

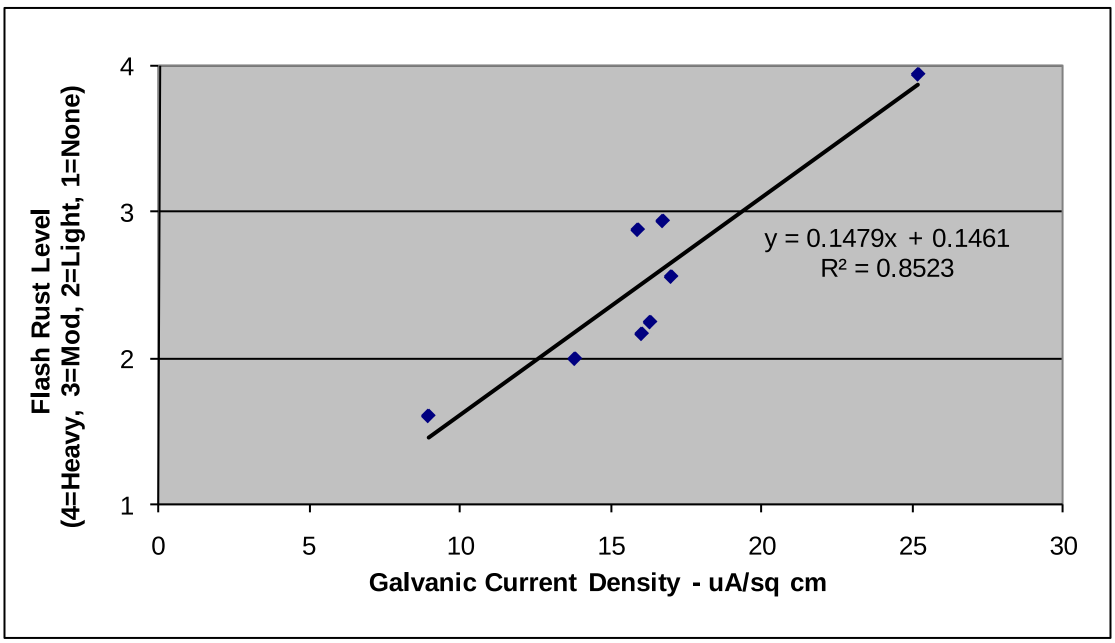

Figure 8. Correlation between Galvanic Current Density and Flash Rust Rating

Adhesion to Flash Rusted Surface

One of the hypothesized mechanisms by which flash rust compromises coating performance is by interfering with coating adhesion. When coatings have been applied over suspect flash rust, it is common to perform an adhesion test in accordance with ASTM D4541, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*. The test method involves adhering a test fixture to a coating. Once the adhesive has cured, the test fixture is pulled to failure. The failure load and location of failure is recorded.

Preliminary work was done to determine if a similar technique could be used to evaluate a flash rusted surface. Conceptually, a test fixture could be glued to the flash rusted surface with quickcure adhesive. The pull-off adhesion would be determined in accordance with ASTM D4541. In theory, a lower failure load would be observed if the flash rust was substantial enough to interfere with adhesion. Figure 9 shows the pull adhesion measured using various adhesives on varying levels of flash rust. This initial data suggested that the test result was highly dependent on the type of adhesive used. Furthermore, many of the adhesives require substantially longer than their advertised cure time to develop full strength. It would take a great deal of research to fully develop a methodology with a standard adhesive, cure time, etc. Even if such a standardized technique could be developed, it would likely require hours to generate test results (due to adhesive dry times). Such test durations would unacceptably interfere with production.

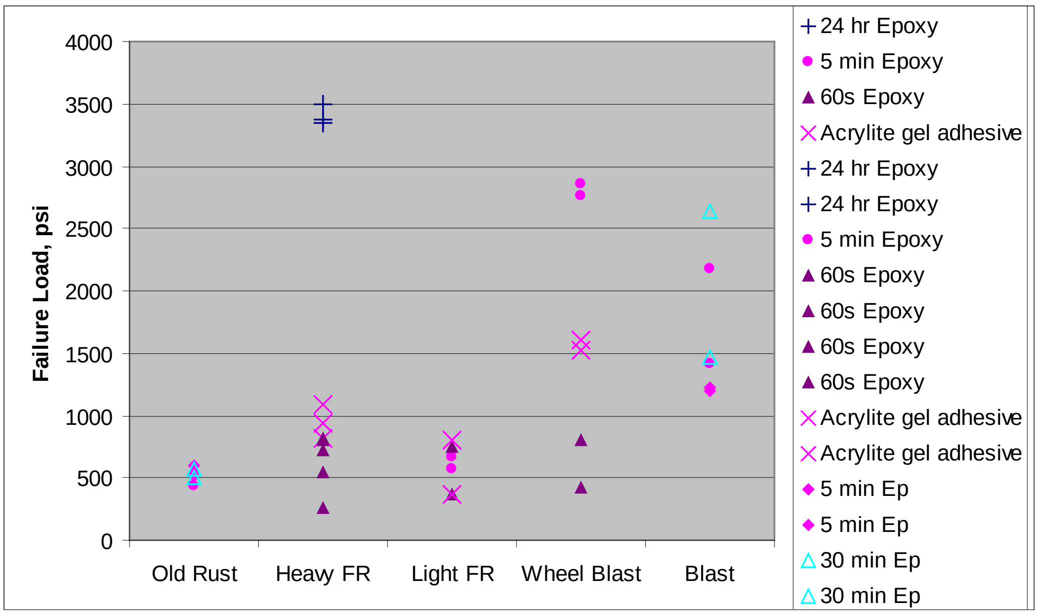

Figure 9. Preliminary pull-off adhesion data.

Conclusions

1. There has been considerable work on a variety of techniques for quantitative evaluation of flash rusted surfaces in recent years. Many of the techniques show promise for evaluation of flash rust. Specifically:
    - Two improved tests for ease of removal of flash rust have been developed and are ready for use in the field. These tests are the qualitative “brush-cloth” test and the quantitative Tape Transmittance test. Both tests focus on the issue of characterizing the amount of loosely adherent flash rust.
    - Colorimetry and electrochemical techniques seem to offer promise as quantitative inspection techniques. However, work remains to fully develop them for use in the field.
    - The adhesion test proved too susceptible to testing variables to be an effective quality assurance method. A variant of the adhesion test which investigates the ability of a coating to “wet out” flash rust might be worthy of investigation.

2. There are a number of characteristics of flash rust which are captured in the present definitions. This includes the degree of loosely adherent dust, color and the ability to view the initial substrate through the flash rust. None of the test methods quantify all aspects of the existing definitions. Further work should be performed to delineate the important aspects of the flash rust definitions, allowing the sole use of one test method to determine the level of flash rust.

Acknowledgements

The work described in this paper could not have been completed without the support of a number of individuals and groups including the National Shipbuilding Research Program and the US Navy. In particular, I would like to acknowledge of Ms Karin Thomas, Naval Surface Warfare Center – Carderock Division for her help in preparing this paper.

References

1) "Review of Acceptable Flash Rusting for Ship Coatings," NSRP report prepared by Atlantic Marine Florida, LLC and Elzly Technology Corporation, November 2007.
2) M. Islam, W. McGaulley, J. Tagert, J. Ellor, and M. Evans, "Experimentation to Develop a Quantitative Method for Characterizing the Level of Flash Rusting Formed on Carbon Steel after Ultra High Pressure Waterjetting," presented at PACE 2006, January, 2006.
3) "Digital Image Processing for Rust Assessment," presentation by Muehlhan Equipment Services at the NSRP Ship Production Panel Meeting, Tampa FL, January 2006.
4) C.S. Tricou, "Quantifying the Impact of Flash Rust on Coating Performance," Final Report submitted to Naval Sea Systems Command under contract #N00039-97-D-0042/0377, January 2005.
5) Philippe Le Calve, DCN, Lorient, France; Phillipe Meunier, SNCF, Paris, France; Jean Marc Lacam, DGA, Paris France, "Quantification of the Products of Corrosion after UHP Waterjetting", JPCL, November 2002.
6) "Manual on How to Inspect Flash Rust," NSRP report submitted by Dr. Lydia Frenzel, November 2008.
7) Photo Reference of Steel Surfaces Cleaned by Water Jetting. Hempel Marine.
8) McGaulley, W., "UHP Waterjetting: Flash Rust Coatings Performance and Quantification," presented at SSPC Chesapeake Chapter Meeting, January 2007.