A Five-Year Performance Study of Low VOC Coatings over Zinc Thermal Spray for the Protection of Carbon Steel at the Kennedy Space Center

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ABSTRACT

The launch facilities at the Kennedy Space Center (KSC) 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.

While currently used coating systems provide excellent corrosion control performance, they are subject to occupational, safety, and environmental regulations at the Federal and State levels that limit their use. Many contain high volatile organic compounds (VOCs), hazardous air pollutants, and other hazardous materials. Hazardous waste from coating operations include vacuum filters, zinc dust, hazardous paint related material, and solid paint. There are also worker safety issues such as exposure to solvents and isocyanates. To address these issues, top-coated thermal spray zinc coating systems were investigated as a promising environmentally friendly corrosion protection for carbon steel in an acidic launch environment. Additional benefits of the combined coating system include a long service life, cathodic protection to the substrate, no volatile contaminants, and high service temperatures. This paper reports the results of a performance based study to evaluate low VOC topcoats (for thermal spray zinc coatings) on carbon steel for use in a space launch environment.

Key words: Thermal Spray, Thermal Spray Coating (TSC), Zinc, Atmospheric Exposure, volatile organic compounds (VOCs), Atmospheric Exposure, sacrificial

INTRODUCTION

An applied coating system is the standard practice that is used for corrosion protection of metallic substrates that are exposed to atmospheric environments. Applied coating systems offer corrosion protection by a variety of mechanisms that may include a barrier effect, a galvanic effect, the use of corrosion inhibitors, or a combination of these. Applied coatings adhere to the substrate through a combination of chemical and physical bonds. An applied coating system is typically comprised of three components/layers: a primer, an intermediate coating, and a topcoat.

For steel substrates, the most common type of primer used is zinc-rich primers. These primers may be either organic or inorganic. Zinc primers protect steel in two ways: they create a barrier, in which the primer covers the steel to prevent contact with corrosive elements, and by galvanic protection, which occurs because zinc is more active than steel and sacrifices (corrodes) preferentially to protect the underlying steel substrate. Generally, intermediate coatings are epoxies and topcoats are polyurethanes, acrylics, or siloxanes. When used in combination, the system is capable of providing excellent corrosion resistance.

Currently used liquid applied coating systems provide excellent corrosion control performance. However, they can be subject to occupational, safety, and environmental regulations at the Federal and State levels that limit their use. Many contain volatile organic compounds (VOCs), hazardous air pollutants (HAPs), and other hazardous materials. Hazardous waste materials that are the byproduct of coating operations include vacuum filters, zinc dust, hazardous paint related material, and solid paint. Furthermore, there can be worker safety issues related to their exposure to solvents and isocyanates.

Thermal spray coatings (TSCs) provide an alternative option to the traditional liquid applied coating systems. The TSC process uses a metal that is melted in an electric arc or flame sprayed onto a surface where it forms a coating for corrosion and/or wear protection. The primary benefits of TSC include:

- Coating service life of 20 to 40 years in a seacoast environment
- Zero-VOC coating process that provides cathodic protection to the substrate
- No isocyanates
- A service temperature of 250 to 2100 degrees Fahrenheit.

TSCs are approved for use in in the NASA Coatings Standard, NASA-STD-5008, “Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on Launch Structures, Facilities, and Ground Support Equipment.”[1] However, no topcoats for use over a TSC basecoat have been tested or approved for NASA launch structures and assets.

This paper reports on TSC/topcoat combinations that were investigated for use on steel structures, components, and ground support equipment in order to provide corrosion protection and reduce VOCs and hazardous waste. In this investigation, low VOC coating systems were applied over zinc TSC primers and evaluated for compatibility with zinc TSC and corrosion protection.

EXPERIMENTAL PROCEDURE

Coupon Material

4 in x 6 in x 3/16 in (10.2 cm x 15.2 cm x .5 cm) flat and composite panels, fabricated from ASTM A36[2] hot rolled carbon steel, were used as a base substrate for each coating system. The composite panels have a 1" channel welded on the front and incorporate surface irregularities, commonly found in actual structures, such as welds, crevices, and sharp edges. The test panels were abrasive blasted to a white metal condition (SSPC-SP5) to remove any mill scale and weld slag that might be present. The anchor profile created by the abrasive blast media was measured and documented. Values ranged from 2.5 to 3.0 mils using the Test-X replica tape method. An example of the coated test panels is shown in Figure 1.

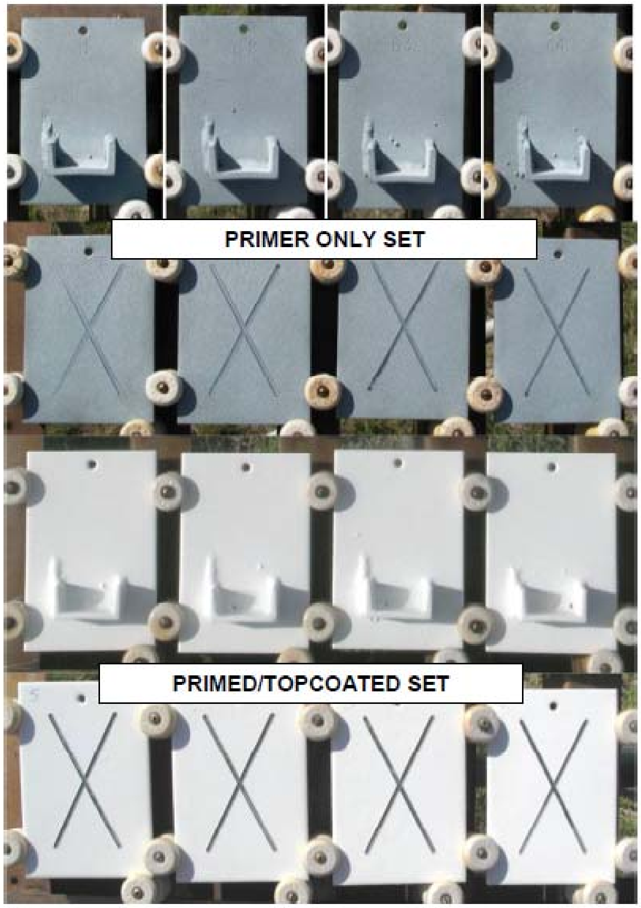

Figure 1: Typical Composite and Scribed Panel Set

Coating Systems

A single TSC basecoat (primer) was chosen for all systems. Additionally, this TSC was used as a control in a non-topcoated condition. This system had previously been tested and passed according to the NASA-STD-5008B requirements.

Internet searches and phone interviews with coating manufacturer representatives were performed to research and solicit suitable midcoat and topcoat systems. This effort resulted in a list of potential candidate coating systems, which were considered for review and selection. The coatings selected for this study were chosen based upon their low volatile organic content and are presented by their generic base resin in Table 1.

Table 1: Generically Labeled Coating Systems

System	Midcoat	Finish coat
control	100% zinc wire applied, no topcoat	
1	epoxy	polyurethane
2	none	acrylic
3	epoxy	acrylic
4	epoxy	polyurethane
5	none	polyurethane
6	none	polyurethane
7	none	acrylic-elastomeric
8	none	TGIC polyester powder
9	epoxy	polyurethane
10	penetrating epoxy	polysiloxane
11	epoxy	polysiloxane
12	epoxy	modified polyurethane

Coating Evaluation Protocol

In preparation for the atmospheric field exposure testing, 8 TSC only panels (control) were coated. Two different conditions were used:

(1) Four primer-only composite panels exposed to normal conditions
(2) Four primer-only flat panels with 0.32 cm (1/8") scribe exposed to normal conditions

Additionally, 12 panels per topcoated system were prepared. Three different conditions were used:

(1) Four full system composite panels exposed to normal conditions
(2) Four full system composite panels exposed to normal conditions plus aluminum oxide (Al_2O_3) acid-slurry applications.
(3) Four full system flat panels with 0.32 cm (1/8") scribe exposed to normal conditions

Figure 2 shows the sample matrix for each topcoated system.

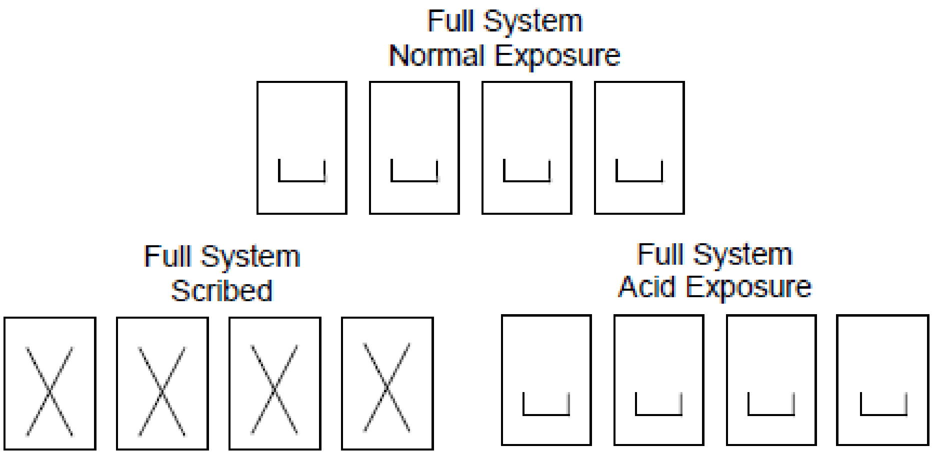

Figure 2: Topcoated TSC Sample Matrix

The acidic slurry was used to represent effluent from solid rocket boosters. The slurry is obtained 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 was periodically applied to the lower 2/3 of the panels using a polyethylene squeeze bottle every six weeks, for the first eighteen months.

Systems that pass the criteria discussed in this paper are added to NASA's approved products list (APL) after 18 months of evaluation. A final evaluation is performed after 5 years of coastal atmospheric exposure. If the coated panels do not provide the required level of protection by the end of the fifth year, the coating system is removed from the APL. If the coatings pass the five-year requirements (according to the same rating criteria), they remain on the APL.

After all coating systems were applied and allowed to cure per the manufacturers requirements, the panels were mounted on test racks and mounted on the KSC Beachside Corrosion Test Site stands. This site is located approximately 1.5 miles south of Launch Complex 39A at KSC (Figure 3). The coated test panels were installed on stainless steel racks that use porcelain insulators as standoffs. The racks were 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 of the Atlantic Ocean is approximately 150 feet.

Figure 3: KSC Beachside Corrosion Test Site

The panels were placed at the atmospheric test site on October 10, 2008, and were evaluated according to the schedule outlined in Table 2. All samples were photo documented prior to exposure, after 18 months of exposure, and again at the end of the 60-month trial period.

Table 2: Coupon Evaluation Schedule

Inspection	Date	Frequency	Inspection Type
1	10/10/2008	0 mo	initial Gloss-Color-Corrosion
2	4/10/2009	6 mo	Gloss-Color
3	10/10/2009	12 mo	Gloss-Color
4	4/10/2010	18 mo	Gloss-Color-Corrosion
5	10/10/2013	60 mo	Corrosion

Adhesion

The NASA coating standard (NASA-STD-5008)[1] requires that inorganic zinc coatings must 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 satisfied by exposing inorganic zinc coated panels in a high temperature oven at a temperature of 400°C for 24 hours. Any visual deterioration, such as the destruction or burning of the coating, would qualify the product as a failure. Loss of adhesion after heating also would constitute a failure due to temperature effects on the film.

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”.[3] The panels are exposed to one heat cycle (400°C for 24 hours) and retested for tensile adhesion to check for adhesion loss or film deterioration caused by heating.

Since the TSC in this study is considered a replacement for the zinc primers, it was tested using the same process. In summary, one half inch aluminum pull stub was prepared and bonded to each of the TSC panels, allowed to dry for 24 hours, and then pulled using a PATTI pneumatic adhesion tester. Afterward, they were placed in an oven at the required temperature and time, and the adhesion test process was repeated.

Gloss

The tri-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 GUs while the 85° angle is used when the 60° angle gloss values are less than 10 GUs. 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 at the 60° angle.

Color

Color measurements were recorded at ambient temperatures (20°- 25° C) on a handheld portable color meter using the CIE L*a*b* format, D-65 illuminant, and a 10° observer. The data was collected and saved as a baseline to calculate deviations in color as a function of time. A color’s "lightness" (L*) runs from light (white = 100) to dark (black = 0). A more reddish color will give 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 will give a positive b* value and a more yellowish color will give a negative b* value.

A single number indicator of overall color change (delta E) will be produced by calculating the square root of the sum of the squares of the lightness (L*) and color differences (a* and b*) according to equation 1 below. The overall color change (delta E) was 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 a_i = initial Red/Green value

L_f = final Lightness value a_f = final Red/Green value

b_i = initial Blue/Yellow value b_f = final Blue/Yellow value

Corrosion Ratings

Corrosion ratings were performed using ASTM D 714 “Standard Test Method for Evaluating Degree of Blistering of Paints”[4], ASTM D 610 “Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces”[5], and ASTM D 1654 “Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments”.[6] These ratings were performed at the end of the 18 month and 60 month atmospheric exposure period.

ASTM D 714 Ratings.

ASTM D 714[4] provides photographic reference standards (Figure 4) that are used to compare the size and frequency of blisters observed on the test panels. 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.

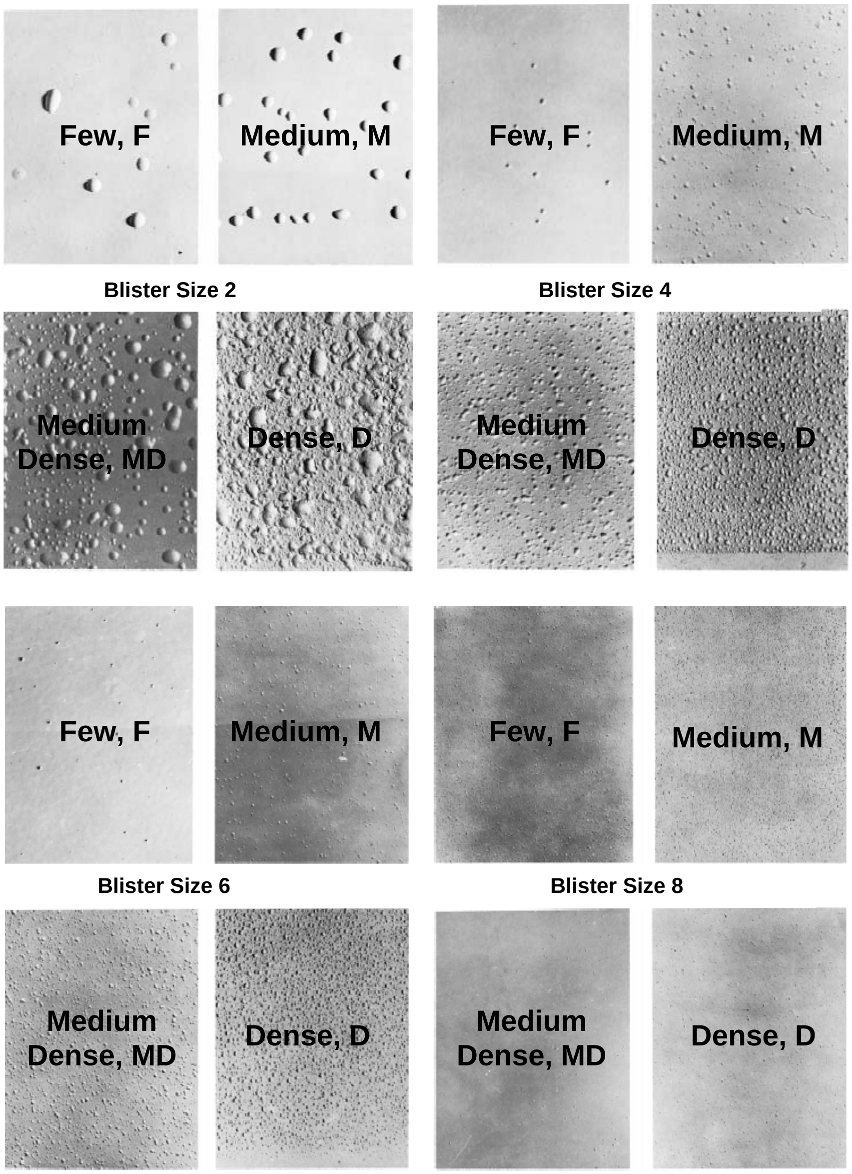

Figure 4: ASTM D 714 Blister Reference Photographs[4]

ASTM D 610 Ratings.

ASTM D 610[5] 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. Rating numbers as a function of surface rusted are provided in Table 3. The ASTM provides a series of visual aids that are used to determine the percent of the panel that is rusted.

Table 3: ASTM D 610 Rating Scale[5]

Rating	Description
10	No rusting or less than 0.01% of surface rusted.
9	Minute rusting, less than 0.03% of surface rusted.
8	Few isolated rust spots, less than 0.1% of surface rusted.
7	Less than 0.3% of surface rusted.
6	Extensive rust spots, but less than 1% of surface rusted.
5	Rusting to the extent of 3% of surface rusted.
4	Rusting to the extent of 10% of surface rusted.
3	Approximately 1/6 of the surface rusted.
2	Approximately 1/3 of the surface rusted.
1	Approximately 1/2 of surface rusted.
0	Approximately 100% of surface rusted.

ASTM D 1654 Ratings.

The ASTM D 1654[6] ratings follow a scale similar to that of the ASTM D 610[5] where the ratings are based on the mean creepage (corrosion or undercutting of the coating) from the scribe (Table 4).

Table 4: ASTM D 1654 Rating Scale[6]
Representative Mean Creepage from Scribe

Millimeters	Approximate Inches	Rating Number
0	0	10
Over 0.0-0.5	0- 1/64	9
Over 0.5-1.0	1/64- 1/32	8
Over 1.0-2.0	1/32- 1/16	7
Over 2.0-3.0	1/16- 1/8	6
Over 3.0-5.0	1/8- 3/16	5
Over 5.0-7.0	3/16- 1/4	4
Over 7.0-10.0	1/4- 3/8	3
Over 10.0-13.0	3/8- 1/2	2
Over 13.0-16.0	1/2- 5/8	1
Over 16.0	5/8-more	0

RESULTS

Adhesion

A single TSC coating (three samples) was used for all adhesion testing. All pre-heat failure mechanisms were adhesive bonding failures between the TSC and the substrate. The post-heat failure was a cohesive failure within the TSC itself. As shown in Table 5, the pre-heat adhesion pull-off values averaged approximately 950 psi while post-heat values averaged 1140 (an increase in adhesion of 190 psi). The increased post-heat pull-off values are common for zinc-coated samples, and indicate that there was no loss of adhesion (or deterioration) from heating. Both values were well above the minimum adhesion criteria of 500 psi stated in SSPC-CS 23.00/AWS C2.23M/NACE No. 12, “Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel”.[7]

Table 5: Thermal Sprayed Zinc (TSC) Primer Adhesion

Sample	Pre-heat (psi)	Post-heat (psi)	difference (psi)
1	933	1023	90
2	956	1160	204
3	954	1237	284

Gloss

The initial and time dependent gloss retention data is presented in Table 6 and Figure 5. 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 outdoor exposure to the environment but does not give a numerical definition of retention.

Gloss measurements were taken according to ASTM D523, “Standard Test Method for Specular Gloss”, in three spots on each panel face and averaged. Analysis of the data shows that systems one, two, and eight retained the highest degree of initial gloss.

After 18 months of beachside atmospheric exposure, System 1 was the only topcoat that exhibited GU values that are indicative of a semi-gloss finish. In most cases, gloss is not a criterion for the use of a coating on NASA’s launch structures.

Table 6: 60° Specular Gloss of Full System Coatings (18 month)

System	Initial Gloss	6-month Gloss	12-month Gloss	18-month Gloss	Final Gloss Retention
1	64.3	62.5	60.9	61.5	96%
2	10.1	9.8	9.9	10.2	101%
3	28.9	16.9	18.6	22.2	77%
4	64.0	65.3	64.1	55.6	87%
5	63.8	56.8	52.6	46.6	73%
6	26.1	18.5	17.8	18.3	70%
7	9.8	3.5	8.9	8.5	87%
8	41.5	37.4	39.5	40.7	98%
9	69.0	59.5	57.7	58.9	85%
10	70.0	70.5	74.3	56.2	80%
11	65.3	62.4	59.6	54.9	84%
12	54.3	49.5	44.7	38.3	71%

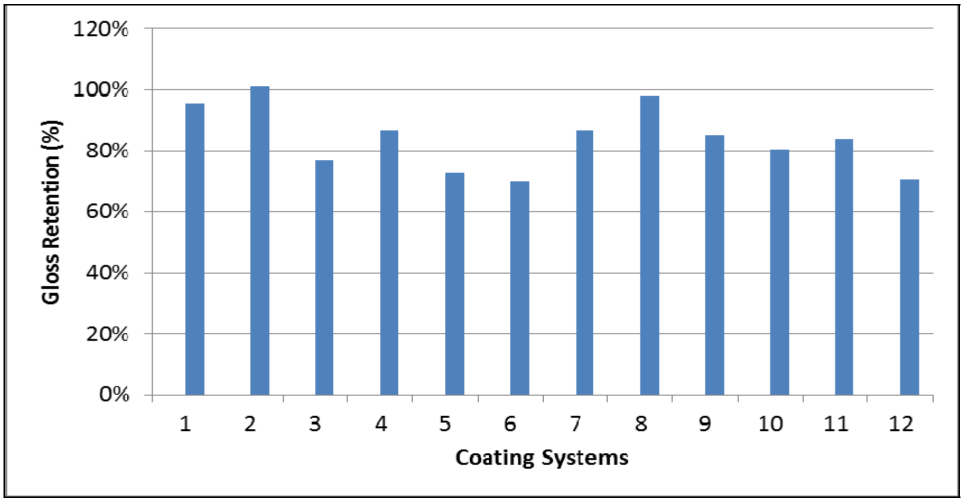

Figure 5: 18-Month Gloss Retention of KSC Field Coatings

Color

While color is not a part of the pass/fail criteria according to NASA-STD-5008[1], appearance may be a criterion for the design engineer. 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 be indicative of physical changes (and possibly degradation) to the coating. Consequently, the color of the coating is monitored and reported through 18 months of exposure.

Generally, a delta E value of 1 would be 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. As shown in Table 7 and Figure 6, all coating systems exhibited color retention that can be considered suitable. A side-by-side comparison of an unexposed and exposed (18 month) coating from system 7 might be distinguishable by the human eye, though the slight change isn't considered significant for safety or aesthetic purposes. Extreme changes in color can be indicative of degradation to the coating system that reduces the corrosion protective properties of the system. In most cases, samples that have poor color retention also perform poorly in the corrosion testing that is performed. For the sample sets tested as a part of this study, significant changes in color were not apparent for any system.

Table 7: Color Difference of Full Coating Systems

System	6 Month ΔE	12 Month ΔE	18 Month ΔE
1	1.6	1.5	1.9
2	1.7	2.0	1.5
3	1.2	2.2	1.6
4	1.4	2.1	1.8
5	1.6	1.5	1.7
6	1.4	1.5	1.5
7	3.2	3.3	3.6
8	1.7	1.8	1.7
9	1.6	1.6	1.6
10	1.4	1.4	1.5
11	1.4	1.7	1.8
12	0.7	0.9	1.3

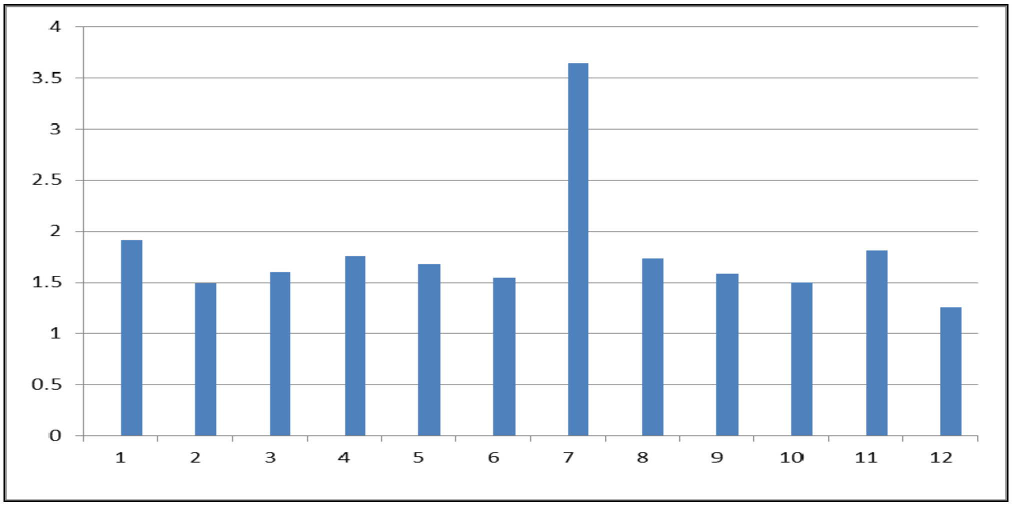

Figure 6: 18-Month Delta E Color Change of KSC Field Coatings

Corrosion Ratings

According to the NASA-STD-5008B Standard, each topcoated TSC must attain a numerical rating of not less than 8 in accordance with ASTM D610[5] and ASTM D1654[6]. Furthermore, the coating must attain a numerical blister rating of not less than 9F in Accordance with ASTM D714[4].

The final rating value for each coating system is an average of the ratings for four individual panels and is listed in accord with the ASTM method of evaluation in Tables 8-10. Where the panel ratings differed from panel to panel, a simple arithmetic mean is reported. In cases where the rating for a single panel showed extraneous degradation in comparison to the other three, the rating was not included in the average due to the possibility of application or preparation defects. All sets were prepared and exposed at the same time. Typically, all rating values were determined from a set of four panels and were averaged.

ASTM D 610 Ratings.

According to the NASA-STD-5008B requirements for the topcoats used in this study, an ASTM D 610 rating of at least an 8 is required for approval of the system. The ratings reported in Table 8 correspond to the composite panels that were acid rinsed. This represents the most severe condition that the topcoats are likely to encounter.

As indicated in Table 8, all coating evaluations showed no indications of corrosion under paint, though several of the specimens suffered from the deleterious effects of topcoat delamination. An example of this phenomenon (for System 10) is shown in Figure 7. Consequently, Systems 8 and 10 did not pass according to the ASTM D610 requirements, though all other systems met this requirement.

Table 8: ASTM D 610 60-Month Visual Corrosion Ratings

	SSPC-VIS 2 "G" Ratings				
System	**Panel 1**	**Panel 2**	**Panel 3**	**Panel 4**	**Average**
control	10	10	10	10	10
1	10	10	10	10	10
2	10	10	10	10	10
3	10	10	10	10	10
4	10	10	10	10	10
5	10	10	10	10	10
6	10	10	10	10	10
7	10	10	10	10	10
8	0	0	0	0	0
9	10	10	10	10	10
10	0	0	0	0	0
11	10	10	10	10	10
12	10	10	10	10	10

Figure 7: Severe Coating Delamination of System 10

ASTM D 1654 Ratings.

Table 9 shows the performance of the scribed coated specimen as tested in accord with ASTM D 1654 "Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments".[6] According to the NASA-STD-5008B Standard, an ASTM D1654 rating of at least an 8 (rounded rating from 4 samples) is required for the topcoats investigated in this study to gain acceptance. The scribed panels were not acid rinsed.

After 18 months of beachside atmospheric exposure, no degradation from the scribe was evident for any sample tested. After 60 months of coastal atmospheric exposure, several of the samples failed to perform to a degree that would allow final acceptance (Table 9). Anomalies included delamination from the scribe for Systems 8 and 10 and corrosion from the scribe for Systems 3, 5, 7 and 9. An example of corrosion under cutting the coating for a single sample from System 9 is shown in Figure 8.

Table 9: ASTM D 1654 60-Month Scribe Failure Ratings

System	Panel 1	Panel 2	Panel 3	Panel 4	Average
control	10	10	10	10	10
1	10	10	10	10	10
2	8	7	8	7	8
3	3	3	3	3	3
4	8	7	8	7	8
5	6	7	6	7	7
6	7	8	8	7	8
7	7	5	6	6	6
8	3	3	3	3	3
9	3	3	3	1	3
10	0	0	0	0	0
11	10	10	10	10	10
12	8	8	8	8	8

Figure 8: Undercutting from the Scribe for Sample from System 9

ASTM D 714 Ratings.

ASTM D 714 “Standard Test Method for Evaluating Degree of Blistering of Paints”[4], was used to evaluate any blistering of or through the coating system. According to the NASA-STD-5008B standard for the topcoats used in this study, a rating of at least a 9F is required to gain acceptance and final approval.

The ratings reported in Table 10 were for the composite panels that were acid rinsed. This represents the most severe condition that the topcoats are likely to encounter. As shown in Table 10, blistering was evident underneath the coatings for Systems 5, 7 and 9. These systems were determined to be unacceptable for final approval.

Table 10: ASTM D 714 Degree of Blistering – 60 Month
(0=None, F=Few, M=Medium, MD=Medium Dense, and D=Dense)

System	Panel 1	Panel 2	Panel 3	Panel 4	Average	Frequency
control	10	10	10	10	10	0
1	9	9	9	9	9	F
2	4	6	4	6	5	M
3	10	10	10	10	10	0
4	10	10	10	10	10	0
5	4	6	4	6	5	MD
6	9	9	9	9	9	F
7	10	10	10	10	10	0
8	10	10	10	10	10	0
9	9	2	2	2	3.75	F
10	10	10	10	10	10	0
11	10	10	10	10	10	0
12	10	10	10	10	10	0

Summary of Corrosion Ratings.

The primary pass/fail criteria for final acceptance of the topcoats are dependent upon the corrosion evaluations that were previously discussed. The combined summary of results is shown in Table 11. As shown on the table, only Systems 1, 4, 6, 11 and 12 were approved. System 11 was the only polysiloxane finish of the two that were tested that was approved. This system utilized an epoxy mid coat. System 6 is the only finish coat that passed without a mid-coat being required. The finish coat was a polyurethane product. Systems 1, 4 and 12 all used epoxy mid-coats with polyurethane topcoats. None of the acrylic topcoats (with or without an intermediate coat) performed to a level that would be acceptable for use on NASA launch structures and assets.

Table 11: 60-Month Summary of Corrosion Related Evaluations

		ASTM's		
System	610	1654	714	Approved
control	Pass	Pass	Pass	Yes
1	Pass	Pass	Pass	Yes
2	Pass	Pass	Fail	No
3	Pass	Fail	Pass	No
4	Pass	Pass	Pass	Yes
5	Pass	Fail	Fail	No
6	Pass	Pass	Pass	Yes
7	Pass	Fail	Pass	No
8	Fail	Fail	Pass	No
9	Pass	Fail	Fail	No
10	Fail	Fail	Pass	No
11	Pass	Pass	Pass	Yes
12	Pass	Pass	Pass	Yes

CONCLUSIONS

Twelve coating systems and a control were tested according to the NASA-STD-5008B requirements for coatings at KSC. Post heat-treated adhesion values of the TSC primer (control) were higher than those obtained for the preheat determinations and met the 500 psi requirement. This TSC primer was topcoated with the twelve systems being studied. After 18 months of coastal atmospheric exposure, all coating systems passed the corrosion requirements of the NASA-STD-5008B standard. In contrast, the 60-month corrosion related determinations only allowed for the recommendation of Systems 1, 4, 6, 11 and 12 to remain on the approved products list. Aesthetically, Systems 1, 2 and 8 retained the highest degree of initial gloss and the only coating that exhibited a color change that might be visible to the human eye in less than ideal lighting conditions is system 7.

ACKNOWLEDGEMENTS

The authors of this paper would like to thank NASA, and the NASA TEERM office for funding the project. The authors would also like to acknowledge technical support from the coating vendors, the NASA Coating Standard Working Group, and Kevin Cooksey.

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