QUALIFICATION OF COATINGS FOR LAUNCH FACILITIES AND GROUND SUPPORT EQUIPMENT THROUGH THE NASA CORROSION TECHNOLOGY LABORATORY

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ABSTRACT

Corrosion protection at NASA's Kennedy Space Center is a high priority item. The launch facilities at the Kennedy Space Center are located approximately 1000 feet from the Atlantic Ocean where they are exposed to salt deposits, high humidity, high UV degradation, and acidic exhaust from solid rocket boosters. These assets are constructed from carbon steel, which requires a suitable coating to provide long-term protection to reduce corrosion and its associated costs.

NASA created the Kennedy Space Center (KSC) Corrosion Laboratory to investigate, evaluate and approve coatings and materials for the agency. The Corrosion Laboratory uses NASA-STD-5008B as a guide to evaluate coatings for use in aggressive launch pad environments at the Kennedy Space Center. The laboratory and standard were developed to establish uniform engineering practices and methods to ensure the inclusion of essential criteria in the coating of ground support equipment and facilities used by or for NASA. The testing requirements are applicable to Ground Support Equipment (GSE) and facilities that support space vehicle or payload programs or projects and to critical facilities at all NASA locations worldwide. The requirements were designed for non-flight hardware used to support the operations of receiving, transportation, handling, assembly, inspection, test, checkout, service, and launch of space vehicles and payloads at NASA launch, landing, or retrieval sites. The criteria and practices are used for items employed at the manufacturing, development, and test sites upstream of the launch, landing, or retrieval sites.

This paper discusses the test protocol used to qualify protective coatings according to the requirements of the KSC Corrosion Technology Laboratory and NASA-STD-5008B. The protocol is illustrated with examples of coatings that did, and those that did not meet the criteria necessary to be placed on the NASA-STD-5008 Approved Products List.

INTRODUCTION

Testing of protective coatings for carbon steel, stainless steel, and aluminum has been an ongoing process for many years at NASA's Kennedy Space Center (KSC). In 1969, a testing program was initiated to evaluate coatings for the long-term protection of carbon steel exposed to a seacoast environment. In 1981, the Space Shuttle launch system introduced a more aggressive environment to the Kennedy Space Center launch facilities. Exhaust from the solid rocket boosters included small particles of alumina with hydrochloric acid absorbed onto the surface of these particles. Wherever a cloud of this exhaust settled, unprotected zinc coatings corroded. Over the years, the KSC Corrosion Technology Laboratory has developed proven methodologies to evaluate and test coatings for use in NASA's unique corrosive environments. Based upon this knowledge, experience, and expertise, NASA-STD-5008B "Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on Launch Structures, Facilities, and Ground Support Equipment"[1] was developed to test and evaluate protective coatings to control corrosion of NASA's launch towers and GSE. This paper discusses the test protocol required for coating systems to be included on NASA's approved products list in the NASA-STD-5008.

TESTING PROCEDURE

In order for a coating system to be used at NASA Centers, it must be listed on the NASA-STD-5008 Approved Products List. Coating systems on this list are qualified according to the requirements of NASA-STD-5008B by the KSC Corrosion Technology Laboratory.[1] Typical protocol requires laboratory adhesion tests, color measurements, gloss measurements, and corrosion evaluations on the coatings exposed at the NASA KSC Beachside Corrosion Test Site (Figure 1).

Figure 1. KSC Beachside Corrosion Test Site

Coupon Materials/Coating Systems

In preparation for the beach exposure testing, test panels are prepared in the KSC Corrosion Technology Laboratory. Unless otherwise noted, test coupons are standard commercially produced 4 inch by 6 inch carbon steel test panels. Two types of panels are used, a flat panel and a flat panel with a one inch C-channel welded on its surface. The metal panels are prepared in accordance with SSPC Technology Guide No. 9, "Guide for Atmospheric Testing of Coatings in the Field." [2] The surface conditioning for steel test coupons is prepared in accordance with the Society of Protective Coating Standards SSPC-SP-1, "Solvent Cleaning", and NACE No. 1/SSPC-SP 5, "White Metal Blast Cleaning". [3,4] Post blast surface roughness is measured in accordance with ASTM D 4417, "Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel", and recorded for informational purposes prior to application of the primer.[5]

The coating system is initially evaluated for application and handling properties such as mixing ease, atomization, and coating appearance on the varying areas of the test panel (flat, edges, angles, welds, etc.). The coatings application laboratory is a temperature controlled facility with a filtered spray booth. The laboratory is equipped with multiple spray guns with graphite packing's, various combinations of fluid needles, fluid nozzles, and air caps suited to spray materials of varying viscosities.

Although the laboratory tests multiple coating systems, inorganic zinc primers are required for launch systems and ground support equipment at the Kennedy Space Center. The inorganic zinc primers are mixed per the manufacturers specifications. Since most products are supplied in 1-gallon kits, partial kits are mixed for the small applications. The exact mix ratios by weight of liquid to zinc powder are used to mix the coatings. The portions are weighed on a calibrated digital balance within one-gram accuracy.

Coatings systems that may be subject to acidic deposition from solid rocket boosters require a topcoat. The tie coats and finish coats are applied at varying DFTs according to the manufacturers' recommendations. Insofar as the directions are complete, manufacturer's instructions are followed in mixing, thinning, and applying the coatings. For the majority of the top-coated panels, the inorganic zinc primer is allowed to cure overnight inside the coatings laboratory. All coatings are applied in the controlled environment of the coatings laboratory. By coating the test panels indoors, the variations in temperature, humidity, and wind conditions encountered outdoors are eliminated. When testing multiple coatings, this allows all the coatings to be applied under the same environmental conditions, by the same painter. Examples of fully prepared flat and composite panels are shown in Figure 2.

Figure 2. Typical Coated Flat and Composite Panels

In preparation for the atmospheric field exposure testing, a matrix of 16 panels per coating system is prepared (Figure 3). Four different conditions are used:

(1) Four primer-only composite panels exposed to normal conditions.
(2) Four full system composite panels exposed to normal conditions.
(3) Four full system composite panels exposed to normal conditions plus aluminum oxide (Al_2O_3) acid-slurry applications.
(4) Four full system flat panels with a scribe exposed to normal conditions.

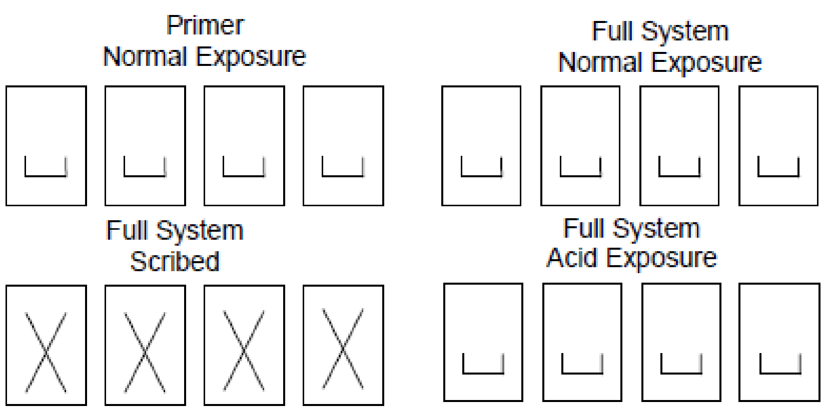

Figure 3. Coating System Coupon Matrix

In preparation for laboratory adhesion testing, an additional set of four “primer only” coated test panels are included into the test matrix. Consequently, 20 test panels are required to test a single coating system for use at KSC.

Coating Evaluation Protocol

The NASA Corrosion Technology Laboratory tests both topcoated and non-topcoated samples at the NASA KSC Beachside Corrosion Test Site. An initial evaluation of the coating system is performed after 18 months of environmental exposure. If the coating passes the adhesion testing and 18-month exposure requirements, it is initially accepted into the qualified products list. The coatings remain at the test sit for a total exposure duration of 60 months. If the coating system qualifies according to the requirements of NASA-STD-5008B, final acceptance of the product is offered and the product remains on the qualified products list. If the system does not meet the requirements, it is removed from the qualified products list altogether.

The coated composite samples are subject to an acid slurry rinse every six weeks for the first eighteen months of exposure. The acidic slurry is used to simulate affluent from NASA's solid rocket boosters, and is produced by combining 0.3-micron Al_2O_3 particles in a hydrochloric acid (HCl) solution that is prepared by diluting concentrated HCl with water in a 1:9 ratio. The slurry is applied to the lower 2/3 of the topcoated panels with a polyethylene squeeze bottle.

Photographs are taken at the start of the 18-month exposure period. After all coating systems are applied and allowed to cure per the manufacturers requirements; the panels are mounted on test racks and transported to the KSC Beachside Corrosion Test Site stands. This site is located approximately 1.5 miles south of Launch Complex 39A at KSC. The coated test panels are installed on stainless steel racks that use porcelain or Teflon insulators as standoffs. The racks are installed on test stands that orient the samples at a 30° angle facing the ocean. The distance of the test stands from the mean high tide line is approximately 150 feet from the Atlantic Ocean. A photograph of a typical test rack is shown in Figure 4.

Figure 4. Typical Coating Test Rack

Laboratory adhesion testing is performed on the primer coated test panels at the beginning of the test protocol. Gloss and color measurements are collected prior to testing, after 18 months of coastal atmospheric exposure, and again after 60 months of atmospheric exposure. Evaluations of blistering according to ASTM D 714, "Standard Test Method for Evaluating Degree of Blistering of Paints", are performed according to the same schedule. [6] Corrosion evaluations according to ASTM D 610, "Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces", and coating degradation from the scribe according to ASTM D 1654 "Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments" are performed after 18 months and 60 months of coastal environmental exposure.[7,8]

Gloss

The gloss meter records the amount of reflective illuminated light at the specified angles of 20°, 60°, or 85°; and gives a value in gloss units (GU). The 60° geometry is used for most specimens, and is the initial angle used to determine whether the 20° or 85° angles may be more applicable. The 20° angle is used when the 60° angle gloss values are higher than 70 GU, while the 85° angle is used when the 60° angle gloss values are less than 10 GU. The 60° angle was used for the systems reported in this document since most of the values were between 10 GU to 70 GU. Gloss measurements were performed on the unexposed surfaces using a calibrated portable gloss meter.

According to NASA-STD-5008B, semi-gloss is defined as 60 GU to 85 GU at a 60-degree angle, and high gloss is defined as a minimum 85 GU at a 60-degree angle.[1] According to NASA-STD-5008B, coatings must retain gloss upon prolonged exterior exposure to the environment. Gloss measurements are taken according to ASTM D523, "Standard Test Method for Specular Gloss", in three spots on each panel face and averaged.

Gloss is an important criterion that affects the aesthetic qualities of a coating system. Additionally, a reduction in gloss can possibly indicate degradation to a coating over time. Table 1 illustrates three coatings (simultaneously tested) in which significant reductions in gloss were exhibited over 18 months of environmental exposure. Figure 5 (which correlates to Table 1) graphically depicts the reduction in gloss of the three coating systems as a function of exposure. The gloss of the sample decreases with time through the 18 months of coastal atmospheric exposure. In the case of System 2, corrosion ratings after 18 months of exposure indicated a substandard performance according to the NASA-STD-5008 requirements.

Table 1. 60° Gloss Measurements (G.U.'s)

	Average Gloss*				
System	initial	6 Month	12 Month	18 Month	Gloss Retention
1	62	62	53	46	74%
2	39	43	24	13	33%
3	69	76	65	47	67%

* average of four coupons

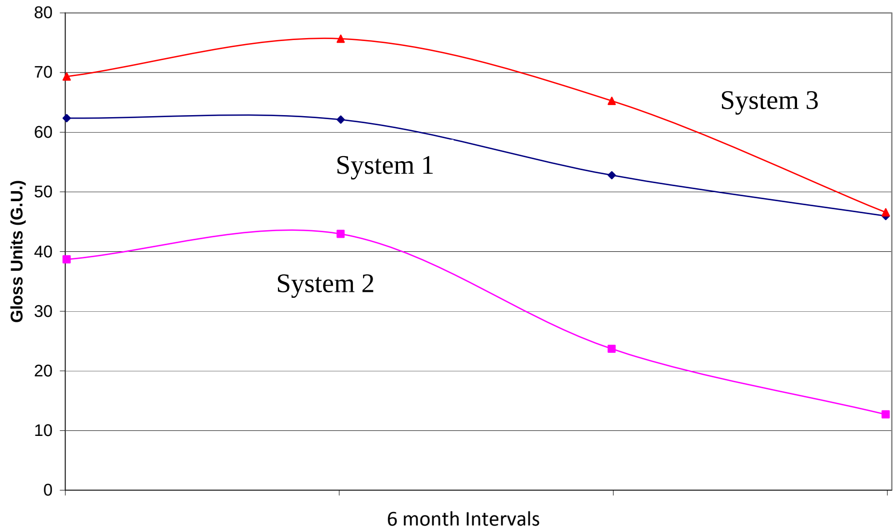

Figure 5. Gloss Retention vs. Exposure Time

Color

Color measurements are recorded according using the CIE L*a*b* format, D-65 illuminant, and a 10° observer; and changes are calculated according to ASTM D2244, "Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates."[10]

A color's "lightness" (L*) runs from light (white = 100) to dark (black = 0). A more reddish color gives a positive a* value, and conversely, a more greenish color will give a negative a* value. As with the a* values, the more bluish color gives a positive b* value, and a more yellowish color gives a negative b* value. A single number indicator of overall color change (delta E) is produced by calculating the square root of the sum of the squares of the lightness (L*) and color differences (a* and b*) according to the following equation (Eq. 1). The overall color change (delta E) is calculated as follows:

$$\text{Delta E}=\sqrt{(L_i - L_f)^2 + (a_i - a_f)^2 + (b_i - b_f)^2} \qquad \text{Eq. 1}$$

Where:

L_i = initial Lightness value $\quad$ a_i = initial Red/Green value

L_f = final Lightness value $\quad$ a_f = final Red/Green value

b_i = initial Blue/Yellow value $\quad$ b_f = final Blue/Yellow value

Generally, a delta E value of 1 is discernable by the human eye in a side-by-side comparison. However, in less than ideal lighting, a delta E value of 2 or 3 can still be considered the same color.

Color is of concern when the coating is used for color coding, safety purposes, identification, or special conditions. As one might imagine, color retention is also a significant issue for projects that the NASA Corrosion Technology Laboratory performs for the military, and the aesthetic qualities are important to industry.

According to NASA-STD-5008B, each coating system must retain its color after prolonged exterior exposure.[1] In a similar fashion to the gloss measurements, changes in the color of a coating system can depict changes (and possibly degradation) to the coating over time. Consequently, the color of the coating is monitored and reported after 18 months of exposure, and again at the end of 60 months of exposure.

Figure 6 presents a case example in which a single (four panel) coating system from a 12 coating sample set exhibited a significant change in color. As Figure 6 shows, sample #9 showed a change in color that is noticeable to the naked eye under less than ideal lighting conditions.

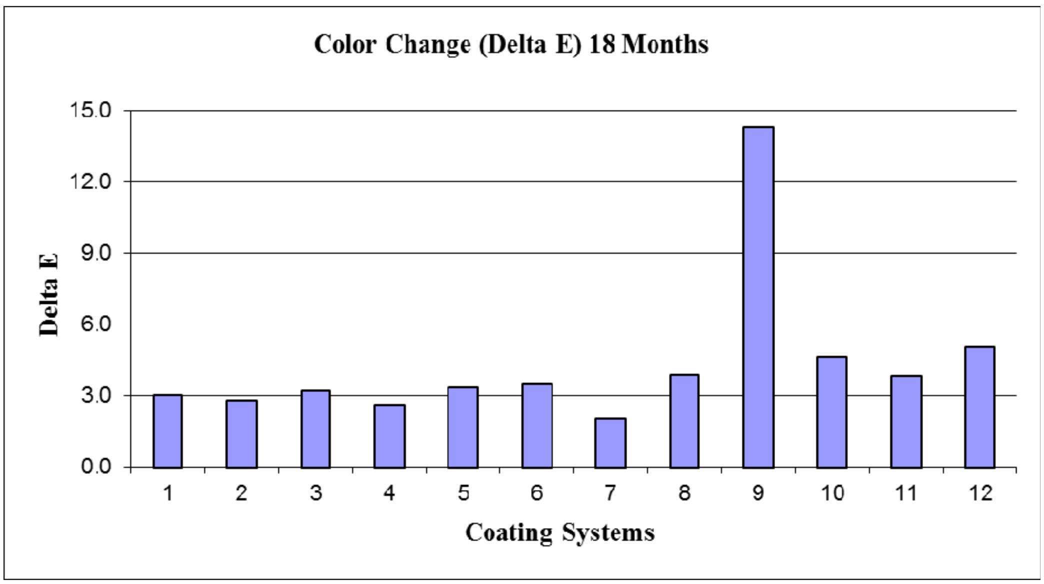

Figure 6. Color Change Coatings through 18 Months of Environmental Exposure

A change in color may signify degradation detrimental changes to the coating system, but in the case of this coating system, corrosion ratings indicated that it performed well. Figure 7 shows the pristine condition of sample set #9 at the beginning of testing. Figure 8 shows the discolored (non-corroded) condition of sample set #9 after 18 months of environmental exposure. The change in color (from a dark gray to green tinge) was noted and documented in the testing report, and the sample was not added to the approved products list.

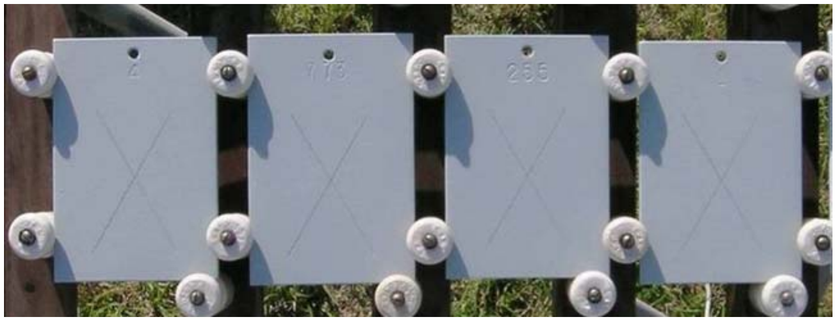

Figure 7. Sample Set #9 at Beginning of Test

Figure 8. Sample Set #9 after 18 Months of Environmental Exposure

Blistering

ASTM D 714, "Standard Test Method for Evaluating Degree of Blistering of Paints" provides photographic reference standards that are used to compare the size and frequency of blisters observed on the test panels.[6] The blister sizes range from 0 to 10, in which 10 represents no blistering and sizes -8, -6, -4, -2 represent progressively larger sizes. The frequency of blisters is reported as Few, Medium, Medium Dense, or Dense.

Per NASA-STD-5008B, the test sample must achieve a blister rating of 9F or better in accordance with ASTM D 714. Since 9F is not a listed rating in ASTM D 714, this means it must be better than an 8F. [1,6] Blister ratings are performed at the beginning of the test, after 18 months, and after 60 months of coastal atmospheric exposure. Blistering is not a problem that is often encountered with commercially produced coating systems that are tested at the NASA Corrosion Technology Laboratory. Unfortunately, exceptions to the rule exist and necessitate this requirement.

Figure 9 depicts a commercially available system that utilized an acrylic topcoat over an inorganic zinc primer from the same manufacturer. The coating system was applied per the manufacturer's requirements, yet significant blistering became evident during the curing stages of the coating. In this example, blistering occurred at the interface between the inorganic zinc and the acrylic topcoat prior to coastal atmospheric exposure. Consequently, the system was rejected for initial inclusion into the NASA Approved Products List.

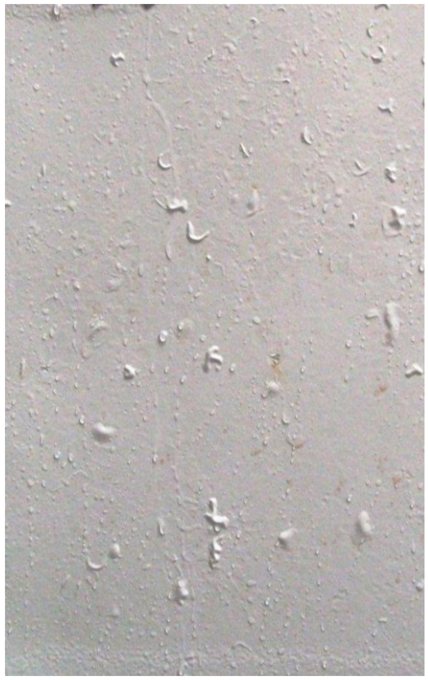

Figure 9. Blistering of Acrylic Topcoat over Inorganic Zinc

Corrosion under Paint

ASTM D 610, “Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surface”, rates the degree of corrosion on a scale from 0 to 10 (worst to best), in which each rating number represents the amount of rusted area.[7] The panels that are used for coating testing have approximately 32 square inches of exposed area. This calculates to 0.0096 square inches of corroded surface for a rating of "9", 0.032 square inches for a rating of "8", 0.096 square inches for a rating of "7", and so on. The entire rating scale can be found in ASTM D 610.[7]

ASTM D610 provides a series of visual aids that are used to determine the degree of rust on the surface of a panel, and are used to interpolate the degree of rusting that has occurred.[7] When panel ratings differ between the four panels in a set, a simple arithmetic mean is reported. In cases where the rating for a single panel shows extraneous degradation in comparison to the other three, the rating is not included in the average due to the possibility of application or preparation defects. All sets are prepared and exposed at the same time, and typically, all rating values are determined from a set of four panels and averaged.

For initial qualification for the NASA Approved products list, coatings are evaluated according to ASTM D 610 after 18 months of coastal atmospheric exposure. Aliphatic polyurethane, water reducible, and polysiloxane topcoats must achieve an ASTM D 610 rating of 8 or better. Inorganic zinc primers and inorganic topcoat systems must achieve an ASTM D 610 rating of 9 or better. The qualifying coating systems will remain on the qualified products list until 60 months of coastal atmospheric exposure is achieved, and are again rated according to aforementioned criteria for final qualification onto the approved products list.

Figure 10 and Figure 11 are two different coating systems that were tested at the same time. Both coating systems were not topcoated, and as a result, were not acid rinsed as a part of the study. The first pictures in each figure corresponds to the results after 18 months of coastal atmospheric environmental exposure, while the second picture in each figure documents the condition of the panels after 60 months of exposure. As the pictures in Figure 10 indicate, no corrosion was evident on the surface of the panel after the 18 month and 60 month evaluations. After 60 months of exposure, this system was approved for final acceptance. In contrast, the coating system in Figure 11 was not initially accepted after 18 months of coastal atmospheric exposure due to corrosion, but remained at the test site through the 60 months of exposure. As the second picture in Figure 11 shows, the extended exposure resulted in a significant increase in corrosion after 60 months.

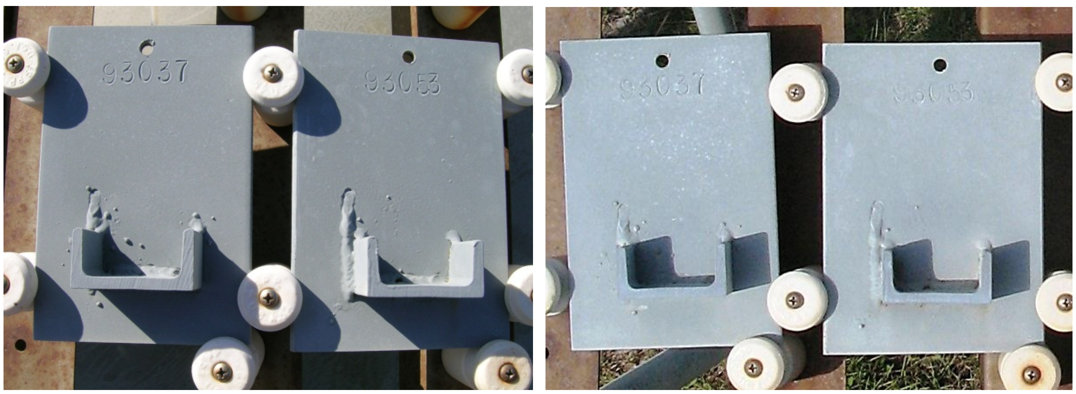

Figure 10. 18 Month and 60 Month Exposure – Approved for Use

Figure 11. 18 Month and 60 Month Exposure – Not Approved for Use

Corrosion from the Scribe

Ratings in ASTM D 1654, "Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments", follow a scale similar to ASTM D 610, except the ratings are based on the mean degradation from the scribe.[8] This process necessitates that the evaluator determine the extent (length) of corrosion that traverses from the scribe on the surface of the panel. Per NASA-STD-5008B, aliphatic polyurethane, water reducible, and polysiloxane topcoats (not acid rinsed) must achieve an ASTM D 1654 rating of 8 or better to be included into the approved products list. Inorganic topcoats (not acid rinsed) must achieve an ASTM D 1654 rating of 9 or better. [1,8] According to ASTM D 1654, a rating of 10 is equivalent to no degradation or undercutting from the scribe. A rating of 9 is achieved when degradation or undercutting from the scribe is up to 0.5 mm. A rating of 8 according to ASTM D 1654 is achieved when degradation or undercutting from the scribe is greater than 0.5mm to 1mm in length. The complete rating system of mean creepage from the scribe can be found in ASTM D 1654.[8]

Figure 12 shows the 18-month and 60-month pictures for a topcoated (not acid rinsed) coating that was qualified for use at KSC. Figure 13 shows the 18-month and 60-month topcoated (not acid rinsed) samples at the NASA Beachside Corrosion Test Site. After 18 months of coastal atmospheric exposure, the samples did not satisfy the requirements of NASA-STD-5008B. The second photograph (in the same figure) shows the extent of degradation of the same system after 60 months of exposure.

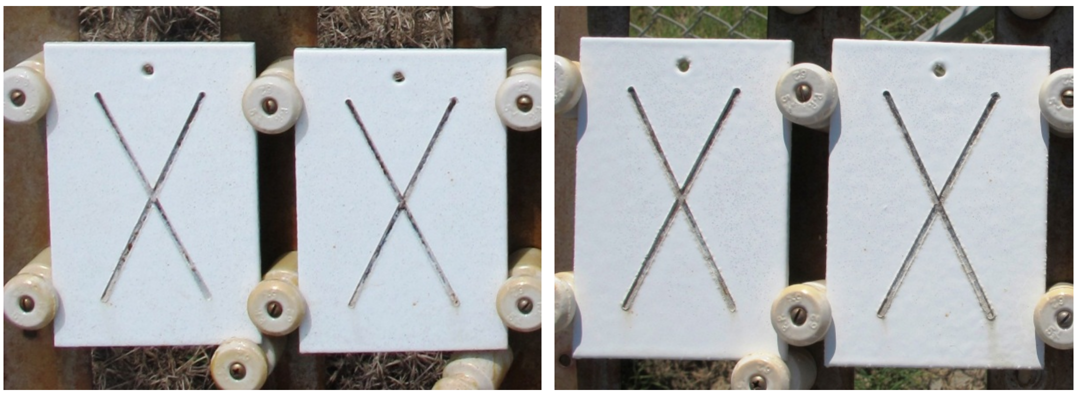

Figure 12. 18 Month and 60 Month Exposure – Approved for Use

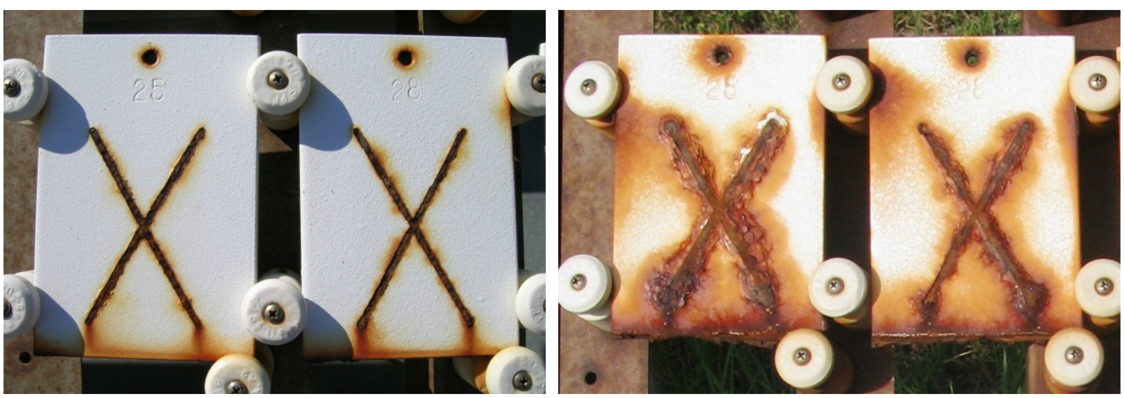

Figure 13. 18 Month and 60 Month Exposure – Not Approved for Use

Adhesion

NASA Corrosion Technology Laboratory protocol requires inorganic zinc primers to have a temperature resistance of at least 400°C (750°F) for use on launch structures and ground support equipment subject to the elevated temperatures from rocket exhaust. This requirement is tested by exposing inorganic zinc coated panels in a high temperature oven at a temperature of 400°C for 24 hours. Prior to heating, each zinc coating is tested for tensile adhesion per ASTM D 4541, "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers".[11] The panels are then exposed to one heat cycle and retested for tensile adhesion to check for adhesion loss or film deterioration caused. Any visual deterioration, such as the destruction or burning of the coating, would qualify the product as a failure. Loss of adhesion after heating would also constitute a failure due to temperature effects on the film thereby disqualifying the coating.

SUMMARY

This paper discusses the testing protocol that The KSC Corrosion Laboratory uses to qualify protective coatings for use on launch structures and ground support equipment at NASA's Kennedy Space Center. Sample preparation and methods of exposure are presented. The methods of exposure center upon laboratory adhesion tests and coastal marine atmospheric exposure. The specific test methodologies that are used to determine whether a coating qualifies for the approved products list are discussed. These metrics are associated with the coatings color, blistering, corrosion under paint, corrosion from the scribe, and adhesion after heating. Coatings are initially qualified for the NASA Approved Products List after the laboratory adhesion testing requirements are passed, and the samples have performed to the specifications required after 18 months of beachside exposure. If a coating system passes the 60-month qualification requirements, it is retained on the approved products list and achieves a "Final Qualification" status.

ACKNOWLEDGEMENTS

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9. ASTM D523-99 "Standard Test Method for Specular Gloss"

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