Joint Test Report

For Validation of Alternatives to Aliphatic Isocyanate Polyurethanes

FINAL

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August 31, 2007

Prepared by
ITB, Inc.
Beavercreek, OH 45432

Submitted by
NASA Technology Evaluation for Environmental Risk Mitigation Principal Center

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PREFACE

This report was prepared by ITB, Inc. through the National Aeronautics and Space Administration (NASA) Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM) under Contract Number NAS10-03029. The structure, format, and depth of technical content of the report were determined by TEERM, Government contractors, and other Government technical representatives in response to the specific needs of this project.

We wish to acknowledge the invaluable contributions provided by all the organizations involved in the creation of this document including Kennedy Space Center, Stennis Space Center, Air Force Space Command, Mississippi Space Services, and the NASA Corrosion Technology Laboratory.

This document has been prepared solely to report the results of the testing performed during this project and is not intended to and does not connote endorsement of the product by NASA.

EXECUTIVE SUMMARY

National Aeronautics and Space Administration (NASA) and Air Force Space Command (AFSPC) have similar missions and therefore similar facilities and structures in similar environments. The standard practice for protecting metallic substrates in atmospheric environments is the application of an applied coating system.

The most common topcoats used in coating systems are polyurethanes that contain isocyanates. Isocyanates are classified as potential human carcinogens and are known to cause cancer in animals. The primary objective of this effort was to demonstrate and validate alternatives to aliphatic isocyanate polyurethanes resulting in one or more isocyanate-free coatings qualified for use at AFSPC and NASA installations participating in this project.

This Joint Test Report (JTR) documents the results of the laboratory and field testing as well as any test modifications made during the execution of the testing. The technical stakeholders agreed upon test procedure modifications documented in this document. This JTR is made available as a reference for future pollution prevention endeavors by other NASA centers, the Department of Defense and commercial users to minimize duplication of effort.

All coating system candidates were tested using approved NASA and AFSPC standard coating systems as experimental controls. This study looked at eight alternative coating systems and two control coating systems and was divided into Phase I Screening Tests, Phase II Tests, and Field Testing.

The Phase I Screening Tests were preliminary tests performed on all the selected candidate coating systems. Candidate coating systems that did not meet the acceptance criteria of the screening tests were eliminated from further testing. Phase I Screening Tests included:

- Ease of Application
- Surface Appearance
- Dry-To-Touch (Sanding)
- Accelerated Storage Stability
- Pot Life (Viscosity)
- Cure Time (Solvent Rubs)
- Cleanability
- Knife Test
- Tensile (Pull-off) Adhesion
- X-Cut Adhesion by Wet Tape

After a review of the Phase I test results, four of the alternative coating systems showed substandard performance in relation to the Control Systems and were eliminated from the

Phase II testing. Due to the interest of stakeholders and time constraints, however, all eight alternatives were subjected to the following Phase II tests, along with field testing at Stennis Space Center (SSC), Mississippi:

- Hypergol Compatibility
- Liquid Oxygen Compatibility
- 18-Month Marine Exposure
    - Gloss Retention
    - Color Retention
    - Blistering
    - Visual Corrosion
    - Creepage from Scribe
    - Heat Adhesion
- Field Exposure (6- and 12-month Evaluation)
    - Coating Condition
    - Color Retention
    - Gloss Retention

The remaining four alternative coating systems determined to be the best viable alternatives were carried on to Phase II testing that included:

- Removability
- Repairability
- Abrasion Resistance
- Gravelometer
- Fungus Resistance
- Accelerated Weathering
- Mandrel Bend Flexibility
- Cyclic Corrosion Resistance

Of the systems that continued to Phase II, three (3) alternative coating systems meet the performance requirements as identified by stakeholders. Two (2) other systems, that were not included in Phase II testing, performed well enough on the 18-Month Marine Exposure, the primary requirement for NASA technical standard NASA-STD-5008, *Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on Launch Structures, Facilities, and Ground Support Equipment*, that they were also considered to be successful candidates.

In total, five (5) alternative coating systems were approved for inclusion in the NASA-STD-5008 Qualified Products List (QPL). The standard is intended to provide a common framework for consistent practices across NASA and is often used by other entities. The standard's QPL does not connote endorsement of the products by NASA, but lists those products that have been tested and meet the requirements as specified.

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ABBREVIATIONS

AFSPC	Air Force Space Command
Al_2O_3	Aluminum Oxide
AST	AquaSurTech
Avg	Average
C	Celsius
cks	centistokes
DFT	Dry Film Thickness
Eq	Equation
F	Fahrenheit
ft-lbs	foot-pounds
FTP	Field Test Plan
GM	General Motors
GU's	Gloss Units
HazMats	Hazardous Materials
hrs	hours
IPC	International Protective Coatings
JTP	Joint Test Plan
JTR	Joint Test Report
KSC	Kennedy Space Center
LOX	liquid oxygen
MEK	Methyl Ethyl Ketone
mil	0.0001 inch
mm	millimeter
MMH	Monomethylhydrazine
N_2H_4	Hydrazine
N_2O_4	Nitrogen Tetroxide
NA	Not Applicable
NASA	National Aeronautics and Space Administration
psi	pounds per square inch
QPL	Qualified Products List
sec	second
SSC	Stennis Space Center
TEERM	Technology Evaluation for Environmental Risk Mitigation Principal Center
UV	ultraviolet
WFT	Wet Film Thickness

1. INTRODUCTION

Headquarters NASA chartered the Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM), formerly the Acquisition Pollution Prevention Office, to coordinate agency activities affecting pollution prevention issues identified during system and component acquisition and sustainment processes. The primary objectives of TEERM are to:

- Reduce or eliminate the use of hazardous materials (HazMats) or hazardous processes at manufacturing, remanufacturing, and sustainment locations.
- Avoid duplication of effort in actions required to reduce or eliminate HazMats through joint center cooperation and technology sharing.

NASA and AFSPC have similar missions and therefore similar facilities and structures in similar environments. Both are responsible for a number of facilities/structures with metallic structural and non-structural components in highly and moderately corrosive environments. Regardless of the corrosivity of the environment, all metals require periodic maintenance activity to guard against the insidious effects of corrosion and thus ensure that structures meet or exceed design or performance life. The standard practice for protecting metallic substrates in atmospheric environments is the application of an applied coating system. Applied coating systems work via a variety of methods (barrier, galvanic and/or inhibitor) and adhere to the substrate through a combination of chemical and physical bonds.

The most common topcoats used in coating systems are polyurethanes that contain isocyanates. Isocyanates are compounds containing the isocyanate group (-NCO). They react with compounds containing alcohol (hydroxyl) groups to produce polyurethane polymers, which are components of polyurethane foams, thermoplastic elastomers, spandex fibers, and the polyurethane paints used in NASA and AFSPC applications.

The Occupational Safety & Health Administration states that the effects of isocyanate exposure include irritation of skin and mucous membranes, chest tightness, and difficult breathing. Isocyanates are classified as potential human carcinogens and are known to cause cancer in animals. The main effects of overexposure are occupational asthma and other lung problems, as well as irritation of the eyes, nose, throat, and skin.

The primary objective of this effort was to demonstrate and validate alternatives to aliphatic isocyanate polyurethanes. Successful completion of this project will result in one or more isocyanate-free coatings qualified for use at AFSPC and NASA installations participating in this project.

Table 1-1 summarizes the target HazMats; processes and materials; applications, affected programs and candidate parts/substrates.

Table 1-1 Target HazMat Summary				
Target HazMat	***Current Process***	***Applications***	***Current Specifications***	***Candidate Parts/Substrates***
Isocyanates used in urethane coatings	Conventional spray and brush application	Any application where a high-gloss finish is required	NASA Approved Products (listed in Appendix B of NASA-STD-5008); AFSPC Approved Products	Carbon Steel

A Joint Test Protocol (JTP) entitled *Joint Test Protocol for Validation of Alternatives to Aliphatic Isocyanate Polyurethanes*, prepared by ITB, Inc., defined the critical requirements and tests necessary to qualify alternatives for Aliphatic Isocyanate Polyurethane applications. The tests were derived from engineering, performance, and operational impact (supportability) requirements defined by a consensus of NASA and AFSPC participants.

A Field Test Plan (FTP) entitled *Field Evaluations Test Plan for Validation of Alternatives to Aliphatic Isocyanate Polyurethanes*, prepared by ITB, Inc., defined the field evaluation and testing requirements for validating alternatives to aliphatic isocyanate polyurethanes and supplemented the JTP. The field evaluations were performed at Stennis Space Center, Mississippi, under the oversight of the Project Engineer.

A Potential Alternatives Report entitled *Potential Alternatives Report for Validation of Alternatives to Aliphatic Isocyanate Polyurethanes*, prepared by ITB, Inc., provided technical analyses of identified alternatives to the current coatings, criteria used to select alternatives for further analysis, and a list of those alternatives recommended for testing.

A Cost-Benefit Analysis entitled *Cost Benefit Analysis for Alternatives to Aliphatic Isocyanate Polyurethanes*, prepared by ITB, Inc., provides financial analyses of identified alternatives to determine if implementation of the candidate alternatives is economically justified.

This JTR documents the results of the laboratory and field testing as well as any test modifications made during the execution of the testing. The technical stakeholders agreed upon test procedure modifications documented in this document. This JTR is made available as a reference for future pollution prevention endeavors by other NASA centers, the Department of Defense and commercial users to minimize duplication of effort.

2. COATING SYSTEMS AND COUPON PREPARATION

Stakeholders identified specific coatings as potential alternatives to the current coating based on available information about these coatings. Technical merits and the potential environmental, safety, and occupational health (ESOH) impacts of these coatings were evaluated. Project participants used this information to select coatings for testing in accordance with the JTP and FTP.

2.1. Coatings Systems

All coating system candidates were tested using approved NASA and AFSPC standard coating systems as experimental controls. This study looked at eight alternatives and two control coating systems. The coating systems evaluated in this study are listed in Table 2-1.

Table 2-1 Coatings Systems Evaluated

System	*Topcoat*	*Intermediate*	*Primer/Wash*	*Manufacturer*
1	Carboxane 2000	Carboguard 893	Carbozinc-11HS	Carboline
2*	Carbothane 134 HB	Carboguard 893	Carbozinc-11HS	Carboline
3	Polysiloxane XLE	*None*	ZincClad 11	Sherwin Williams
4	Fast Clad HB	*None*	ZincClad 11	Sherwin Williams
5	Sher-Cryl HPA	*None*	ZincClad 11	Sherwin Williams
6	Interfine 979	Interseal 670HS	Interzinc 22	International Protective Coatings (IPC)
7	Interfine 878	Interseal 670HS	Interzinc 22	IPC
8*	Devthane 359	Devthane 201	Cathacoat 304	Devoe
9	AquaSurTech (AST) D45	AST Crosslinker	AST Decontaminator	Kimetsan
10	PSX 1001	383H	Dimetcote 9H	Ameron

* Control Coating

2.2. Coupon Preparation

A matrix of the coupons prepared for each coating system in this study is shown in Table 2-2.

Table 2-2 Coupon Matrix per System

Size	*Quantity*	*Type*	*Alloy*
4"× 6"× 0.1875"	24	Composite	A-36 Steel
4"× 6"× 0.1875"	45	Flat	A-36 Steel
3"× 6"× 0.1875"	6*	Flat	A-36 Steel
4"× 12"× 0.1875"	6	Flat	A-36 Steel
4"× 4"× 0.32"	6	Flat	1008 Steel
3"× 5"× 0.032"	12	Flat	1008 Steel
0.75" round	60	Flat Disc	304 Stainless Steel
4"× 4"	15	Flat	Aluminum Foil

* 40 for the Control Coatings

Details of the coating processes were collected and recorded on the "Coating System Application Evaluation and Inspection Report" form. Documentation is provided in Appendix A of this report.

Coating technicians followed all manufacturer application instructions and documented all relevant conditions at the time of application. All coupons were inspected upon arrival and prepared according to the JTP.

A summary of the calculated target wet film thicknesses (WFT) and spray equipment used for application of each coating system is listed in Table 2-3. A Binks Air Nozzle Guide, Fluid Nozzle Guide, and Needle Selection Chart can be found in Appendix B.

Table 2-3 Spray Equipment Set-up and Calculated Wet Film Thicknesses								
System	***Coat*** [a]	***Gun***	***Fluid Tip***	***Air Cap***	***Fluid Tip***	**Fluid (psi** [c]**)**	**Air (psi** [c]**)**	***WFT*** [b] **(mils** [d]**)**
1	Primer	Binks 2001	67vt	67pb	567vt	15	50	2.5-3.5
	Mid	Binks 2001	66ss	63pb	563a	20	50	3.9-7.7
	Top	Binks 2001	66ss	63pb	563a	12	30	4.0-9
2	Primer	Binks 2001	67vt	67pb	567vt	15	50	2.5-3.5
	Mid	Binks 2001	66ss	63pb	563a	20	50	3.9-7.7
	Top	Binks 2001	66ss	63pb	563a	12	50	2.8-3.5
3	Primer	Binks 18	66	66pb	65n	15	55	4.5-7.5
	Top	Binks 2001	66ss	63pb	563a	15	80	3.5-8.0
4	Primer	Binks 18	66	66pb	65n	15	55	4.5-7.5
	Top	Binks 2001	66ss	63pb	563a	15	50	6.0-10
5	Primer	Binks 18	66	66pb	65n	15	55	4.5-7.5
	Top	Binks 2001	66ss	63pb	563a	15	40	12.0-19
6	Primer	Binks 2001	67ss	67pb	567	15	80	3.0-4.0
	Mid	Binks 2001	66ss	63pb	565	25	80	5.0-10
	Top	Binks 2001	66ss	63pb	565	15	50	5.0-8.0
7	Primer	Binks 2001	67ss	67pb	567	15	80	3.0-4.0
	Mid	Binks 2001	66ss	63pb	565	25	80	5.0-10
	Top	Binks 2001	66ss	63pb	565	15	50	3.0-4.0
8	Primer	Binks 2001	67ss	67pb	567	20	80	2.5-5.0
	Mid	Binks 2001	66ss	63pb	565	25	60	4.0-6.0
	Top	Binks 2001	66ss	63pb	565	25	60	6.5-10
9	Primer	Binks 95G	66ss	66sd	565	gravity	40	3.0-3.3
	Mid	Binks 95G	66ss	66sd	565	gravity	40	3.0-3.3
	Top	Binks 95G	66ss	66sd	565	gravity	40	2.7-3.0
10	Primer	Binks 2001	66ss	67pb	565	15	65	3.5-4.5
	Mid	Binks 2001	66ss	63pb	565	15	60	5.0-10
	Top	Binks 2001	66ss	63pb	565	5	50	3.5-5.5

[a] Agitated pot for all primers
[b] Calculated using Manufacturers' data sheets
[c] pounds per square inch (psi)
[d] 0.001 inch (mil)

All coupons were inspected as the coating systems were applied. Manufacturers recommended dry film thicknesses (DFT) were verified. DFT measurements were collected for each coating layer (primer, mid-coat, topcoat, etc.) in accordance with SSPC-PA2, *Measurement of Dry Coating Thickness with Magnetic Gages*, 2004. Measurements were made during the application process using a type II Quanix Keyless coating thickness gauge (accuracy of ±0.04 mils +2%). A summary of the applied and recommended coating thicknesses is referenced in Table 2-4 for each system.

Table 2-4 Applied and Recommended Dry Film Thicknesses for Test Coupons

System	*Primer*		*Intermediate*		*Topcoat*	
	*Applied**	*Range*	*Applied**	*Range*	*Applied**	*Range*
1	3.3 mils	2-6 mils	3 mils	3-6 mils	6 mils	3-7 mils
2	3.3 mils	2-6 mils	3.5 mils	3-6 mils	2.5 mils	2-2.5 mils
3	2.5 mils	3-5 mils	none	none	5.4 mils	3-7 mils
4	2.7 mils	3-5 mils	none	none	3.1 mils	2.5-4 mils
5	2.6 mils	3-5 mils	none	none	8.5 mils	5-8 mils
6	4.5 mils	2-4 mils	6.4 mils	4-6 mils	5.4 mils	4-6 mils
7	4.5 mils	2-4 mils	6.4 mils	4-6 mils	3.6 mils	2-3 mils
8	2.2 mils	2-4 mils	3.2 mils	2-3 mils	5.3 mils	4-6 mils
9	1.4 mils	1.2-1.4 mils	1.3 mils	1.2-1.4 mils	0.70 mils	0.75 -1 mil
10	5 mils	2.5-4 mils	6.2 mils	4-8 mils	2.9 mils	2-3 mils

* Average of all coupons for that system

All coated coupons were separated by coating system, cataloged, and stored in plastic totes inside a humidity controlled room until needed for testing.

3. PHASE I SCREENING TESTS

Screening tests were preliminary tests performed on selected candidate coating systems. Candidate coating systems that did not meet the acceptance criteria of the screening tests were eliminated from further testing. Table 3-1 lists screening tests and includes acceptance criteria and the reference specifications, if any, used to conduct the tests. The test and evaluation were based on the aggregate knowledge and experience of the assigned technical project personnel and prior testing where "None" appears under *Test Method References*. Additional information about each test can be found in the JTP.

Table 3-1 Phase I Screening Test Requirements

Test	***JTR Section***	***Test Specimen***	***Acceptance Criteria***	***Test Methodology References***
Ease of Application	3.1.	Coupon	Smooth coat, with acceptable appearance, no runs, bubbles or sags; Ability to cover the properly prepared/primed substrate with a single coat (one-coat hiding ability); Measure Dry Film Thickness	SSPC-PA-2
Surface Appearance	3.2.	Coupon	No streaks, blistering, voids, air bubbles, cratering, lifting, blushing, or other surface defects/irregularities; No micro-cracks observable at 10X magnification	ASTM D 523; ASTM D 2244
Dry-To-Touch (Sanding)	3.3.	Coupon	No rolling or scribing during sanding, and "easy" sanding (as evaluated by technician)	None
Accelerated Storage Stability	3.4.	Mixed Coating System	No skinning, grains, or lumps of the coating; no pressure buildup, corrosion on the container, odor of spoilage or cloudy appearance of catalyst	ASTM D 1849

Table 3-1 Phase I Screening Test Requirements				
Test	***JTR Section***	***Test Specimen***	***Acceptance Criteria***	***Test Methodology References***
Pot Life (Viscosity)	3.5.	Mixed Coating System	Procedure A: High Solids Coatings Viscosity of both test batches shall not exceed 60 seconds after 4 hours (hrs) of continuous mixing in a closed container maintained at 75 ± 5° F (Batch 1) and 95 ± 5° F (Batch 2). The admixed materials must still be sprayable 4 hours after mixing Procedure B: Waterborne Coatings Coating viscosity shall not exceed admix viscosity by more than 15 seconds after 4 hours, with no gelling of the admixed coating after 6 hours	ASTM D 1200
Cure Time (Solvent Rubs)	3.6.	Coupon	No effect on surface or coating on the cloth (Resistance Rating 5)	ASTM D 4752
Cleanability	3.7.	Coupon	Cleaning efficiency equal to or better than control coatings	MIL-PRF-83282D; MIL-PRF-85285
Knife Test	3.8.	Coupon	Candidate coating adhesion performs as well or better than control coatings	FED-STD-141
Tensile (Pull-off) Adhesion	3.9.	Coupon	Pull-off strength achieved at time of failure equal to or better than control coatings	ASTM D 4541
X-Cut Adhesion by Wet Tape	3.10.	Coupon	Candidate coating adhesion performs as well or better than control coatings and greater than or equal to "4a" as specified in ASTM D 3359	ASTM D 3359; FED-STD-141

All of the information from the evaluation was recorded on the "Coating System Application Evaluation and Inspection Report" and can be found in Appendix A for each individual system. The following sections summarize the results for each qualifying test.

3.1. Ease of Application

This screening test was conducted to identify and eliminate those candidate coating systems that are difficult to properly apply under normal maintenance operation conditions. The evaluation was conducted while preparing coupons for each coating.

All coatings were fairly easy to apply using the manufacturers recommended mixing instructions, application equipment, and air pressures (see Table 2-3 above). The ease of application was evaluated based upon the following criteria:

- Ability to provide a smooth coat with an acceptable appearance.
- No runs, bubbles, or sags.
- One coat hiding ability.

The results based upon these criteria are summarized in Table 3-2.

Table 3-2 Results for Ease of Application

System	*Wet Coat*	*Finish*	*Runs*	*Bubbles*	*Sags*	*Hiding*
1	Smooth	Gloss	>7 wet	No	>7 wet	1 coat
2*	Smooth	Gloss	No	No	No	2 coat [b]
3	Smooth	Gloss	No	Yes [a]	No	1 coat
4	Smooth	Gloss	No	Yes [a]	No	1 coat
5	Smooth	Gloss	No	Yes [a]	No	1 coat
6	Smooth	Gloss	No	No	No	1 coat
7	Smooth	Gloss	No	No	No	1 coat
8*	Smooth	Gloss	No	No	No	1 coat
9	Smooth	Semi-Gloss	>1 wet	No	>1 wet	2 coat [b]
10	Smooth	Gloss	No	No	No	1 coat

* Control Coating
[a] Due to spraying directly on zinc primer (no intermediate coating)
[b] Thin film coating

System -9 was determined to be more difficult to apply than the Control Coatings because it requires a different set-up of equipment which would require additional personnel training. Once training was completed, however, it is expected that application would be no more difficult than that of the other systems. Proper application of a coating is necessary to ensure the best performance of any system and may affect test results.

3.2. Surface Appearance

The purpose of this test was to evaluate and compare the surface appearance of the candidate and control coating systems. The surface of each coated test coupon was examined for coating defects with the unaided eye and with 10X magnification. Micro-cracks extending no more than 1/4-inch from the panel edge are acceptable. A slight orange peel appearance is acceptable. The surface appearance of the topcoat is required to be evaluated only after the entire primer/topcoat system has been applied.

A representative set of coated test coupons from each system were examined for coating defects using the unaided eye and 10X optical magnification. Evaluations of the surface appearance were performed based upon the following criteria:

- Streaks
- Blistering
- Cratering
- Lifting
- Voids
- Bubbles
- Blushing
- Micro-cracks

Observations of any of the above coating defects were noted and recorded on the "Coating System Application Evaluation and Inspection Report" (Appendix A). The results are summarized in Tables 3-3 and 3-4.

Table 3-3 Results for Unaided Eye Evaluation of Surface Appearance

System	*Observation*
1	Smooth glossy finish with uniform color.
2*	Slight orange peel, glossy finish with uniform color.
3	Smooth glossy finish with uniform color.
4	Smooth semi-gloss appearance with uniform color.
5	Smooth semi-gloss appearance with uniform color.
6	Slight orange peel, glossy finish with uniform color.
7	Slight orange peel, glossy finish with uniform color.
8*	Smooth glossy finish with uniform color.
9	Smooth semi-gloss appearance with uniform color.
10	Smooth glossy finish with uniform color.

* Control Coating

Table 3-4 Results for 10x Magnification Evaluation of Surface Appearance

System	***Observation***
1	No defects or irregularities observed.
2*	No defects or irregularities observed.
3	No defects or irregularities observed.
4	Small crater-like anomalies observed on surface.
5	Small crater-like anomalies observed on surface.
6	No defects or irregularities observed.
7	No defects or irregularities observed.
8*	No defects or irregularities observed.
9	No defects or irregularities observed.
10	No defects or irregularities observed.

* Control Coating

Baseline color and gloss measurements were collected using ASTM D 2244, *Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates, 2002*, and ASTM D 523, *Standard Test Method for Specular Gloss*, as a guide. Complete documentation for color and gloss is located in Appendix C.

Color measurements were recorded at ambient temperatures (20°- 25° C) on a ColorTec-PCM handheld portable color meter using the CIE L*a*b* format, D-65 illuminant, and a 10° observer. Although CIE color space is not spherical, it does help to envision color space as a ball centered on a three-dimensional axis (Figure 3-1).

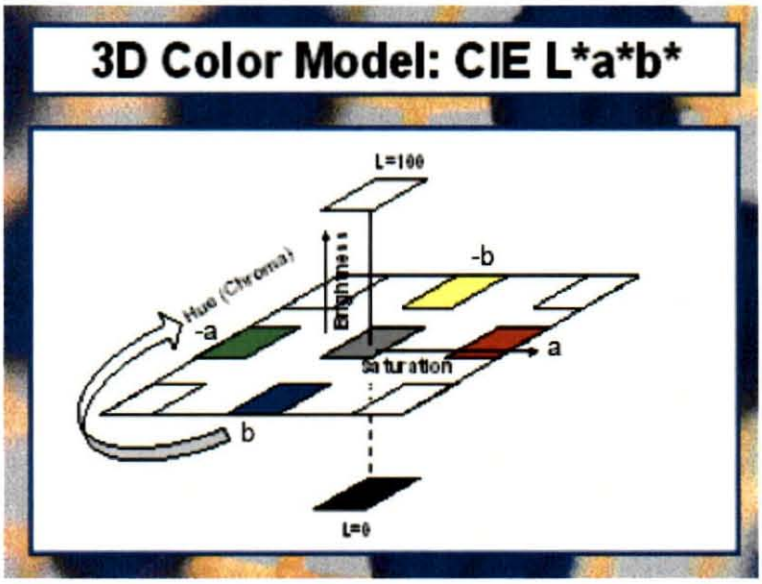


Figure 3-1 CIE 3-D Model

A color's "lightness" (L*) runs from light (white) to dark (black), going from the top to the bottom of the vertical axis. The "a*" value signifies the location of color between red and green. A reddish color will give a positive a* value, and conversely, a greenish color will give a negative a* value. The "b*" value represents a color position between the yellow and blue axis. As with the a* values, a bluish color will give a positive b* value and a yellowish color will give a negative b* value. The initial (pre-test) CIE L*a*b* color measurement data is listed in Table 3-5.

Table 3-5 Initial Color Measurement Data

System	*L**	*a**	*b**
1	95.39	-1.59	7.60
2	92.61	-2.45	4.78
3	94.26	-2.28	3.60
4	93.76	-2.57	4.26
5	93.74	-2.11	2.92
6	93.93	-2.41	2.43
7	94.78	-1.95	2.20
8	96.51	-1.92	1.46
9	94.10	-1.89	2.54
10	96.60	-1.80	2.42

A single number indicator representing the overall change in color, delta (Δ) E is calculated by the taking the square root of the sum of the squares of the color difference of the three dimensions of color space as stated in Equation 1.

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

where:

L_i = initial Lightness value

L_f = final Lightness value

a_i = initial Red/Green value

a_f = final Red/Green value

b_i = initial Blue/Yellow value

b_f = final Blue/Yellow value

Gloss measurements were performed on the unexposed surfaces in the same locations as the color measurements using a BYK Gardner μ-Tri-Gloss Portable Gloss Meter. The gloss meter records the amount of reflective illuminated light at specified angles (20°, 60°, or 85°) and gives a value in gloss units (GU's). The 60° geometry is used for most specimens and is the starting point 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's and the 85° angle is used when the 60° angle gloss values are less than 10 GU's.

The data in Table 3-6 shows gloss measurement values which were used as a baseline for comparison to gloss measurements taken periodically throughout the exposure period.

Table 3-6 Results of Baseline Gloss Measurements

System	*20° Gloss (GU's)*	*65° Gloss (GU's)*	*80° Gloss (GU's)*
1	41.0	82.3	88.4
2*	29.9	79.1	73.6
3	34.0	81.2	89.2
4	49.4	83.1	91.2
5	9.5	46.2	62.1
6	18.1	65.1	66.2
7	14.5	56.8	58.8
8*	13.6	57.3	55.4
9	1.6	7.4	9.6
10	19.9	70.8	67.4

* Control Coating

3.3. Dry-To-Touch (Sanding)

This test documents the time that a coating is "dry to the touch", so that the item can be handled without damaging the coating. Coatings were applied to test coupons in accordance with manufacturers' directions/specifications and allowed to air dry for 24 hours.

At the end of the 24 hour drying period, the coupons were lightly abraded with a 3M Co. Scotch Brite, light duty, very fine-nylon web pad to determine if the coating was dry. All coatings in this study passed the acceptance criteria. There was no rolling or scribing of the coatings while the test was performed and each system can be considered to be "easy sanding".

3.4. Accelerated Storage Stability

The stability of a coating system while in extended storage is an important parameter in determining an acceptable coating for steel structures. This test simulates 6 months to a year of storage and evaluates any changes in consistency and certain other properties that may take place when liquid coatings are stored.

One quart samples were obtained from each coating system. Each un-opened container was evaluated for skinning, corrosion on the interior of the can, odors of putrefaction, rancidity, or souring. The samples were weighed and stored undisturbed for one-month at 125° ± 2° F. After the cans were allowed to cool they were re-weighed, opened, and the interiors were re-evaluated. After the evaluation, the coatings were mixed, applied to test coupons, and rated per ASTM D 1849-95, *Standard Test Method for Package Stability of Paint*, approved 1995, reaffirmed 2003. The ratings for the container condition and coating finish run from 10 to 0, with 10 showing no effect and 0 showing complete failure as shown in Table 3-7.

Table 3-7 ASTM D 1849 Ratings for Container Condition and Coating Finish

ASTM Rating	*Failure Mode*
10	None
8	Very Slight
6	Slight
4	Moderate
2	Considerable

The container condition and coating finish results can be found in Tables 3-8 and 3-9. ASTM D 1849-95 container weight losses are reported in Table 3-10.

Table 3-8 Results of Container Condition Evaluation

System	Skinning		Pressure		Corrosion		Odor	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	10	10	10	10	10	10	10	4
2*	10	8	10	10	10	10	10	4
3	10	10	10	8	10	10	10	10
4	10	10	10	10	10	10	10	10
5	10	8	10	10	10	10	10	10
6	10	8	10	10	10	10	10	2
7	10	8	10	8	10	10	10	4
8*	10	8	10	10	10	10	10	8
9	10	6	10	10	10	10	10	10
10	10	10	10	6	10	10	10	10

* Control Coating

Table 3-9 Results of Post-Oven Coating Finish Evaluation

System	Coating Appearance		
	Grains	Lumps	Streaks
1	10	10	10
2*	10	10	10
3	10	10	10
4	10	10	10
5	10	10	10
6	10	10	10
7	8	8	10
8*	10	10	10
9	10	10	10
10	10	10	10

* Control Coating

Table 3-10 Results of Container Weight Loss

System	***Weight* (grams)**		***% Loss***
	Pre-oven	***Post-oven***	
1	1503.2	1501.8	0.09
2*	1180.8	1180.8	0.00
3	1161.3	1161.3	0.00
4	1000.2	999.4	0.08
5	1199.5	1198.9	0.05
6	1207.7	1207.5	0.02
7	1217.8	1217.8	0.00
8*	1185.8	1185.1	0.06
9	1162.3	1162	0.03
10	1110.2	1109.8	0.04

* Control Coating

3.5. Pot Life (Viscosity)

This test provided data to characterize the pot life envelope. Knowledge of initial viscosity and viscosity change, in relation to time and temperature is important for determining the effective time frame for coating application. Viscosities were measured using NIST traceable Zahn cups.

The test was separated into two procedures, one for water-based systems and the other for solvent-based systems. The water-based procedure required that the coatings remain at ambient temperatures (75° ± 5° F) for a period of 4 hours, while viscosity measurements were recorded at 30 minute intervals. The solvent-based coatings required a room temperature sample, which was continuously stirred and heated to 95° ± 5° F for a period of 4 hours.

Due to the varying coating formulations and viscosities, an appropriate cup was found (for each system) by a process in which the contents of the cup would empty within a 30 to 60 second timeframe. Once the initial cup was determined, it was used throughout the remainder of the testing for that coating system. The test was stopped once the time required to empty the cup exceeded 60 seconds. This equates to a 2-3x increase in the products resistance to flow from its initial measurement.

As shown in Table 3-11, the heated Control Systems -2 and -8 exceeded the sixty second criteria well before the allotted 4 hour pot life time limit. System -2 failed at 90 minutes and System -8 failed at 120 minutes. Both systems were considered not sprayable.

Table 3-11 Results of Heated Samples Evaluation (Solvent-based Only)

System	*Zahn Cup*	*Cup Time*	*Initial Viscosity (cks [a])*	*Cup Time*	*Final Viscosity (cks [a])*	*Time Interval*	*Sprayable*
1	5	48	1298	57	1545	4 hrs	Yes
2*	4	32	475	115	1743	1.5 hrs	No
3	4	56	845	31	459	4 hrs	Yes
4	Water-based coating						
5	Water-based coating						
6	4	30	428	66	990	4 hrs	Yes
7	3	35	336	48	484	4 hrs	Yes
8*	5	35	911	60	1627	2 hrs	No
9	Water-based coating						
10	3	28	260	14	102	4 hrs	Yes

* Control Coating
[a] centistoke (cks)

The viscosity of room temperature samples is shown in Table 3-12. Control System -2 failed to pass the 60 second criteria with the room temperature sample failing after 150 minutes.

Table 3-12 Results of Room Temperature Viscosity Evaluation

System	*Zahn Cup*	*Cup Time*	*Initial Viscosity (cks)*	*Cup Time*	*Final Viscosity (cks)*	*Time Interval*	*Sprayable*
1	5	48	1298	79	2161	4 hrs	No
2*	4	32	475	108	1637	2.5 hrs	No
3	4	56	845	50	746	4 hrs	Yes
4	4	60	899	76	1143	4 hrs	Yes
5	4	46	684	56	838	4 hrs	Yes
6	4	30	428	93	1394	4 hrs	Yes
7	3	35	336	67	672	4 hrs	Yes
8*	5	35	911	52	1394	4 hrs	Yes
9	1	73	101	77	109	4 hrs	Yes
10	3	28	260	28	102	4 hrs	Yes

* Control Coating

3.6. Cure Time (MEK and Acetone Solvent Rubs)

Although methyl ethyl ketone (MEK) use is being phased out, the MEK solvent rub test was also conducted since it is more stringent than an acetone rub test. This test is a commonly accepted industrial criterion for determining coating cure and only small amounts of MEK is consumed. Inspecting at two-day intervals is required to determine the actual cure time.

The surface of each 4"× 6" substrate was divided into three equal rub test areas. Twenty-five double-rubs (back and forth) were performed every two days, for a total duration of up to 14 days. This operation was performed on two triplicate sets of panels from each coating system using clean cheesecloth wetted with MEK and acetone, respectively. DFT measurements were obtained (to verify coating thickness loss) from the center section of each wipe area (depicted in Figure 3-2) before and after the procedure. Photographs before and after each operation were taken to verify the visual examination and record the extent of coating degradation.

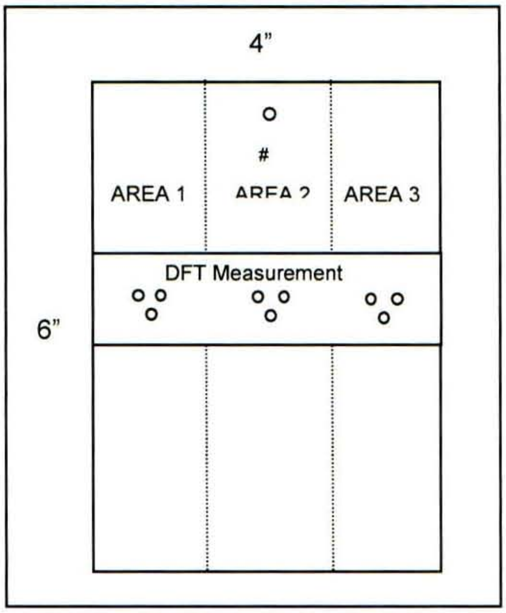


Figure 3-2 Typical Solvent Rub Areas

The ratings for the cure time run from 5 to 0, with 5 showing no effect and 0 showing complete failure as shown in Table 3-13.

Table 3-13 ASTM D 4752 Resistance Ratings	
Rating	***Remarks***
5	No effect on surface; no coating on cloth.
4	Burnished appearance in rubbed area; slight amount of coating on cloth.
3	Some marring and apparent depression of the film.
2	Heavy marring; obvious depression in the film.
1	Heavy depression in the film but no penetration to the primer.
0	Penetration to the primer.

While all of the coating systems cured rapidly, within a 2 or 4 day period; Systems -4, -5, and -10 did not have a high resistance to MEK or acetone as indicated in Table 3-14.

Table 3-14 Results of Cure Time Evaluation

System	***ASTM Rating***		***Days to Cure***	***Film Loss***
	MEK	***Acetone***		
1	5	5	2	0
2*	5	5	4	0
3	5	5	2	0
4	1	0	14+	2.3 mils
5	1	1	14+	2.5 mils
6	5	5	2	0
7	5	5	2	0
8*	5	5	2	0
9	5	5	2	0
10	0	0	14+	2.9 mils

* Control Coating

System -4 (Figure 3-3) and System -10 (Figure 3-4) showed complete removal of the topcoat, while System -5 (Figure 3-5) was heavily depressed after a 14 day cure time.

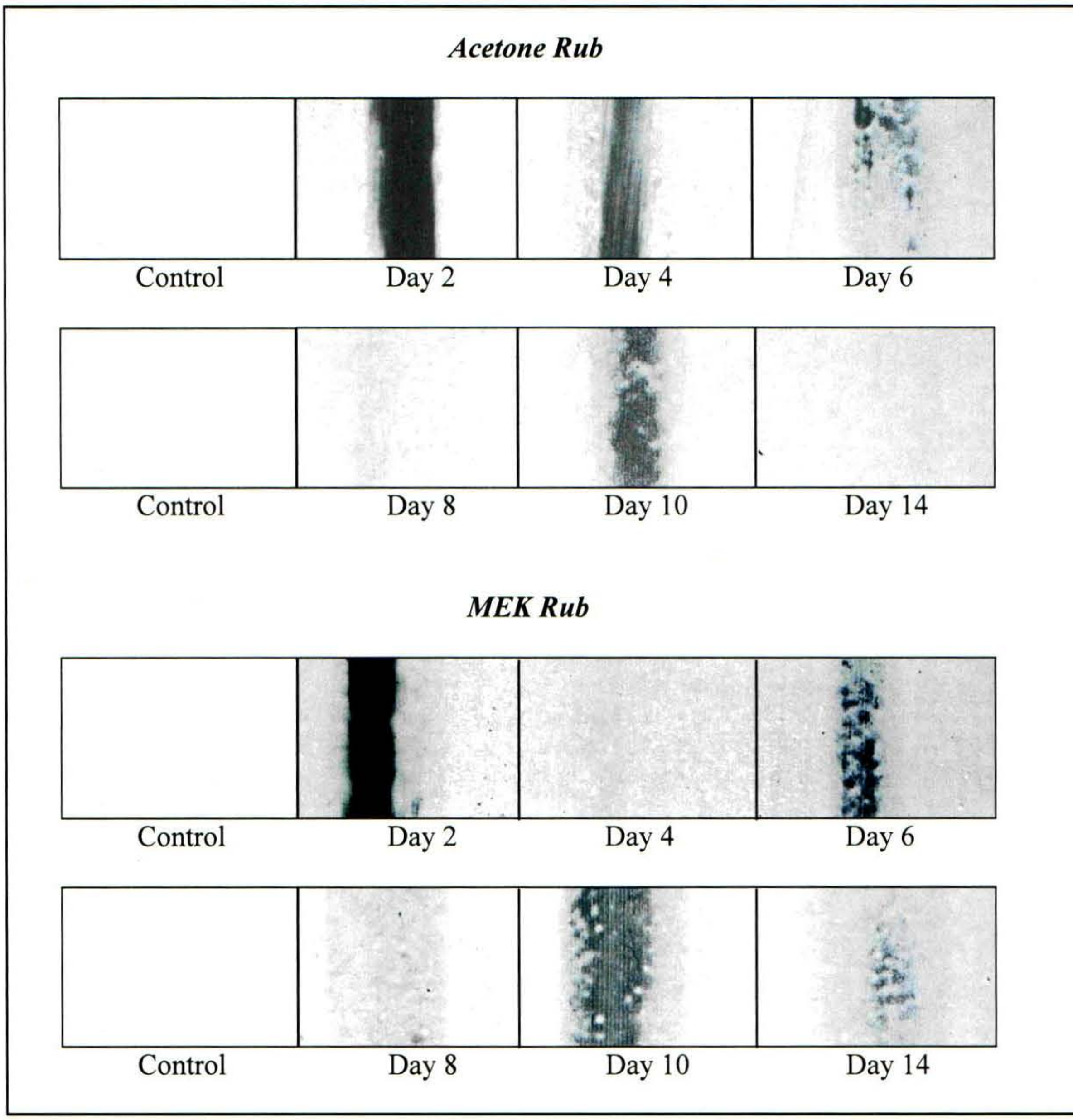


Figure 3-3 Photographs of System -4 Cure Time Evaluation

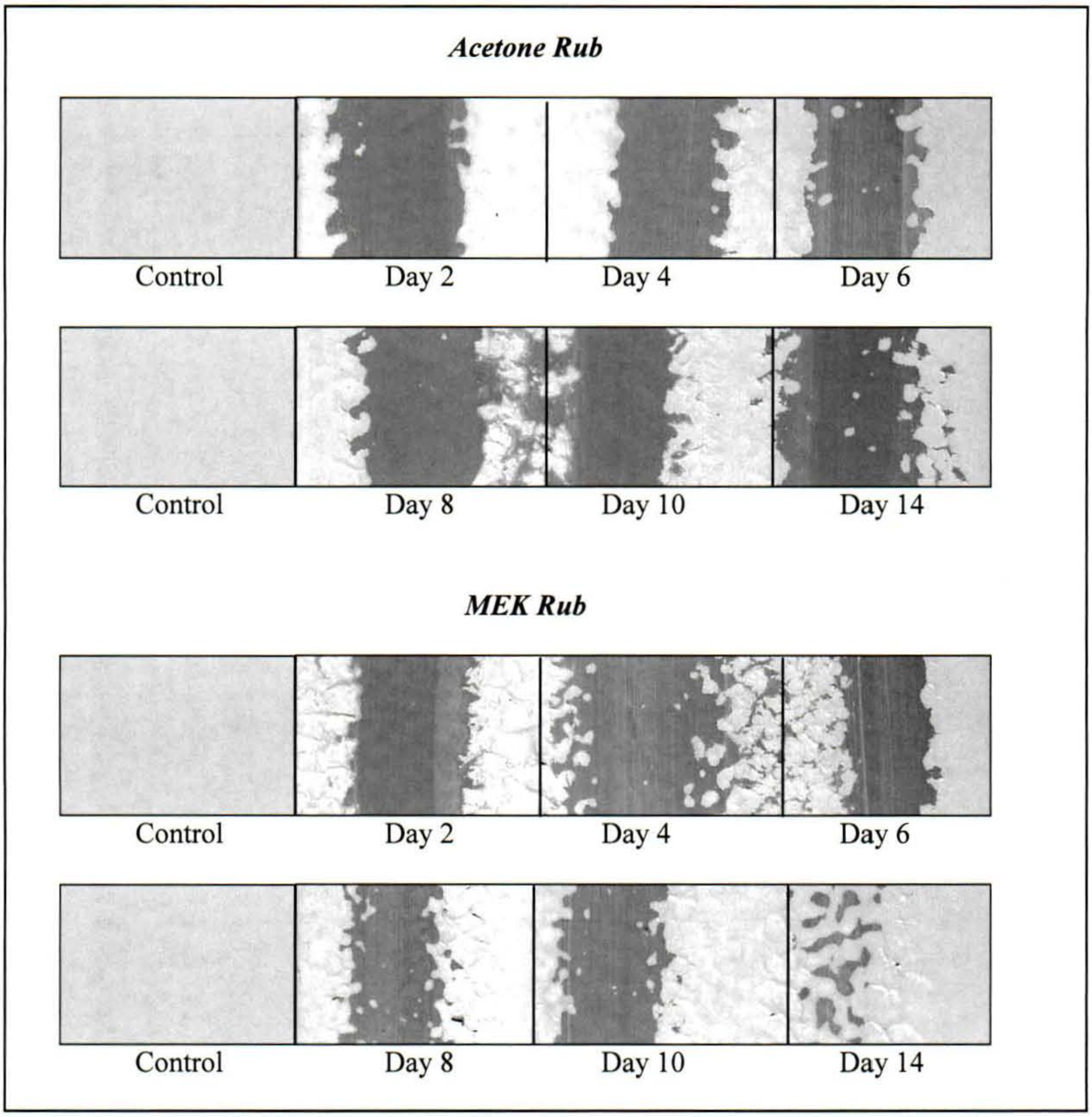


Figure 3-4 Photographs of System -10 Cure Time Evaluation

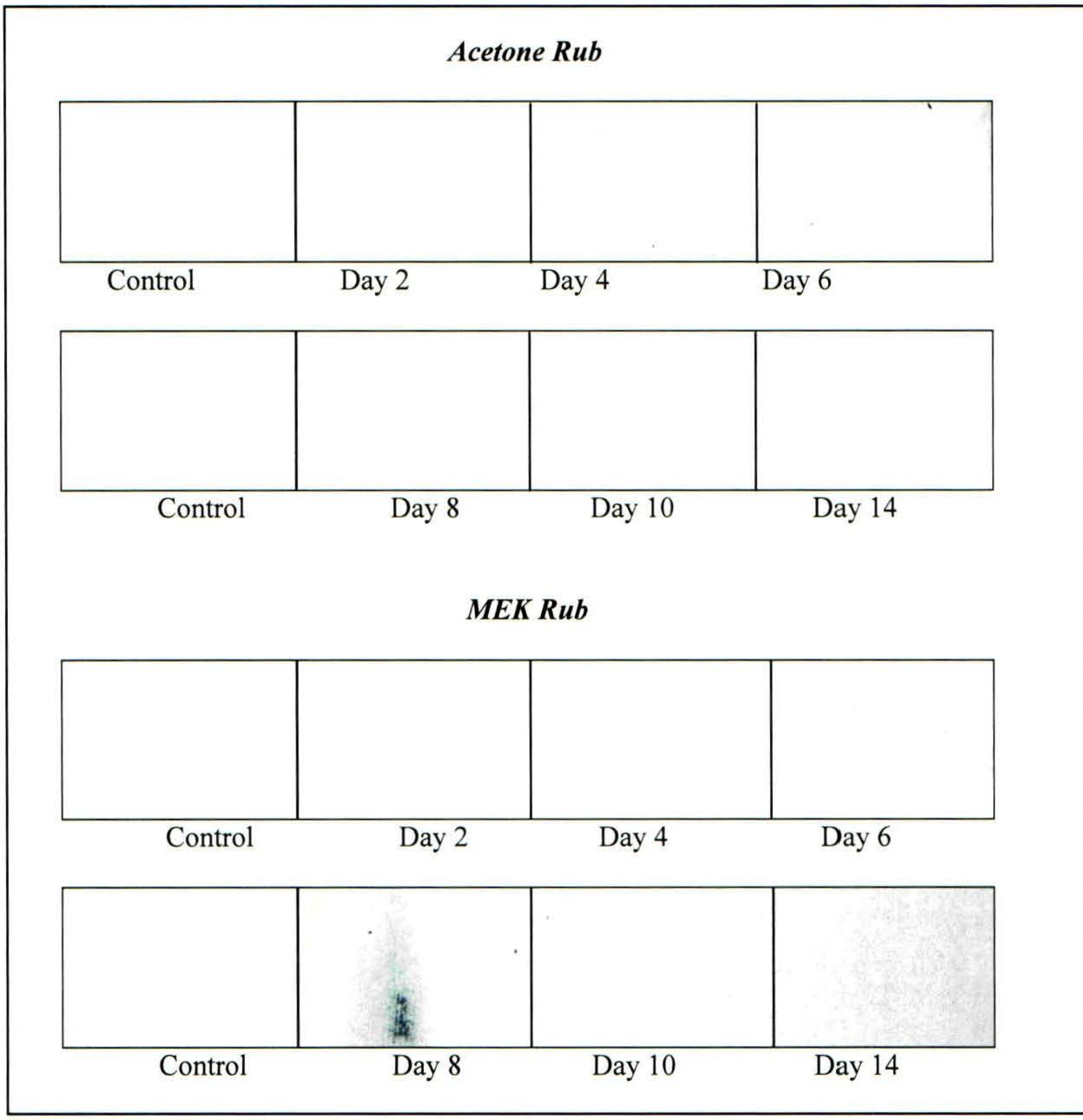


Figure 3-5 Photographs of System -5 Cure Time Evaluation

3.7. Cleanability

This test evaluated the resistance of the topcoat to soil adhesion and staining. Artificial soil was prepared by placing 50 ± 0.5 grams of carbon black and 500 ± 1 gram of hydraulic fluid [conforming to MIL-PRF-83282D (*Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft, Metric, NATO Code Number H-537*, issued 1986, revised 1997)] into a one quart jar. The mixture was homogenized using a high-shear mixer for 15 ± 1 minute.

Baseline lightness values (A) for the unsoiled test coupons were performed using a colorimeter. The artificial soil was applied to the surface of the coupons using a soft bristle acid brush. Excess soil was removed by placing a folded absorbent tissue onto the surface and passing a 5-pound rubber roller over the tissue two times. The soiled surface was brushed using ten one-directional strokes of a hog bristle brush and the sample coupon was placed in an oven. The soiled coupons were held at an elevated temperature of 221° ± 4° F for 60 ± 1 minute. After the coupons were allowed to cool, the soiled lightness value (B) was recorded.

A standard cleaner formula was prepared by mixing one part by volume of cleaner with nine parts by volume of de-ionized water. A scrape adhesion tester was modified for the cleanability study by attaching a cellulose sponge to the arm. The soiled test coupons were secured in the base of the tester with the sponge positioned at a 45° angle. The sponge was saturated with the diluted cleaning agents and placed onto the test coupon. The sponge and soiled coupon were allowed to remain in contact with the coupon for 60 ± 5 seconds and were then cleaned with 5 passes of the sponge. Additionally, the coupons were turned through a 90° angle and cleaned for an additional 5 cycles. The coupons were then rinsed with room temperature tap water and allowed to dry.

The final lightness values of the cleaned coupons (C) were recorded, and the cleaning efficiency percentage was calculated using Equation 2.

$$\text{Cleaning Efficiency Percentage} = [(C - B) \div (A - B)] \times 100 \qquad \text{(Eq. 2)}$$

where:

A = baseline lightness value

B = soiled lightness value

C = final lightness value

The results are summarized in Table 3-15. The complete set of photodocumented samples can be found in Appendix D.

Table 3-15 Results of Cleanability Evaluation

System	*Cleaning Efficiency*
1	97
2*	97
3	97
4	37
5	7
6	99
7	98
8*	98
9	96
10	15

* Control Coating

3.8. Knife Test

This test evaluated coatings for brittleness, toughness, and tendency to ribbon by cutting a narrow ribbon of the coating with a serviceable knife that has a sharp blade.

The test was performed in accordance with FED-STD-141, *Paint, Varnish, Lacquer and Related Materials: Methods of Inspection, Sampling and Testing*, approved 2001, Method 6304.2. Using that method, six parallel lines, 2 millimeters (mm) apart, were cut into the surface of the coated test coupon in three different areas (Figure 3-6) and was visually evaluated using the criteria stated in the standard.

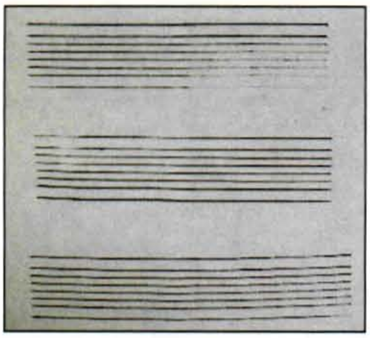


Figure 3-6 Sample of Knife Test Sample

Knife Test photodocumentation for each system can be found in Appendix E, while the reported results are documented in Table 3-16.

Table 3-16 Results of Knife Test

System	*Coating Condition*
1	Some chipping on scribed lines/ no peeling
2*	No chipping or peeling
3	Slight chipping/ no peeling
4	No chipping or peeling
5	No chipping or peeling
6	No chipping or peeling
7	No chipping or peeling
8*	No chipping or peeling
9	No chipping or peeling
10	Several lines disbonded and peeled

* Control Coating

3.9. Tensile (Pull-Off) Adhesion

This test evaluated the pull-off strength (commonly referred to as adhesion) of the coatings. The test determines the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached. This test method uses a class of apparatus known as portable pull-off adhesion testers. They are capable of applying a concentric load and counter load to a single surface so that the entire coating system can be evaluated, even though only one side is accessible.

Measurements are limited by the strength of adhesion between the loading fixture and the specimen surface; or the cohesive strengths of the adhesive, coating layers, and substrate. The nature of the failure is reported as percentages of cohesive and adhesive failures of the respective interfaces (Figure 3-7).

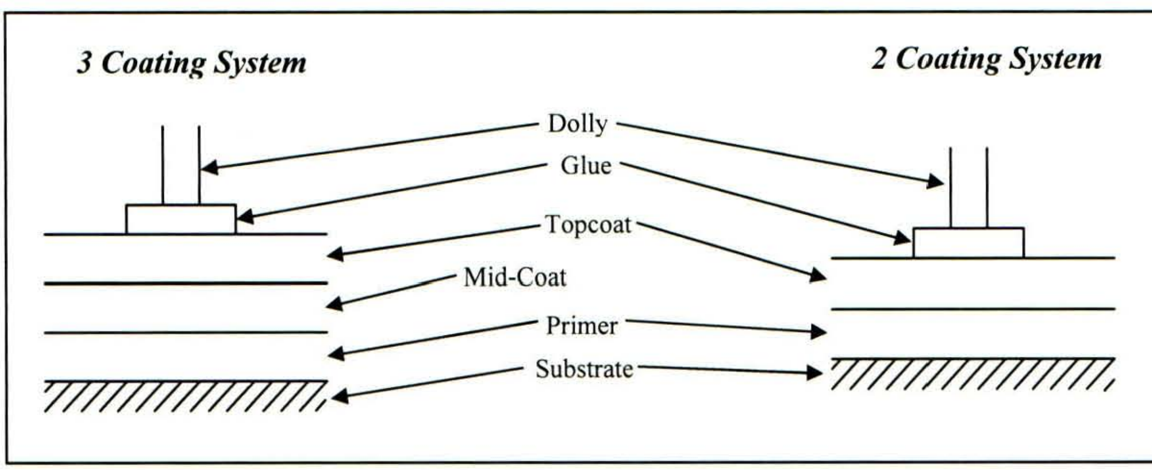


Figure 3-7 Coating System Interfaces

This test was performed in accordance with ASTM D 4541, *Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Testers*, approved 2002. The adhesion test results found in Table 3-17 are averages of three dolly pulls for each coating system.

Table 3-17 Results of Tensile Adhesion Testing

System	Adhesion (psi)	Failure Interface			
		Primer	Mid-Coat	Topcoat	Glue
1	1765	10% C	—	90% A	—
2*	2100	85% C	10% A	2% A	3% A
3	2050	—	—	100% A	—
4	935	—	—	100% A	—
5	760	—	—	100% C	—
6	1830	95% C	2% A	2% A	1% A
7	1785	99% C	1% A	—	—
8*	2180	35% C	40% C	—	25% A
9	2235	—	—	—	100% A
10	855	—	—	85% A	15% A

* Control Coating
A = Adhesion Failure
C = Cohesion Failure

Photodocumentation can be found in Appendix F.

3.10. X-Cut Adhesion by Wet Tape

This test method established the adequacy of intercoat and surface adhesion of an organic coating immersed in water by applying pressure sensitive tape over a scribed area of the coating. The X-cut with parallel lines scribe procedure increases the severity of this test over a dry tape adhesion test using a single "X" scribe and provides quantitative data for the adhesion of a coating system to the underlying metal substrate.

This test was performed in accordance with ASTM D 3359, *Standard Test Methods for Measuring Adhesion by Tape Test*, approved 1995, revised 2002, Test Method A. Each test panel was immersed in de-ionized water at room temperature for 24 hours. After removal from the water, each panel was wiped dry using a soft cloth. Within one minute of removing the panel from the water, two parallel lines were scribed one inch apart and a "X" was scribed between the parallel lines.

NOTE: This is a modification of the scribing described in Method 6301.2 of FED-STD-141.

Tape was applied across all scribed areas. After the tape was firmly affixed by passing a 4.5-pound roller across the taped surface eight times, it was quickly and smoothly pulled off at a 45° angle to the surface. The coating was visually examined for blistering and loss of adhesion. The degree of failure was rated on a scale from 0A to 5A as outlined in ASTM D 3359-02. A description of the ratings is shown in Table 3-18.

Table 3-18 ASTM D 3359 Ratings for Wet Tape Adhesion Testing

ASTM Rating	*Failure Mode*
5A	No peeling or removal.
4A	Trace peeling or removal along incisions or at their intersection.
3A	Jagged removal along incisions up to 1.6 mm (1/16") on either side.
2A	Jagged removal along most incisions up to 3.2 mm (1/8") on either side.
1A	Removal from most of the area of the X under the tape.
0A	Removal beyond the area of the X.

The results of the "X" cut adhesion tests are found in Table 3-19. Photodocumentation can be found in Appendix F.

Table 3-19 Results for X-Cut Adhesion by Wet Tape Testing		
System	***ASTM Rating***	***Failure Mode***
1	4A	Scribe tool caused jagged edges along incision
2*	5A	No damage
3	2A	Jagged removal along most incisions up to 3.2 mm (1/8") on either side
4	0A	Coating was severely blistered and was removed
5	5A	No damage
6	5A	Scribe tool caused jagged edges along incision
7	5A	Scribe tool caused jagged edges along incision
8*	5A	Scribe tool caused jagged edges along incision
9	5A	No damage
10	0A	Coating was removed between parallel lines

* Control Coating

3.11. Summary of Phase I Screening Tests

After a review of the Phase I Tests (Table 3-20), the following results were found:

- System -1 performed worse than the Control Systems in the Pot Life (Room Temperature), Knife, Tensile (Pull-off) Adhesion, and X-Cut Adhesion by Wet Tape tests and equal to the Control Systems in the remainder of the tests, except for the Pot Life (Heated) test in which it performed better than the Control Systems.
- System -3 performed worse than the Control Systems in the Tensile (Pull-off) Adhesion and X-Cut Adhesion by Wet Tape tests and equal to the Control Systems in the remainder of the tests, except for the Pot Life (Heated) test in which it performed better than the Control Systems.
- System -4 performed worse than the Control Systems in the Cure Time (Solvent Rubs), Cleanability, Tensile (Pull-off) Adhesion, and X-Cut Adhesion by Wet Tape tests; better than the Control Systems in the Accelerated Storage Stability and Pot Life (Heated) tests, and equal to the Control Systems in the remainder of the tests.
- System -5 performed worse than the Control Systems in the Cure Time (Solvent Rubs), Cleanability, and Tensile (Pull-off) Adhesion tests and equal to the Control Systems in the remainder of the tests, except for the Pot Life (Heated) test in which it performed better than the Control Systems.
- System -6 performed worse than the Control Systems only in the X-Cut Adhesion by Wet Tape test and equal to the Control Systems in the remainder of the tests, except for the Pot Life (Heated) test in which it performed better than the Control Systems.
- System -7 performed worse than the Control Systems only in the Accelerated Storage Stability test and equal to the Control Systems in the remainder of the tests, except Pot Life (Heated) test where it performed better than the Control Systems.
- System -9 performed worse than the Control Systems only in the Ease of Application test, performed better than the Control Systems in the Pot Life (Heated) and Tensile (Pull-off) Adhesion tests, and equal to the Control Systems in the remainder of the tests.
- System -10 performed worse than the Control Systems in the Cure Time (Solvent Rubs), Cleanability, Knife, Tensile (Pull-off) Adhesion, and X-Cut Adhesion by Wet Tape tests and equal to the Control Systems in the remainder of the tests, except for the Pot Life (Heated) test in which it performed better than the Control Systems.

After a review of the Phase I test results, Coating Systems -1, -4, -5, and -10 showed substandard performance in relation to the Control Systems and were eliminated from the Phase II testing. Although these systems were removed from Phase II testing, they were included in the 18-Month Marine Environment and Field Testing due to the time required for those tests. All coating systems were also included in the Hypergol and Liquid Oxygen (LOX) Compatibility Testing.

Coating Systems -3, -6, -7, and -9 were determined to be the best viable alternatives and were carried on to Phase II testing.

Table 3-20 Summary of Phase I Screening Tests as Compared to Control Coatings

Test	*Coating System*									
	1	*2*	*3**	*4*	*5*	*6**	*7**	*8*	*9**	*10*
Ease of Application	S	C	S	S	S	S	S	C	W	S
Surface Appearance	S	C	S	S	S	S	S	C	S	S
Dry-To-Touch (Sanding)	S	C	S	S	S	S	S	C	S	S
Accelerated Storage Stability	S	C	S	B	S	S	W	C	S	S
Pot Life (Heated)	B	C	B	B	B	B	B	C	B	B
Pot Life (Room Temp)	W	C	S	S	S	S	S	C	S	S
Cure Time (Solvent Rubs)	S	C	S	W	W	S	S	C	S	W
Cleanability	S	C	S	W	W	S	S	C	S	W
Knife Test	W	C	S	S	S	S	S	C	S	W
Tensile (Pull-off) Adhesion	W	C	W	W	W	S	S	C	B	W
X-Cut Adhesion by Wet Tape	W	C	W	W	S	W	S	C	S	W

* Carried on to Phase II testing

C = Control Coatings

B = Performance Better than Control Coatings

S = Performance Similar to Control Coatings

W = Performance Worse than Control Coatings

4. PHASE II TESTS

The four coating systems that performed best in the Phase I (Screening) Tests were carried on to Phase II Testing. Systems carried on to Phase II Testing are shown in Table 4-1.

Table 4-1 Coatings Systems Evaluated in Phase II

System	*Topcoat*	*Intermediate*	*Primer/Wash*	*Manufacturer*
2*	Carbothane 134 HB	Carboguard 893	Carbozinc-11HS	Carboline
3	Polysiloxane XLE	*None*	ZincClad 11	Sherwin Williams
6	Interfine 979	Interseal 670HS	Interzinc 22	IPC
7	Interfine 878	Interseal 670HS	Interzinc 22	IPC
8*	Cathacoat 359	Cathacoat 201	Cathacoat 304	Devoe
9	AST D45	AST Crosslinker	AST Decontaminator	Kimetsan

* Control Coating

Table 4-2 lists the Phase II tests, acceptance criteria and the reference specifications, if any, used to conduct the tests. The test and evaluation are based on the aggregate knowledge and experience of the assigned technical project personnel and prior testing where "None" appears under *Test Method References*.

In order to reduce costs, both Control Coatings were not used for every Phase II test.

Table 4-2 Phase II Testing Requirements				
Test	***JTR Section***	***Test Specimen***	***Acceptance Criteria***	***References***
Removability	4.1.	Coupon	Less than one minute to penetrate substrate; Tested during Repairability and Abrasion Resistance Tests; Measure DFT of remaining coating	ASTM G 155
Repairability	4.2.	Coupon	Ease of removal and replacement of damaged areas of the test coatings, color matching of aged versus new material; No streaks, blistering, voids, air bubbles, over-spray "halo", cratering, lifting, blushing, or other surface irregularities, No peel away of the repaired coating during the dry tape adhesion test	ASTM D 523; ASTM D 2244; ASTM D 3359
Abrasion Resistance	4.3.	Coupon	Coating removal (weight loss) less than or equal to control coating or less than 4 mm^2 exposed substrate	ASTM D 4060
Gravelometer	4.4.	Coupon	Rating should be equal to or better than control	ASTM D 3170
Fungus Resistance	4.5.	Coupon	Does not support fungal growth and meets adhesion requirements	ASTM D 3359; MIL-STD-810F
Accelerated Weathering	4.6.	Coupon	Color change performance less than one ΔE unit at 500 hour intervals	ASTM D 523; ASTM D 2244; ASTM G 155
Mandrel Bend Flexibility	4.7.	Coupon	No peeling or delamination from the substrate and no cracking greater than 1/4-inch from the edges	ASTM D 522

Table 4-2 Phase II Testing Requirements

Test	*JTR Section*	*Test Specimen*	*Acceptance Criteria*	*References*
Cyclic Corrosion Resistance	4.8.	Coupon	Candidate coating performs as well or better than the control coatings; No significant blistering, softening, or lifting of coating	GM 4465 P; GM 9540 P
Hypergol Compatibility	4.9.	Coupon	Slight to Moderate Reactivity Observed: When test data based on visual observations with the unaided eye reveal reactivity (but no ignition) and/or any changes in the visual characteristics, bulk characteristics, and/or surface characteristics of the test sample	KSC MTB-175-88; NASA-STD-6001
LOX Compatibility	4.10.	Coupon	Twenty samples must not react when impacted at 72 foot-pounds (ft-lbs); If one sample out of 20 reacts, 40 additional samples must be tested without any reactions	ASTM D 2512; NASA-STD-6001
18-Month Marine Environment	4.11.	Coupon	Gloss change and panel condition of candidate coating rated equal to or better than control coatings	ASTM D 610; ASTM D 714; ASTM D 523

4.1. Removability

This test determined the relative ease of coating removal on a 2-inch diameter area of a test coupon using aluminum oxide blast media after the coupon is artificially weathered. Coating systems must typically be removed after prescribed periods of use. Evaluation of relative removal ease for candidate alternate coating systems after aging is necessary for predicting the effectiveness of field maintenance operations.

The panels used for this test were 3"× 6". The coated test panels were weathered for 500 hours in accordance with ASTM G 155, *Standard Practice for Operating Light Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials*, approved 2000, G 155 corresponding test cycle for G 26, Method A (continuous light with intermittent water spray), prior to testing for Removability.

Before performing the Removability test; color, gloss, and coating thickness measurements were performed on each panel. The weathered panels were placed on a rack and tilted to a 60° angle to the horizontal. The abrasive blast nozzle was directed at a single area until the coating was removed, or until a maximum duration of one 1 minute had been achieved.

All of the coating systems passed the minimum requirement of removing a 2-inch diameter area with a dwell time under 1 minute (Table 4-3). Examples of the areas in which the coating was removed are shown in Figure 4-1.

Table 4-3 Results of Removability Test				
System	***Panel***	***Thickness***	***Time* (sec [a])**	***Avg* [b] *per mil* (sec)**
2*	7	9.0	37	3.7
	8	8.5	32	
	9	9.5	31	
3	53	6.0	35	5.6
	54	5.5	33	
	55	7.5	37	
6	66	14.0	57	3.4
	67	20.0	60	
	68	19.0	59	
7	71	12.0	40	3.3
	72	14.0	44	
	73	13.0	44	
9	81	3.5	15	4.0
	82	3.8	15	
	83	4.1	15	

* Control Coating

[a] seconds (sec)

[b] Average (Avg)

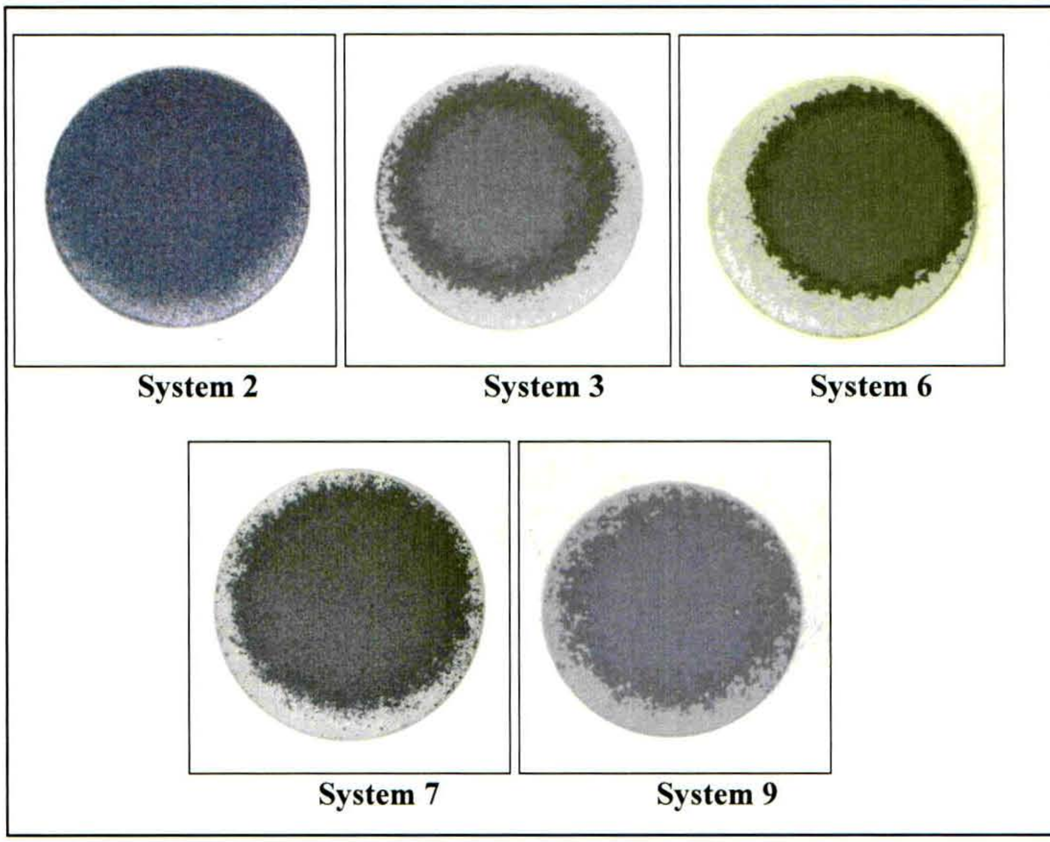


Figure 4-1 Typical Removability Photographs

4.2. Repairability

This test determined the relative ease of replacing and blending-in coatings that have been removed or otherwise damaged. The dry tape adhesion test provided a procedure for establishing acceptability of intercoat and surface adhesion of an organic coating by applying pressure-sensitive adhesive tape over a scribed area of the coating, then removing. The test panels previously used for the Removability test were used for the Repairability test.

The three procedures used to investigate the Repairability of the coatings included:

A. repair of the baseline control coating with a baseline coating,
B. repair of the baseline control coating with each of the alternative coatings, and
C. repair of each alternative coating with that alternative coating.

Only one set of coupons with the baseline coating repaired with the baseline coating was required for comparison. The repairs were performed in accordance with the coating manufacturers' repair instructions.

Each repaired coupon was examined to evaluate the appearance of the repair. The repaired area was inspected to ensure that the quality of the coating repair matched the original, aged coating on the top half of the test coupon using before and after color and gloss measurements (Tables 4-4 and 4-5).

Table 4-4 Results of Repairability Color Change (delta E) Test

System	*ΔE from Self*	*ΔE from Control*
2*	3.4	3.4
3	0.4	3.1
6	0.9	3.8
7	1.6	4.8
9	2.9	4.5

*Control Coating

Table 4-5 Results of Repairability Gloss Change Test				
System	***ΔGloss from self (GU's)***	***ΔGloss from self***	***ΔGloss from control (GU's)***	***ΔGloss from control***
2*	34.4	60.0%	34.4	60.0%
3	8.5	13.9%	12.6	22.0%
6	1.3	2.4%	-3.8	-6.6%
7	9.9	29.5%	-13.9	-24.2%
9	0.5	5.9%	-48.9	-85.4%

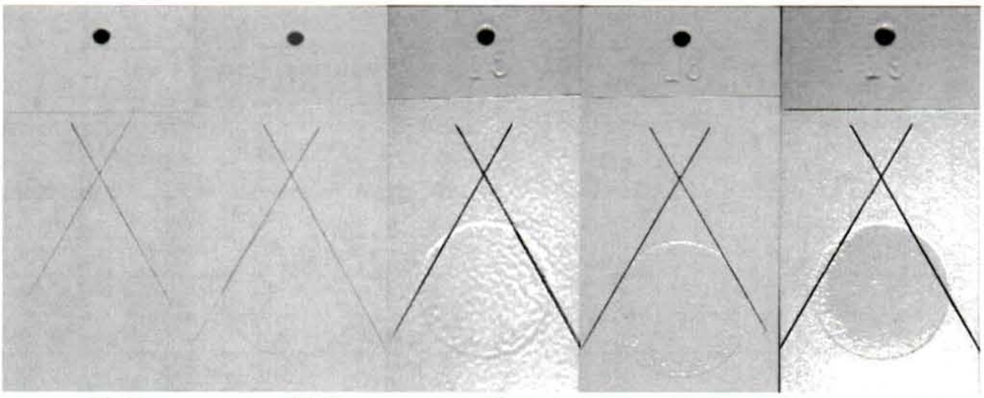
*Control Coating

As shown in Tables 4-4 and 4-5, all of the alternative coatings performed better than Control System -2 when compared with itself. Control System -2 showed a greater change in color and gloss with a delta E of 3.4 units and an increase in gloss of 34.4 GU's, or 60%. When trying to match the alternatives with the control coating, all systems performed similar in color matching with delta E values less than 1 unit of each other, except for System -7 which was 1.4 units.

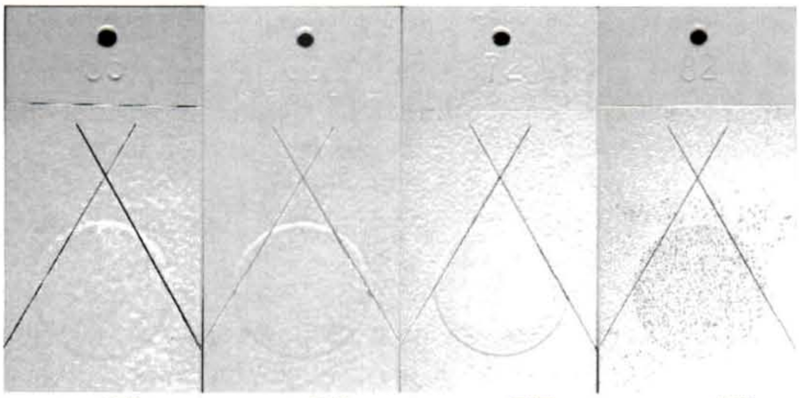
Repaired Systems -3, -6, and -7 gloss values were closer to that of the unrepaired section with values ranging within 24.2%. The gloss values for System -9 showed a greater change with a 85.4% loss of gloss when compared to the unrepaired section.

To ensure adherence of the coating repair, a dry tape adhesion test was performed after the prescribed cure times. This test was performed in accordance with Method A of ASTM D 3359, *Standard Test Methods for Measuring Adhesion by Tape Test*, approved 1995, revised 2002.

Two incisions forming an "X" were scribed through the coating so that the smaller angle of the "X" was between 30°- 45°. Each sample was inspected to ensure that the coating was scribed to the substrate. The scribe had a 45-degree bevel and each line of the "X" was at least 1.5 inches long. After the samples were scribed, a piece of tape was placed over the intersection of the "X" and affixed to the surface by passing a 4.5 lb. roller over it 8 times. The tape was rapidly removed at an angle of approximately 180° and the surface was inspected to investigate peeling from the scribe. All of the repaired panels passed the adhesion test with values of 5A, no peeling or removing of coating observed (Figure 4-2).



2*/2 2*/3 2*/6 2*/7 2*/9



3/3 6/6 7/7 9/9

*** Control Coating**

 # / # = Original System / Repair System

Figure 4-2 Photographs of Repairability Results

4.3. Abrasion Resistance

This test evaluated the abrasion protection (wear resistance) provided by a coating. Tests were conducted in accordance with ASTM D 4060 (*Standard Test Method for Abrasion Resistance of Organic Coating by the Taber Abraser*, revised 2001). Three test coupons (4"× 4"× 1/16") were coated and cured in accordance with the manufacturer's instructions.

Dry film thickness, photographs, and weights were recorded for each test coupon prior to abrasion, after 500 cycles, after 1000 cycles, or until failure, which is represented by the removal of coating from the substrate. The test was performed using a Model 5150 Tabor Abraser with an H-18 abradant wheel and a 1000 gram load. The abrasive wheels were refaced for 50 cycles using an S-11 disk at start-up and at every 500 cycle interval thereafter. Wear cycles per mil were calculated using Equation 3.

$$W = D/T \qquad \text{(Eq. 3)}$$

where:

D = number of cycles of abrasion

T = thickness of coating loss, mils

The results of the Abrasion Resistance Test are shown in Table 4-6.

Table 4-6 Results of Abrasion Resistance Test

System	*Cycles*	*Coating Thickness Loss (mils)*	*Wear Cycles per mil*
2*	400	2.30	174
3	1000	2.53	395
6	700	5.06	138
7	283	2.85	99
8*	878	7.00	125
9	277	2.25	123

*Control Coating

From the data presented in Table 4-6, System -3 was the only coating system that survived the full 1000 cycles, far surpassing Control Systems -2 and -8. Systems -3, -6, and -9 performed equally well or better than Control System -8 (± 1 standard deviation), which was used for the low end pass/fail criteria (Figure 4-3).

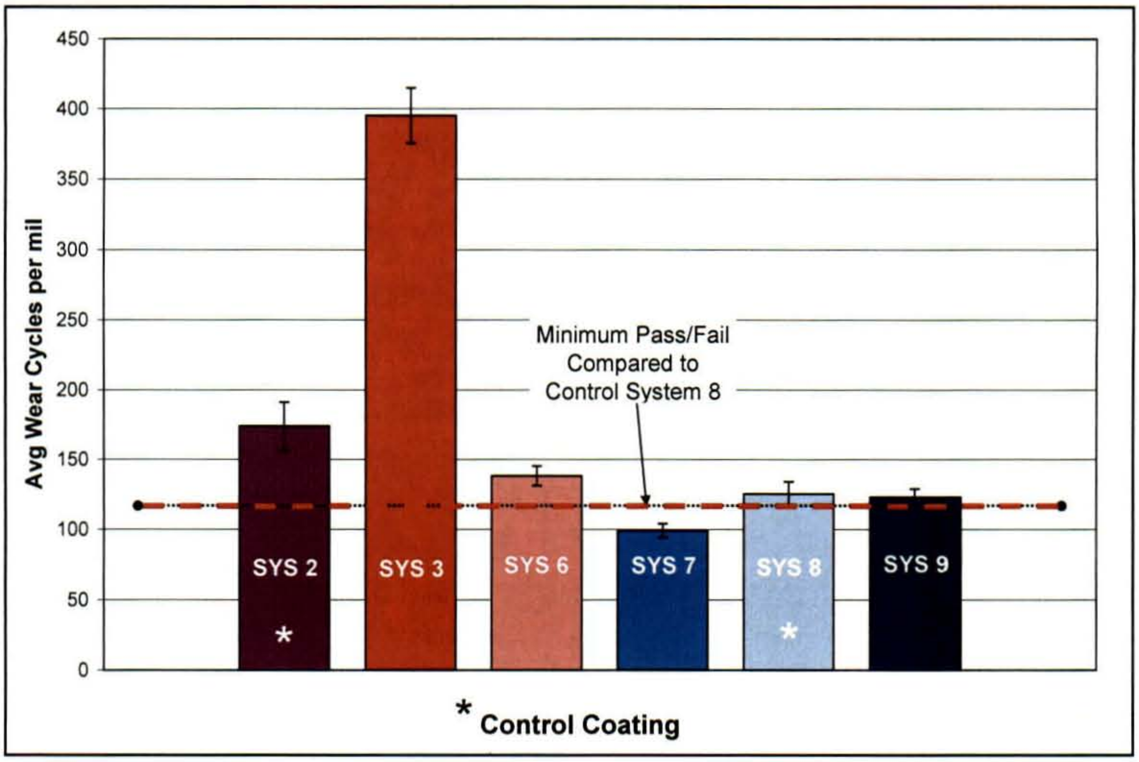


Figure 4-3 Taber Abrasion Wear Cycles per mil

4.4. Gravelometer

This procedure evaluated the resistance of the coatings to chipping by gravel impact. The test is designed to reproduce the effect of gravel or other media striking exposed paint or coated surfaces. This test documents the chip protection provided by the coating for the substrate. Structures, particularly those near launch sites, are often subjected to flying debris.

The coupons used for this test were 6"× 12". Tests were conducted in accordance with ASTM D 3170, *Standard Test Method for Chipping Resistance of Coatings*, approved 1973, revised 2003. The test consisted of propelling standardized road gravel by means of a controlled air blast. The testing apparatus (gravelometer) used for this test is designed to contain road gravel, a test panel holder and a pneumatic gravel projecting mechanism (Figure 4-4).

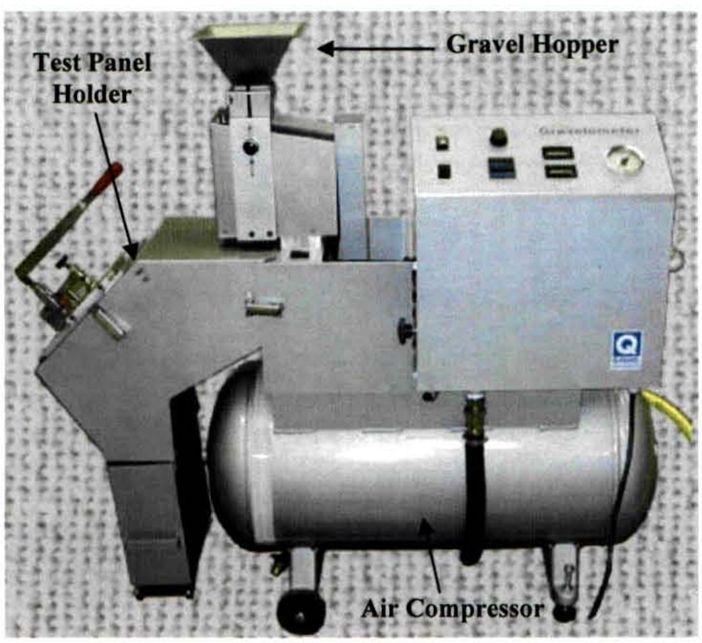


Figure 4-3 Gravelometer Apparatus

All testing was conducted under ambient temperature conditions as specified in Paragraph 5.4.3 of ASTM D 3170. After the gravel impact, tape was applied to remove any loose paint chips remaining on the panel to evaluate the degree of chipping. The chip rating system consists of one or more number/letter combinations in which the numbers indicate the number of chips removed from the surface, and the letters (A through D) designate the size of the corresponding chips (Table 4-7). The size designation is approximate due to the irregular nature of chipping. The rating number scale is judged on a scale from 10 to 0, with a rating of 10 indicating no coating removal and 0 indicating over 250 chips observed (Table 4-8).

Table 4-7 ASTM D 3170 Chip Size Categories

Rating Letter	*Size of Chips*
A	<1 mm
B	1 to 3 mm
C	3 to 6 mm
D	> 6 mm

Table 4-8 ASTM D 3170 Number Categories for Chip Ratings

Rating Number	*Number of Chips*
10	0
9	1
8	2 to 4
7	5 to 9
6	10 to 24
5	25 to 49
4	50 to 74
3	75 to 99
2	100 to 149
1	150 to 250
0	> 250

The resistance to chipping for Systems -3, -6, -7, and -9 was compared to the Control Systems -2 and -8. The coupons were photographed and are presented in Figure 4-5 to give a visual representation of the results. For all systems, adhesion failures predominated with disbondment occurring between the primer and topcoat.

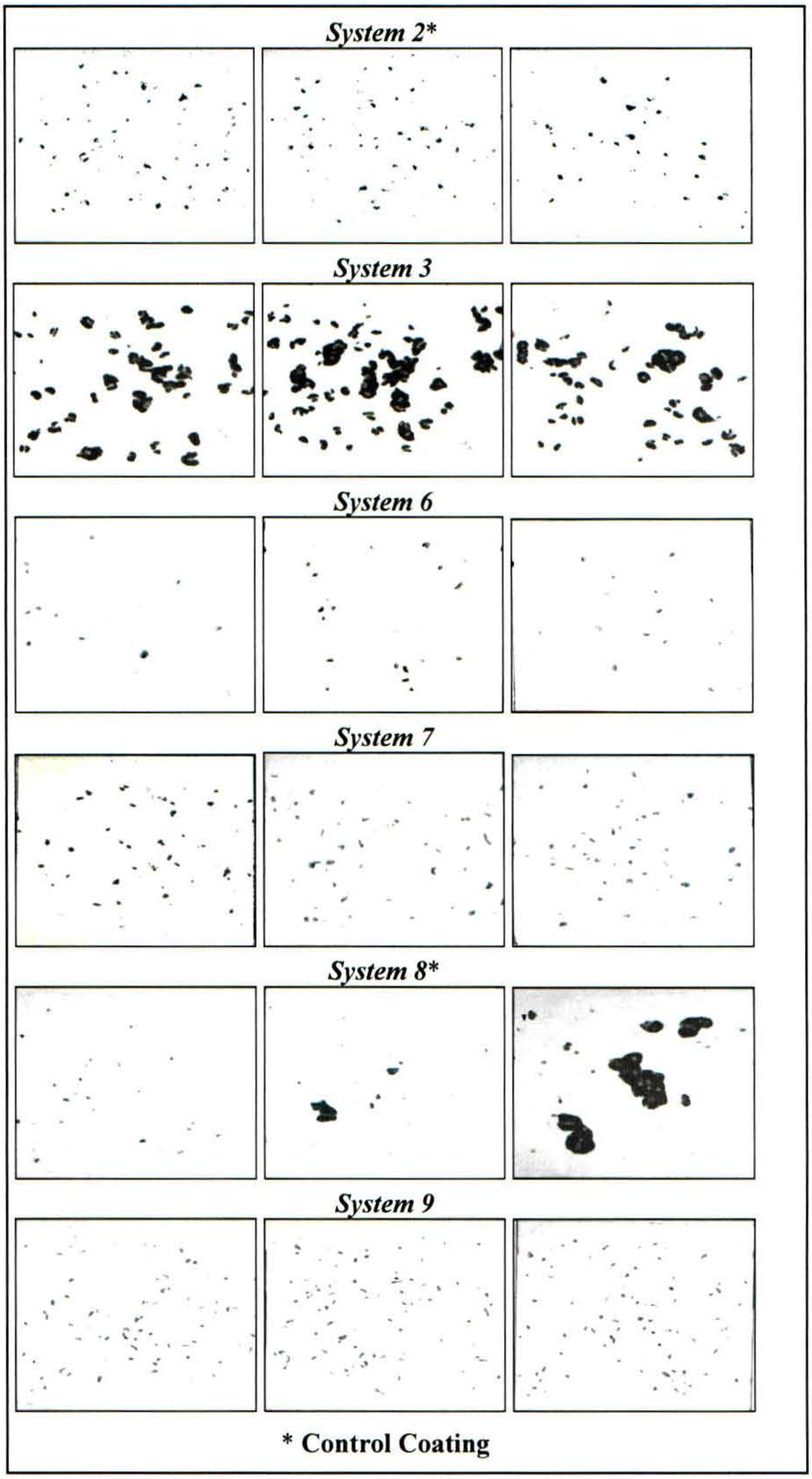


Figure 4-5 Gravelometer Chip Photographs

The size and number of failures is noted in Table 4-9. Control System -8 proved to have the least number of chips (10 to 24), but the greatest chip size (>6 mm). A visual comparison indicates that all of the systems performed equal to or better than Control System -2, except for System -3 which experienced larger size chip damage. The photographs and tabulated results show System -6 exhibited the highest degree of performance, sustaining the smallest and fewest chipped regions.

Table 4-9 Results of the Gravelometer Test

System	Panel	Rating		Failure Mode
		Number	Size	
2*	A	4	B	Adhesional- primer to topcoat
	B	4	B	Adhesional- primer to topcoat
	C	5	B	Adhesional- primer to topcoat
3	A	5 & 7	C/D	Adhesional- primer to topcoat
	B	5 & 6	C/D	Adhesional- primer to topcoat
	C	5 & 7	C/D	Adhesional- primer to topcoat
6	A	6	B	Adhesional- primer to topcoat
	B	6	B	Adhesional- primer to topcoat
	C	6	B	Adhesional- primer to topcoat
7	A	5	B	Adhesional- primer to topcoat
	B	5	B	Adhesional- primer to topcoat
	C	5	B	Adhesional- primer to topcoat
8*	A	6	B	Adhesional- primer to topcoat
	B	6 & 9	B/D	Adhesional- primer to topcoat
	C	6 & 7	B/D	Adhesional- primer to topcoat
9	A	4	B	Adhesional- primer to topcoat
	B	4	B	Adhesional- primer to topcoat
	C	4	B	Adhesional- primer to topcoat

* Control Coating

4.5. Fungus Resistance

The fungus resistance test was performed to measure the extent to which a coating will support fungal growth and indicate how the fungal growth affects the adhesion of the topcoat. The fungal resistance testing was performed in conjunction with Bionetics Corporation, which is an onsite environmental contractor that provides full operational support for biological and physical research programs at Kennedy Space Center (KSC).

Bionetics Corporation provided the support required to perform the fungal growth testing and monitored the coupons over the 84 day growth period. Once the period was completed, the test coupons were inoculated and returned to the NASA Corrosion Technology Laboratory where they were photographed and adhesion tests were performed. The adhesion tests were performed as outlined in section 3.1.9 of the JTP. The procedure was previously reported in section 3.10. (X-Cut Adhesion by Wet Tape) of this report.

The fungus resistance test indicated that the fungus had no effect on the adhesion of the topcoats. All systems performed as previously tested (Table 3-19) with fungal adhesion ratings listed in Table 4-10. A complete set of before and after photographs and the Bionetics Corporation lab report can be found in Appendix G.

Table 4-10 Results of the Fungus Wet Tape Adhesion Testing

System	*ASTM Rating*	*Failure Mode*
2*	5A	No damage
3	2A	Jagged removal along most incisions up to 3.2 mm (1/8") on either side.
6	5A	Scribe tool caused jagged edges along incision
7	5A	Scribe tool caused jagged edges along incision
8*	5A	Scribe tool caused jagged edges along incision
9	5A	No damage

* Control Coating

Visual observations revealed noticeable differences in the appearance of the topcoats on Systems -3 and -9. Low magnification photographs verified the anomalies found on Systems -3 and -9 and confirmed the lack of damage on the remaining systems. Large and small blisters randomly appeared on the surface of the topcoats of Systems -3 and -9 as shown in Figures 4-6 and 4-7.

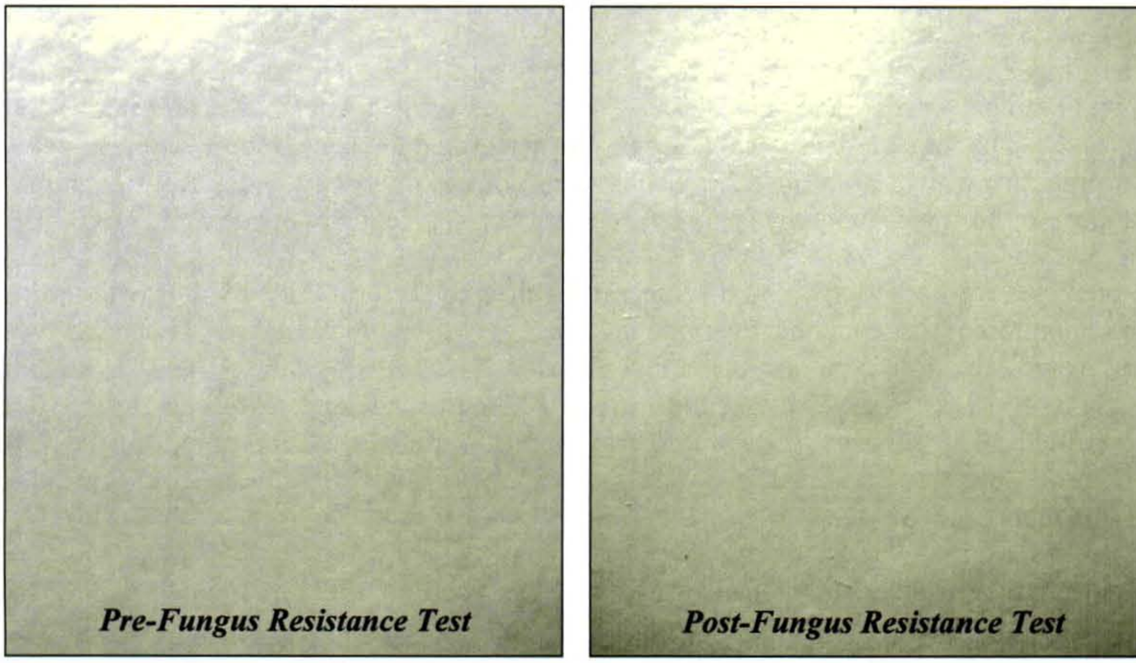


Figure 4-6 Photographs of Pre- and Post-Fungus Resistance Test for System -3

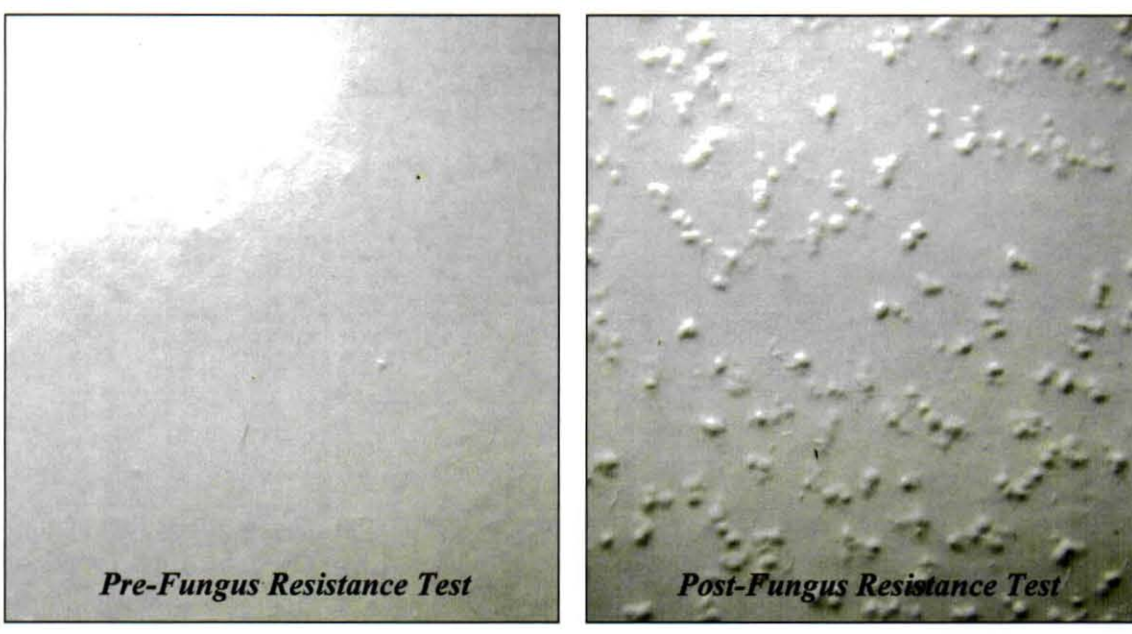


Figure 4-7 Photographs of Pre- and Post-Fungus Resistance Test for System -9

4.6. Accelerated Weathering

Accelerated weathering was used to evaluate the degree of color and gloss retention when the coating systems were exposed to a simulated outdoor weathering environment. The protocol was deemed necessary since steel structures must withstand daily outdoor exposure to sunlight and wet/dry cycles.

The coupons used for this test were 3"× 6" and were coated per the manufacturers' specification on the specification sheets. The initial gloss and color measurements were recorded after application. Baseline color and gloss measurements were collected using ASTM D 2244, *Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates*, and ASTM D 523, *Standard Test Method for Specular Gloss*, as a guide. A description of the color and gloss measuring processes are outlined in section 3.2. of this report. Gloss measurements (reported in GU's) were collected with a reflective illuminated light at a 60° angle.

After the initial color and gloss measurements were collected, the coupons were exposed to ultra-violet light (UV), through a borosilicate inner and outer filter to simulate sunlight and intermittent moisture according to ASTM G 155, *Standard Practice for Operating Light Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials*, approved 1996, Method A (continuous light with intermittent water spray). Color and gloss measurements were collected at 500 hour intervals or until failure; per the JTP, testing was discontinued when the acceptance criteria was no longer met.

The criteria required a color change performance of less than one delta E unit for a 500 hour period of exposure. Delta E values, as a change from the previous measurement, is documented in Table 4-11. As indicated by the data in Table 4-11, the only coating system with a delta E that changed by less than 1 from the previous 500 hour evaluation was System -9, with a delta E of 0.9 units.

Table 4-11 Change in Delta E Color Values for Accelerated Weathering from Previous 500 Hour Measurement

System	*500 hour ΔE*	*1000 hour ΔE*
2*	0.5	1.1
3	0.3	1.0
6	0.5	1.1
7	0.4	1.7
8*	0.7	1.4
9	0.6	0.9

* Control Coating

Table 4-12 documents the specular gloss readings for the coupons which were subject to accelerated weathering.

Table 4-12 Results of 60° Specular Gloss Accelerated Weathering

System	*Initial Gloss*	*1000 Hour Gloss*	*1000 Hour Gloss Retention*
2*	79.3	75.2	94.8%
3	81.0	75.4	93.0%
6	66.7	63.7	95.5%
7	54.0	50.3	93.1%
8*	57.3	54.5	95.1%
9	7.2	10.2	141.7%

* Control Coating

Figure 4-8 shows the final gloss retention as a percentage of the initial GU measurements.

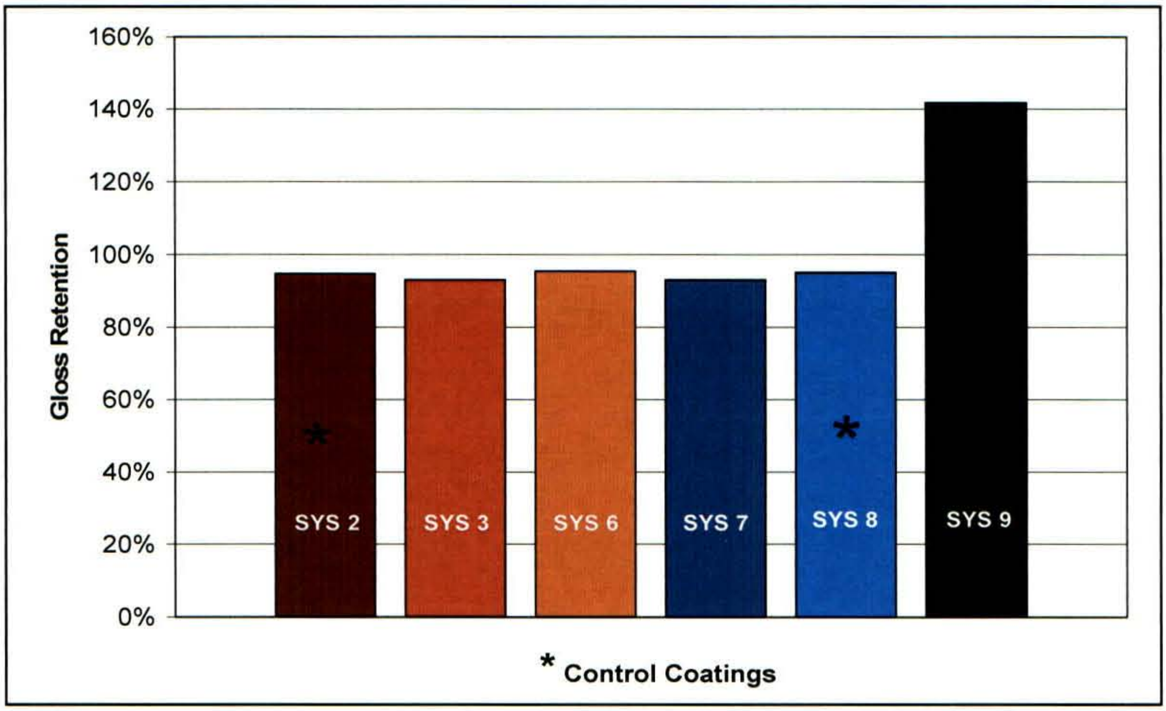


Figure 4-8 Gloss Retention of Accelerated Weathering Coatings – 1000 hour Exposure

As indicated by the gloss retention values in Figure 4-7, accelerated weathering impacted gloss retention values on Systems -3, -6 and -7; in a manner similar to Control Systems -2 and -8. Calculated values of gloss retention ranged from 93.0% – 95.5%. The gloss retention for System -9 was the single exception to this trend, exhibiting a value of 141.7%. This behavior is inconsistent with the trend of decreasing gloss retention as a function of time at the KSC Beach Corrosion Test Site. The difference is understandable, however, considering that the panels at the beach were subject to much more corrosive conditions. As a result, the beach site panels showed a significant increase in corrosion products that had an obvious effect on the gloss readings.

While the 141.7% increased gloss retention value appears significant, the initial gloss readings were averaged to a 7.2 GU value. As a result, the change in gloss at the 1000 hour termination of the test resulted from a mere 3.0 GU increase. Additionally, the accuracy of the gloss unit determination may have been influenced by the use of a 60° incident angle with the gloss meter. Ordinarily, an 85° incident angle would have been used for the measurements since the initial gloss readings for System -9 samples were less than 10 GU. For uniformity in comparison between coating systems, however, it was decided that a 60° incident angle would be utilized early in the testing.

Table 4-13 documents the 500 hour and 1000 hour delta E color values for the coating systems that were subjected to accelerated weathering. As a general rule, a delta E value of 1 is discernable with 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.

Table 4-13 Coating Color Differences (delta E) from Initial Measurement

System	*500 hour ΔE*	*1000 hour ΔE*
2*	0.5	0.7
3	0.3	1.2
6	0.5	0.9
7	0.4	1.5
8*	0.7	0.8
9	0.6	1.2

* Control Coating

As shown in Figure 4-9, all coating systems performed within 1 delta E of Control System -8. As a consequence, while all systems produced a very slight variation in color at the 1000 hour mark, no delta E values were exhibited by the candidate coatings that are indicative of a noticeably increased change in color as compared to Control System -8. In other words, no system changed by a degree which was noticeably different from the degree of change for Control System -8.

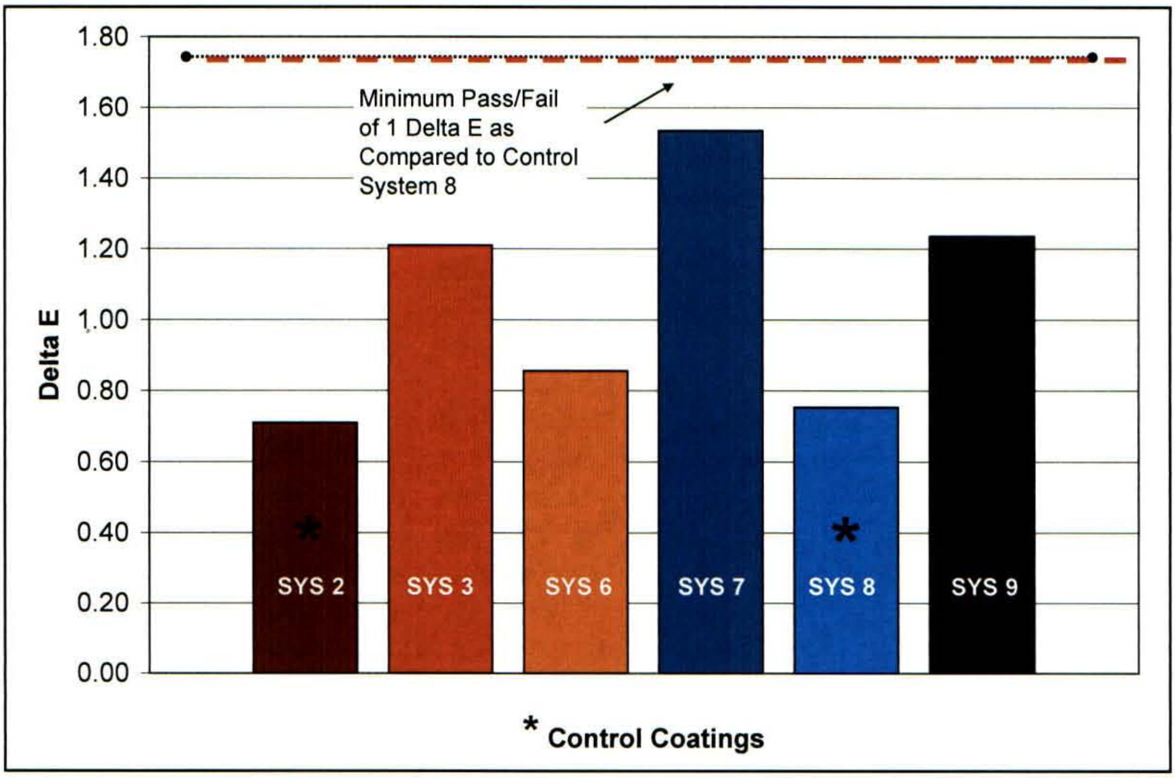


Figure 4-9 Delta E Color Difference – 1000 hour Exposure

4.7. Mandrel Bend Flexibility

This test evaluated the flexibility of the coatings and their adhesion to a substrate when the test coupon is bent around a 1/4-inch fixed diameter mandrel. The bend test was conducted in accordance with ASTM D 522, *Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings*, approved 1993, revised 2001, Test Method B, at ambient temperature. This method was used to determine whether the candidate coatings provided the same flexibility, adhesion, and elongation when compared to the control coatings.

Three 3"× 5" 22-guage steel panels (for each coating system) were prepared and allowed to cure in accordance with the manufacturers' instructions. The test panels were placed over a 1/4" mandrel with the uncoated side in contact and with at least 2 inches of coupon "overhang" on either side. Using steady fingertip pressure, the panels were bent to an angle of approximately 180° around the mandrel at a uniform velocity in a 1 second duration. The panels were immediately removed from the mandrel and were examined and photographed for cracking that was visible to the unaided eye. For each system that did not show evidence of cracking (Table 4-14), elongation was calculated using Equation 4.

$$E = e_l + tc_l \qquad \text{(Eq 4)}$$

where:

E = total elongation, %

e_l = mandrel elongation factor, %

t = coating thickness, mils

c_l = film thickness correction factor

Table 4-14 Mandrel Bend Test Data (1/4" Mandrel)

System	*Elongation (E) %*	*Pass/Fail (< 1/4")*
2*	18.2	Pass
3	NA [a]	Fail
6	16.8	Pass
7	18.9	Pass
8*	NA [a]	Fail
9	20.4	Pass

* Control Coating
[a] Not applicable (NA)

Systems -6, -7, and -9 showed a similar or better degree of performance in relation to Control System -2 (Figure 4-10). Both Control System -8 and System -3 failed on the 1/4" mandrel. These systems were re-tested using a larger mandrel (1/2"), but still failed.

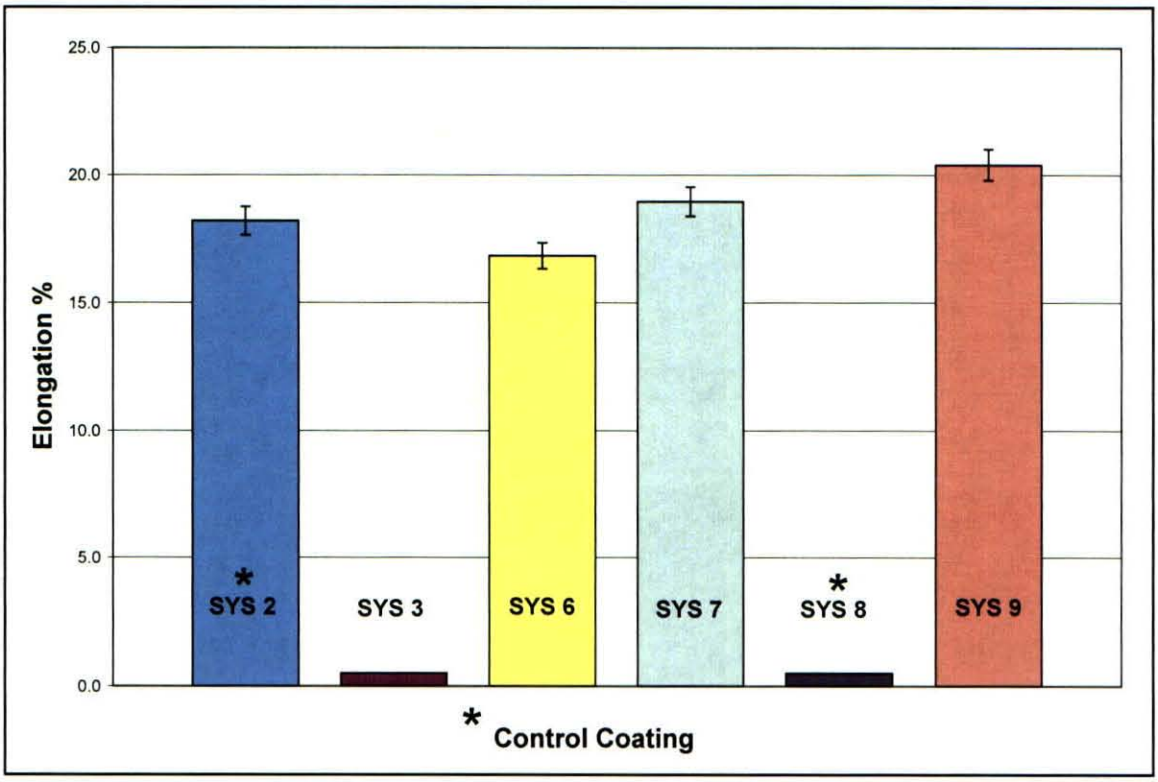


Figure 4-10 Coating Elongation from Mandrel Bend Test

4.8. Cyclic Corrosion Resistance

Cyclic corrosion testing was performed in accordance with General Motors (GM) 9540P, *Accelerated Corrosion Test*, approved December 1997. The test evaluates the ability of a coating system to prevent corrosion of a metallic substrate in a simulated (neutral pH) corrosive environment. The test procedure provides a combination of cyclic conditions, such as a wet salt solution spray cycle, various temperatures, humidity, and ambient conditions.

The coupons were placed on non-conductive racks at a 30° angle in an Auto-Technology CCT-NC-40 programmable cyclic corrosion chamber (Figure 4-11).

Figure 4-11 Cyclic Corrosion Chamber

One single GM 9540P cycle consisted of the following steps:

- **Step 1.** Expose the coupon to salt water spay (0.9% sodium chloride, 0.1% calcium chloride and 0.025% bicarbonate of soda) for one minute.
- **Step 2.** Allow the coupon to remain under ambient atmospheric exposure conditions for 89 minutes.
- **Step 3.** Expose the coupon to salt water spray (0.9% sodium chloride, 0.1% calcium chloride and 0.025% bicarbonate of soda) for one minute.
- **Step 4.** Allow the coupon to remain under ambient atmospheric exposure conditions for 89 minutes.

Step 5. Expose the coupon to salt water spray (0.9% sodium chloride, 0.1% calcium chloride and 0.025% bicarbonate of soda) for one minute.

Step 6. Allow the coupon to remain under ambient atmospheric exposure for 89 minutes.

Step 7. Expose the coupon to salt water spray (0.9% sodium chloride, 0.1% calcium chloride and 0.025% bicarbonate of soda) spray for one minute.

Step 8. Allow the coupon to remain under ambient atmospheric exposure for 209 minutes.

Step 9. Expose the coupon to high humidity conditions [in accordance with GM 4465 P, *Water Fog Humidity Test*, revised 1995, at 120 ± 3° F and 1-2 milliliter/hour collection rate].

Step 10. Dry the coupons by exposure to 140 ± 3° F at < 30% Relative Humidity.

Coupons were evaluated at the conclusion of a week of testing (5 cycles). The test continued for 60 cycles (12 weeks). Photographs were taken before, during, and after the completion of the test and can be found in Appendix H of this document. Results are shown in Table 4-15.

Table 4-15 Results of Cyclic Corrosion Test

System	*Pass/Fail*
2*	Pass
3	Pass
6	Pass
7	Pass
8*	Pass
9	Fail

* Control Coating

All coating systems, except System -9, provided equal or better performance in relation to the control systems. System -9 showed signs of corrosion which initiated on the back side (primer only) of the coupons after the first week. The corrosion steadily worsened, affecting the edges and front of the coupon by the end of week 6 and finally covering the front by week 12 (Figure 4-12).

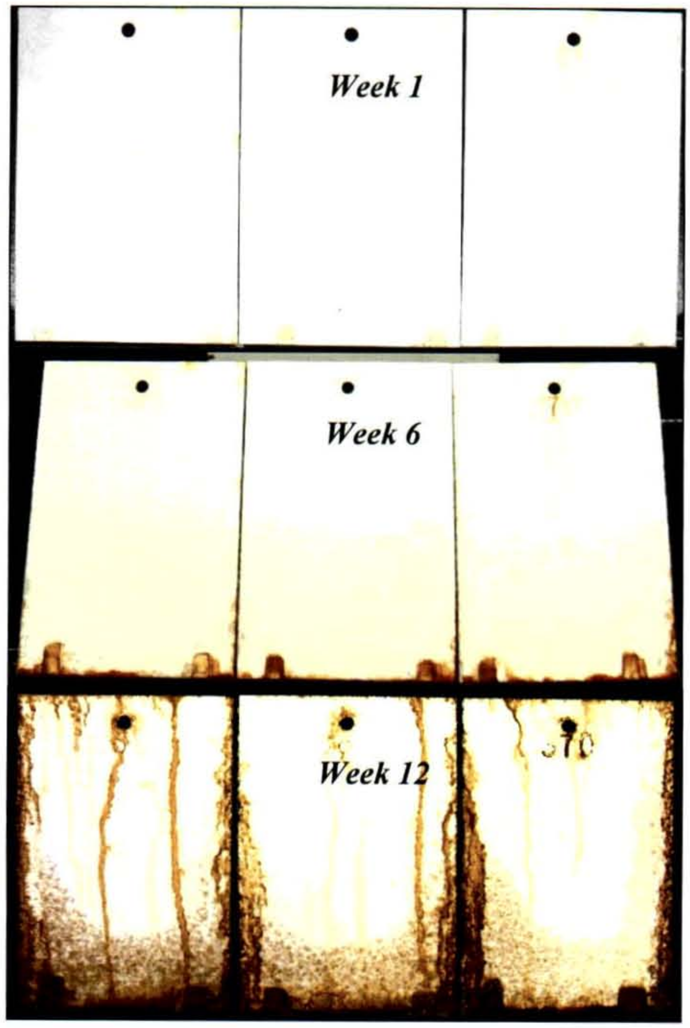


Figure 4-12 Photographs of System -9 Cyclic Corrosion Test

4.9. Hypergol Compatibility

This procedure evaluated the effects on coatings from casual exposure to hypergolic fluids [nitrogen tetroxide (N_2O_4), hydrazine (N_2H_4), and monomethylhydrazine (MMH)] and provided a method to determine if a fluid could react exothermally or spontaneously ignite on contact with the material. This test is specified in NASA-STD-6001 and materials intended for use in space vehicles, specified test facilities, and specified ground support equipment must meet the requirements of that document.

Testing was performed in accordance with KSC MTB-175-88, *Procedure for Casual Exposure of Materials to Hypergolic Fluids*, dated September 12, 1994, Test Method 7.1, Reactivity Test Method. The test coatings were applied on aluminum foil (measuring 4"× 4") in a thickness equivalent to normal use and were cured in accordance with the manufacturers' instructions. Once cured, the samples were packaged and delivered to the NASA Material Science Laboratory for submission to Wiltech for testing.

Results of the Hypergolic Compatibility testing are shown in Table 4-16. All coatings (except for System -5) passed the acceptance criteria for the casual exposure to hypergolic fuels as outlined in section 3.2.10. of the JTP. The official NASA Material Science Laboratory document KSC-MSL-2005-0559 for this test can be found in Appendix I.

Table 4-16 Results of Hypergol Compatibility Testing

System	*Hypergol*	*Temperature Delta (°C)*	*Rating*	*Pass/Fail*
1	MMH	0.9 @ 10 min	Not significant	Pass
	N_2H_4	1.2 @ 4 min	Not significant	Pass
	N_2O_4	N	Slight to moderate	Pass
2*	MMH	0.3 @ 10 min	Slight to moderate	Pass
	N_2H_4	0.7 @ 4 min	Not significant	Pass
	N_2O_4	N	Slight to moderate	Pass
3	MMH	1.1 @ 10 min	Not significant	Pass
	N_2H_4	0.7 @ 2 min	Not significant	Pass
	N_2O_4	N	Slight to moderate	Pass
4	MMH	1.1 @ 10 min	Slight to moderate	Pass
	N_2H_4	0.7 @ 4 min	Not significant	Pass
	N_2O_4	N	Slight to moderate	Pass
5	MMH	3.2 @ 8 min	Temperature increase	Fail
	N_2H_4	0.9 @ 10 min	Not significant	Pass
	N_2O_4	N	Not significant	Pass
6	MMH	1.3 @ 4 min	Not significant	Pass
	N_2H_4	0.6 @ 2 min	Not significant	Pass
	N_2O_4	N	Slight to moderate	Pass
7	MMH	2.7 @ 6 min	Not significant	Pass
	N_2H_4	1.6 @ 8 min	Not significant	Pass
	N_2O_4	N	Slight to moderate	Pass
8*	MMH	0.5 @ 4 min	Slight to moderate	Pass
	N_2H_4	1.2 @ 4 min	Not significant	Pass
	N_2O_4	N	Slight to moderate	Pass
9	MMH	1.1 @ 10 min	Not significant	Pass
	N_2H_4	0.9 @ 2 min	Not significant	Pass
	N_2O_4	N	Slight to moderate	Pass
10	MMH	0.4 @ 4 min	Not significant	Pass
	N_2H_4	0.4 @ 2 min	Not significant	Pass
	N_2O_4	N	Slight to moderate	Pass

* Control Coating

N = Signifies no temperature rise measured due to evaporative cooling effect with N_2O_4.

4.10. LOX Compatibility

The purpose of this test was to determine if materials in oxygen environments react when mechanically impacted. A reaction from mechanical impact can be determined by an audible report, an electronically or visually detected flash, or obvious charring of the sample, sample cup, or striker pin. This test is specified in NASA-STD-6001 and materials intended for use in space vehicles, specified test facilities, and specified ground support equipment must meet the requirements of that document.

The test was performed in accordance with NASA-STD-6001, *Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion,* issued 1998, Test Method 13A, Mechanical Impact for Materials in Ambient Pressure LOX.

Test samples were prepared by coating 3/4" round stainless steel disks according to ASTM D 2512-82, *Compatibility of Materials with Liquid Oxygen (Impact Sensitivity Threshold* and *Pass-Fail Techniques*). After proper curing, the samples were packaged and shipped to White Sands Test Facility for impact testing. The candidate and control coatings showed no reaction from the casual exposure to the liquid oxygen (prior to impact). After impaction of 72 ft-lbs of force, all of the coatings showed some type of reaction (Table 4-17). Thus, all of the coating systems, including the control systems, failed the acceptance criteria as stated in section 3.2.11. of the JTP, which necessitates no observable reactions. The official NASA Material Science Laboratory document KSC-MSL-2005-0560 is found in Appendix I of this document.

Table 4-17 Results of Hypergol Compatibility Testing		
System	***Reaction***	***Pass/Fail***
1	A,B,C	Fail
2*	A,C	Fail
3	A,B,C	Fail
4	A,B,C	Fail
5	A,B,C	Fail
6	A,B,C	Fail
7	A,B,C	Fail
8*	A,B,C	Fail
9	A,B,C	Fail
10	A,C	Fail

* Control Coating
A = Flash
B = Noise
C = Charring or discoloration

4.11. 18-Month Marine Environment

This test documents the actual exposure of the coatings to UV radiation, as well as different cycles of salt spray exposure. NASA requires this test for validation of alternative coating systems. This test evaluates the performance of the test and control coatings after an 18-month outdoor exposure in a marine environment.

In preparation for the marine exposure testing, a matrix of 18 coupons was coated. Four different coupon configurations were used:

(1) Primer-only composite panels exposed to normal conditions.
(2) Full system composite panels exposed to normal conditions.
(3) Full system composite panels exposed to normal conditions with aluminum oxide (Al_2O_3) acid-slurry applications.
(4) Full system flat panels with 0.8 mm (1/32") scribe exposed to normal conditions.
(5) Primer-only flat panels for laboratory testing.

Each system consisted of a set of four primer-only composites, two sets of four composites with the full system, a set of three flat panels with the full system, and a set of three primer-only flat panels for heat adhesion (Figure 4-13).

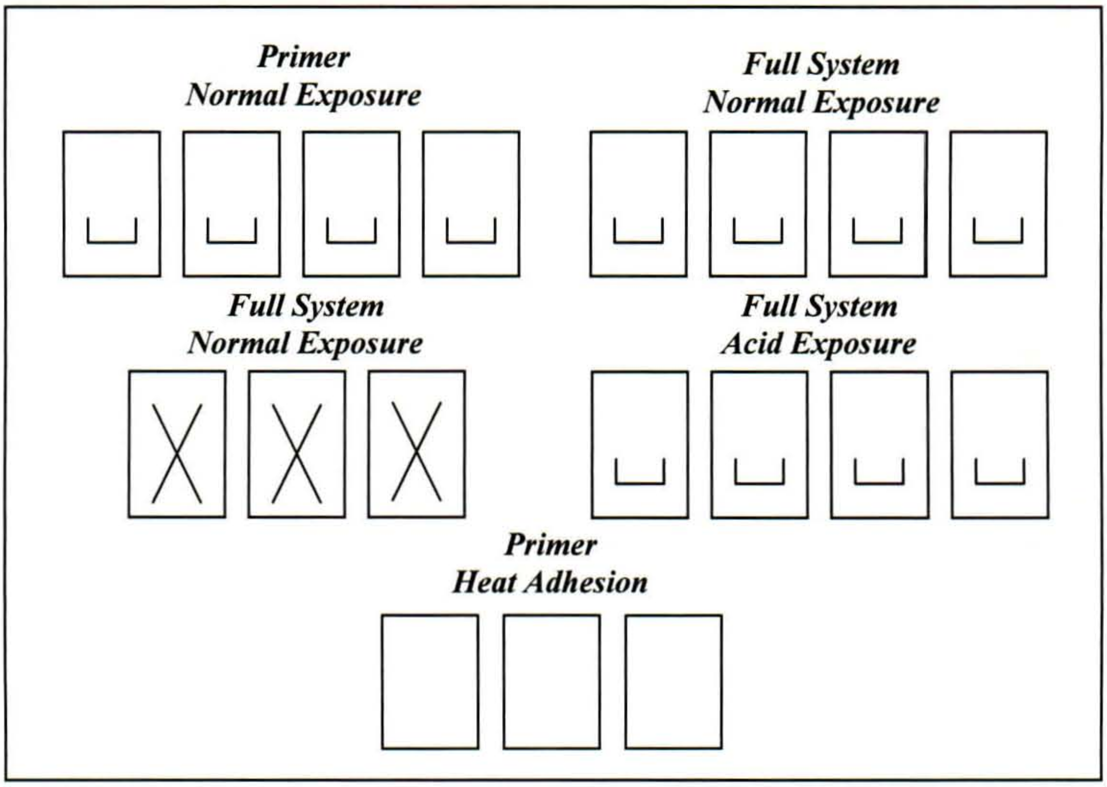


Figure 4-13 Typical 18-Month Beach Exposure Coating System Coupon Matrix

The coupons were scribed prior to exposure and were rated using ASTM D 1654, *Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments*, and ASTM D 714, *Standard Test Method for Evaluating Degree of Blistering of Paints.*

One set of composites was exposed to an acid-slurry at six week intervals to mimic the post-launch pad environment. The slurry was produced by combining 0.3 micron Al_2O_3 particles in a 10% (by volume) hydrochloric acid solution. The slurry was periodically applied to the lower 2/3 of the panels using a polyethylene squeeze bottle.

The topcoated composite coupons were evaluated using ASTM D 610, *Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces*, and ASTM D 1654, *Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments*. A rating of 8 or better was required for both standards. ASTM D 714, *Standard Test Method for Evaluating Degree of Blistering of Paints*, was used to evaluate the degree of blistering at the end of the 18-month exposure period. According to NASA-STD-5008, a coating must continue to provide acceptable protection and performance for a period of five years.

The rating process consisted of adhesion testing of the primers, gloss measurements, and visual ASTM evaluations of the coated surfaces. Photographs were taken at the start of the 18-month exposure period. After all coating systems were applied and allowed to cure, the coupons were mounted on test racks and transported to the KSC Beach Corrosion Test Site stands. This site is located approximately 1.5 miles south of Launch Complex 39A at KSC (Figure 4-14). The coated test panels were installed on stainless steel racks that use porcelain insulators as standoffs. The racks were installed on galvanized pipe test stands which oriented the samples at a 30° angle facing the ocean. The distance of the test stands from the mean high-tide line is approximately 30 meters (100 feet) from the Atlantic Ocean.

Figure 4-14 Beach Corrosion Test Site at KSC

The coupons were placed at the atmospheric test site on April 20, 2005, and were evaluated by the schedule outlined in Table 4-18. Full rack layout diagrams and photographs identifying the location and respective coating systems can be found in Appendix J.

Table 4-18 18-Month Beach Exposure Coupon Evaluation Schedule

Inspection	*Date*	*Frequency*	*Inspection Type*
1	10/20/2005	6 mo	Gloss-Color
2	4/20/2006	12 mo	Gloss-Color
3	12/10/2006*	18 mo	Gloss-Color-Corrosion
4	4/20/2010	60 mo	Corrosion

* Two months added due to hurricane evacuations

4.11.1. Gloss Retention

Gloss measurements were performed on the unexposed surfaces using a calibrated BYK Gardner Tri-Gloss portable gloss meter at the 60° angle. The 60° angle was used for the systems because most of the values were between 10 to 70 GU's. Measurements were taken in three spots on the coupon face and averaged. The initial and six-month interval data, along with the final gloss retention data is presented in the Table 4-19.

Table 4-19 Results of 18-Month Beach Exposure Gloss Measurements

System	*Initial Gloss*	*6-month Gloss* (GU's)	*12-month Gloss* (GU's)	*18-month Gloss* (GU's)	*Final Gloss Retention*
1	82.3	61.2	77.4	71.9	87%
2*	79.1	47.6	61.5	32.2	41%
3	81.2	48.3	41.0	42.5	52%
4	83.1	53.8	34.3	9.1	11%
5	46.2	29.5	45.3	33.1	72%
6	65.1	50.2	50.8	44.7	69%
7	56.8	48.7	42.6	38.2	67%
8*	57.3	43.1	27.4	7.7	13%
9	7.4	5.1	4.1	3.3	45%
10	70.8	52.4	60.4	50.5	71%

* Control Coating

As shown in Table 4-19, all of the coating systems exhibited significant drops in gloss. Compared to Control Systems -2 and -8, all of the coatings retained a higher percentage of gloss, except for System -4 which only retained 11%. System -1 performed the best with the highest gloss retention of 87% (Figure 4-15).

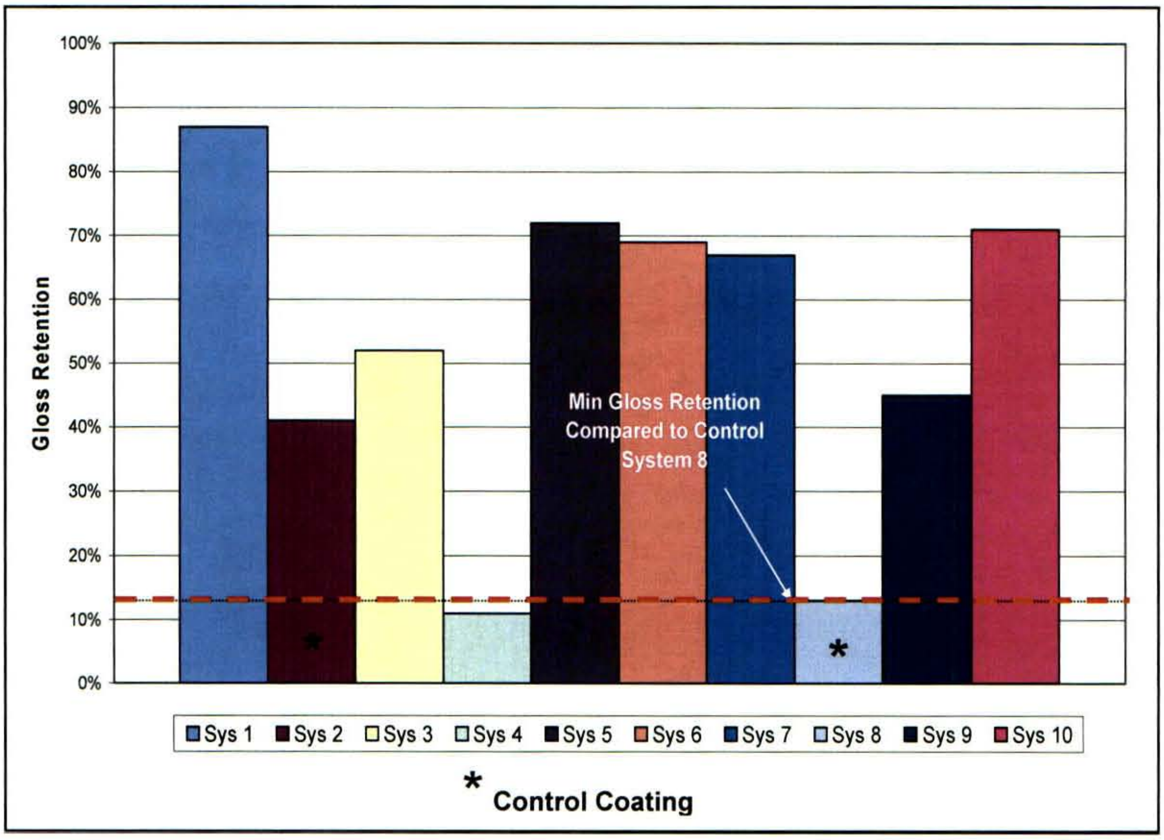


Figure 4-15 Results of 18-Month Marine Exposure Gloss Retention

4.11.2. Color Retention

Color measurements were recorded at ambient temperatures (20°- 25° C) on a ColorTec-PCM handheld portable color meter using the CIE L*a*b* format, D-65 illuminant, and a 10° observer. A description of the CIE color space was provided in section 3.2. of this report. Briefly, a color's "lightness" (L*) runs from light (white) to dark (black). 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 (ΔE) was calculated by taking the square root of the sum of the squares of the lightness and color difference according to Equation 5.

$$\Delta E = \sqrt{(L_i - L_f)^2 + (a_i - a_f)^2 + (b_i - b_f)^2} \qquad \text{(Eq. 5)}$$

where:

L_i = initial Lightness value

L_f = final Lightness value

a_i = initial Red/Green value

a_f = final Red/Green value

b_i = initial Blue/Yellow value

b_f = final Blue/Yellow value

As a general rule, 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. The results of the color retention test are shown in Table 4-20.

Table 4-20 Results of 18-Month Beach Exposure Color Change Measurements

System	*6 Month ΔE*	*12 Month ΔE*	*18 Month ΔE*
1	1.2	2.18	1.76
2*	2.2	2.76	2.74
3	4.4	2.09	2.97
4	4.2	2.03	1.70
5	6.2	3.19	2.73
6	3.0	2.69	2.58
7	4.6	2.81	3.14
8*	4.7	2.62	3.33
9	10.5	34.29	51.31
10	6.1	5.14	6.75

* Control Coating

As shown in the table, all coating systems exhibited changes in color with values of delta E greater than 1 unit (Figure 4-16). Compared to Control Systems -2 and -8, all of the coatings' color retention properties were comparable to the control, except for Systems -9 and -10. System -1 and -4 provided the highest retention of color with delta E's of 1.74 and 1.70, respectively.

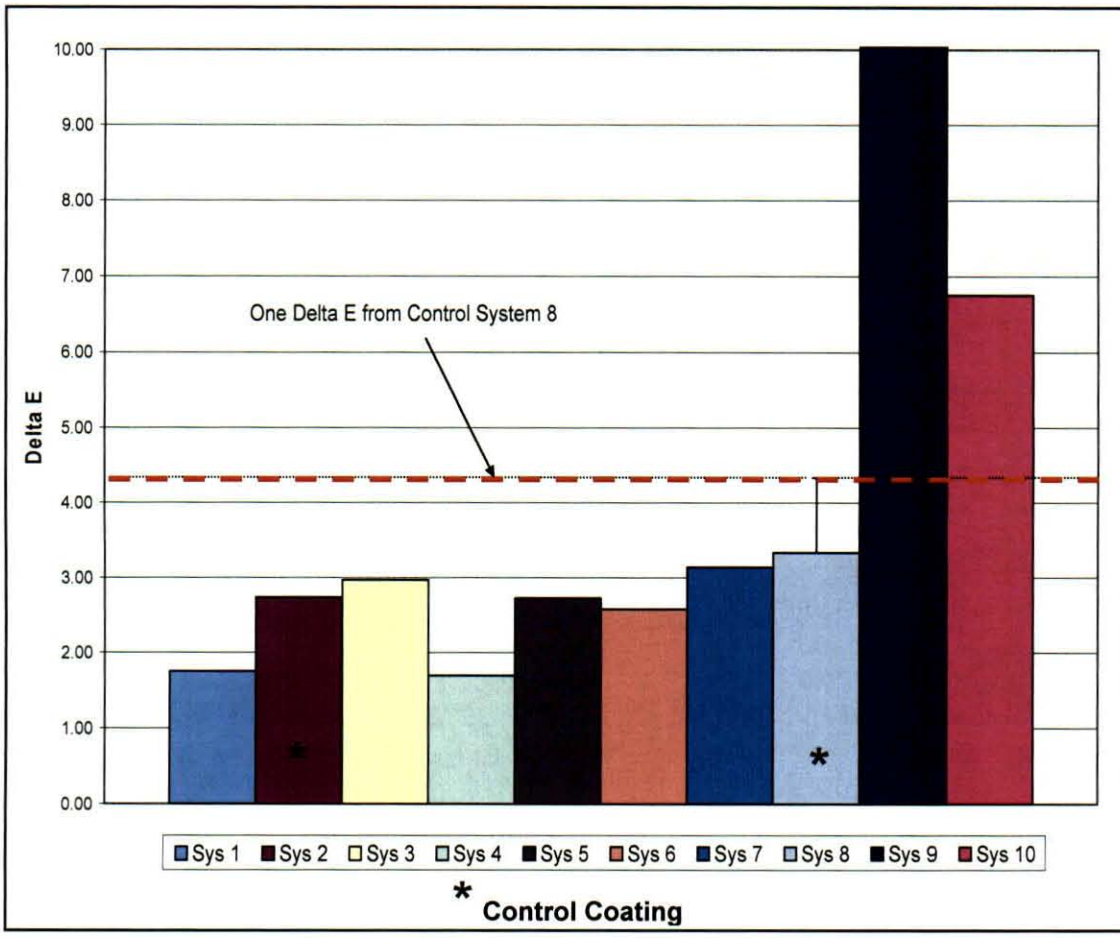


Figure 4-16 18-Month Marine Exposure Color Change Results

4.11.3. Corrosion Ratings

At the end of the 18-month exposure period, corrosion ratings were performed using ASTM D 714-02, *Standard Test Method for Evaluating Degree of Blistering of Paints*; ASTM D 610-01, *Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces*; and ASTM D 1654-92, *Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments*; as guidelines.

ASTM D 714 provides photographic reference standards which 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, and the frequency is reported as Few, Medium, Medium Dense, or Dense (Figure 4-17).

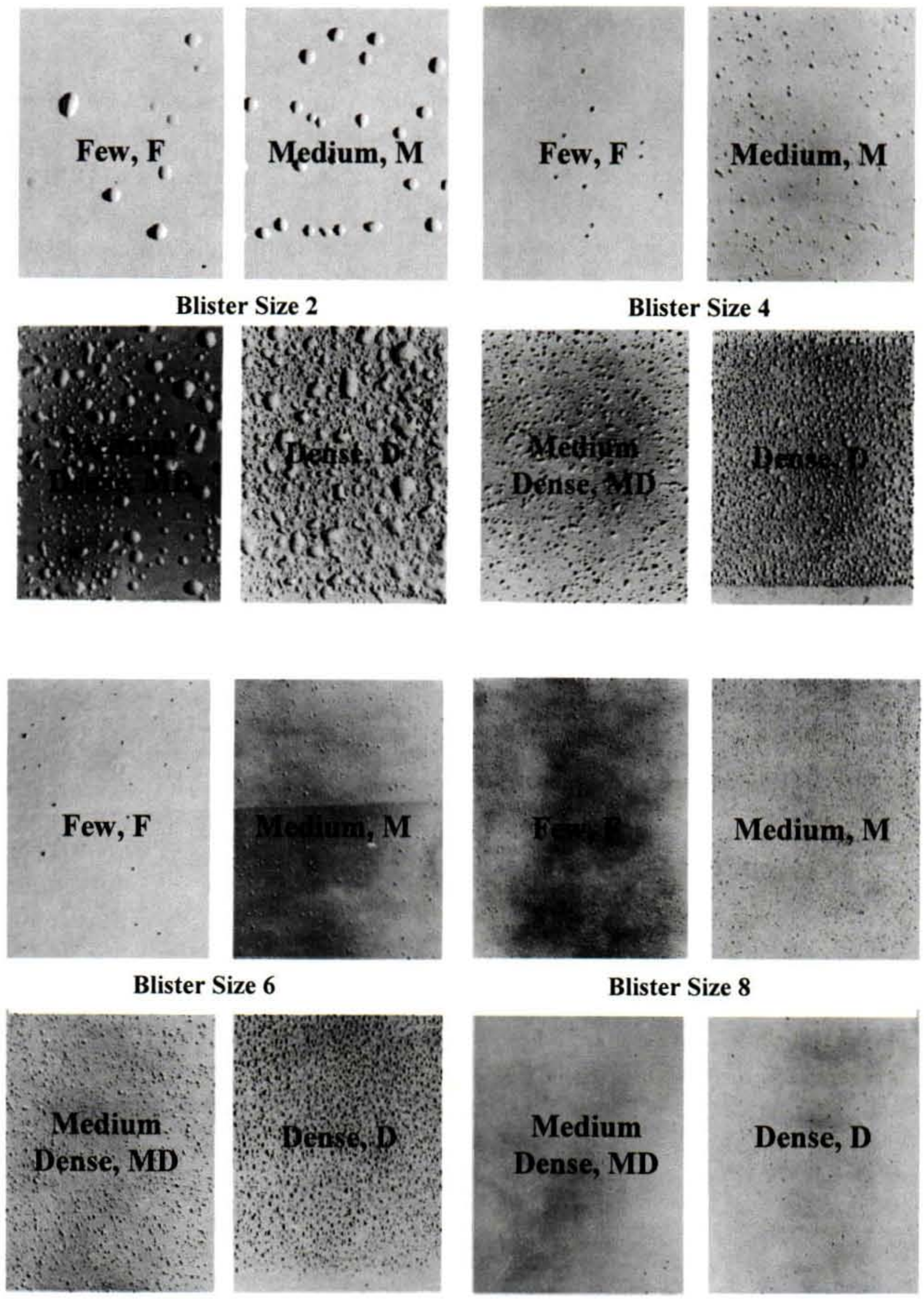


Figure 4-17 Photographs of ASTM D 714 Blister Reference

ASTM D 610 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 (Table 4-21). The ASTM D 1654 ratings follow a scale similar to ASTM D 610, except the ratings are based on the mean creepage from the scribe (Table 4-22).

Table 4-21 ASTM D 610 Corrosion Ratings Scale

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

Table 4-22 ASTM D 1654 Ratings Scale

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

The coupons were visually inspected and rated at the end of the exposure period. Photodocumentation of the coated coupons was performed prior to exposure and after 18 months at the beach site (Appendix J).

The composite panels used for coating testing have approximately 32 square inches of exposed area. This calculates to 0.0096 square inches 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, according to ASTM D 610. Typically, all rating values presented are an average of four panels, which were prepared and exposed at the same time. The final rating value of each coating system is an average of four ratings and is listed in accordance with the ASTM method of evaluation (Tables 4-23 through 4-25). 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.

Table 4-23 Results of ASTM D 610 Visual Corrosion Evaluation

System	Coat	SSPC-VIS 2 "G" Ratings				
		Panel 1	Panel 2	Panel 3	Panel 4	Average
1,2*	Primer	9	9	8	9	9
1	Top	8	8	7	8	8
2*	Top	8	8	8	8	8
3,4,5	Primer	6	6	8	9	7
3	Top	7	9	7	7	8
4	Top	7	7	7	7	7
5	Top	7	7	8	7	7
6,7	Primer	10	10	10	9	10
6	Top	8	10	10	9	9
7	Top	9	8	9	8	9
8*	Primer	9	9	9	10	9
8*	Top	8	8	8	8	8
9	Top	1	1	1	1	1
10	Primer	10	10	10	10	10
10	Top	9	8	8	8	8

* Control Coating

Table 4-24 Results of ASTM D 1654 Scribe Failure Ratings

System	*Panel 1*	*Panel 2*	*Panel 3*	*Panel 4*	*Average*
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*	10	10	10	10	10
9	2	2	2	2	2
10	10	10	10	10	10

* Control Coating

Table 4-25 Results of ASTM D 714 Blistering Ratings

System	*Panel 1*	*Panel 2*	*Panel 3*	*Panel 4*	*Average*
1	10	10	10	10	10
2*	10	10	10	10	10
3	10	10	10	10	10
4	4-M	4-M	4-M	4-M	4-M[a]
5	4-M	4-M	4-M	4-M	4-M[a]
6	10	10	10	10	10
7	10	10	10	10	10
8*	10	10	10	10	10
9	4-D	4-D	4-D	4-D	4-D
10	10	10	10	10	10

* Control Coating

[a] Blisters in coating were concentrated at crevices around welded angles

As shown in the tables, all systems showed signs of coating degradation over the 18-month atmospheric exposure period with ASTM D 610 corrosion ratings ranging from a rating of 1 for System -9, to a rating of 9 for Systems -6 and -7. In comparison to the Control Systems -2 and -8 (with ratings of 8), Systems -4, -5, and -9 performed poorly with ratings of -7, -7, and -1, respectively.

All systems performed flawlessly in the ASTM D 1654 scribe evaluations, except for System -9 which exhibited a scribe rating of 2. Systems -4, -5, and -9 exhibited poor performance according to the ASTM D 714 blister evaluation, with a rating of Blister Size 4 and frequencies of Medium, Medium, and Dense for the respective systems (Figure 4-18).

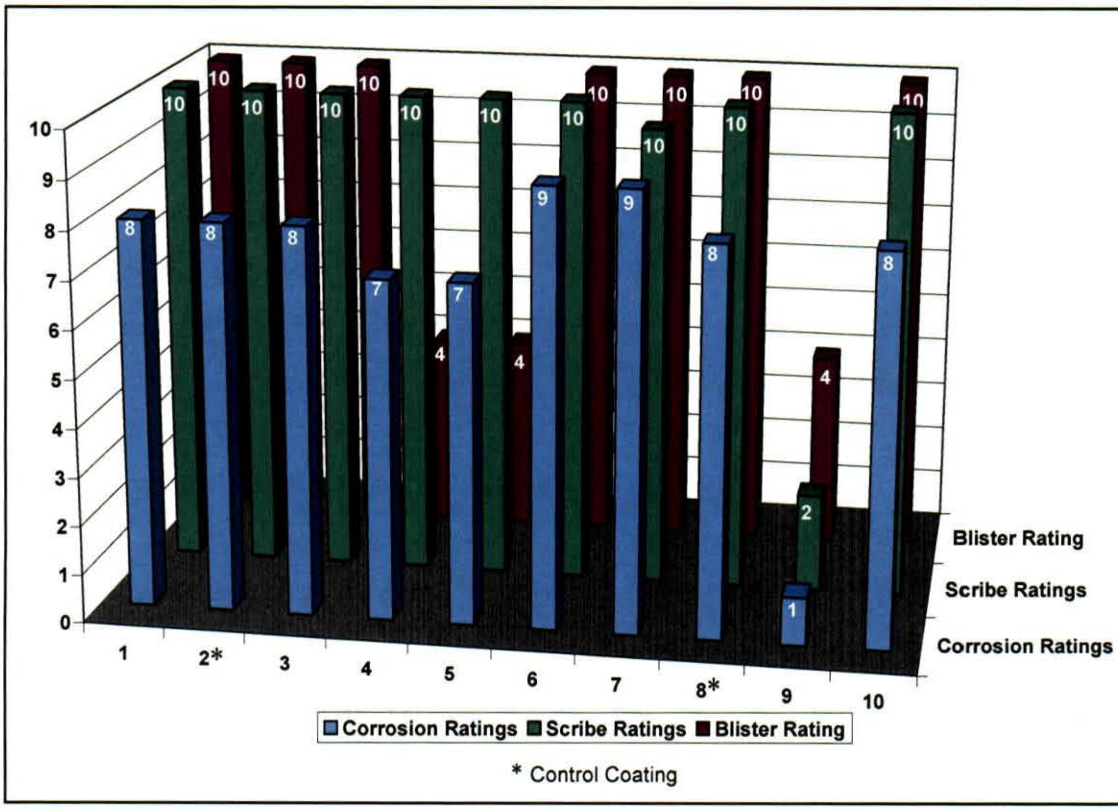


Figure 4-18 18-Month Beach Exposure Corrosion Ratings

4.11.4. Heat Adhesion

As a part of the 18-month Marine Environment test, the KSC coating standard, NASA-STD-5008, requires that inorganic zinc (IOZ) coatings must have a temperature resistance of 400° C (750° F) for use on launch structures and ground support equipment subject to the elevated temperatures associated with rocket exhaust. This requirement is satisfied by exposing the IOZ coated panels in a high temperature oven to a temperature of 400° C for 24 hours. Any visual deterioration, such as destruction or burning of the coating, would indicate failure of the product. Loss of adhesion after heating also constitutes a failure due to temperature effects on the film.

Each of the IOZ coatings was tested for tensile adhesion using ASTM D 4541-02, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*. The test was performed prior to exposure and after the 24-hour heating cycle was complete. The adhesion test values are reported as an average of three pulls. The pre-heat adhesion pull-off values ranged from 400-900 psi. The increased post-heat pull-off values are not uncommon for IOZ coated samples and indicate that there was no adhesion loss or film deterioration (Table 4-26). System -9 is not an IOZ based coating system and therefore was not tested for heat adhesion stability.

Table 4-26 Results of 18-Month Marine Primer Exposure Heat Adhesion Testing

System	*Pre-heat* (psi)	*Post-heat* (psi)
1,2*	975	1670
3,4,5	400	2650
6,7	815	1490
8*	590	1140
9	NA	NA
10	860	1262

* Control Coating

4.12. Summary of Phase II Tests

After a review of the Phase II Tests (Table 4-27), the following results were found:

- System -3 performed poorly in the Mandrel Bend, Gravelometer, and X-cut Adhesion tests; but better than the control systems in the Abrasion Resistance and similar to the control systems for all other Phase II tests.
- System -6 performed better than the control systems in the Gravelometer, 18-Month Gloss Retention, and 18-Month Visual Corrosion tests; and similar to the control systems for all other Phase II tests.
- System -7 showed performed better than the control systems in the 18-Month Gloss Retention and 18-Month Visual Corrosion tests; worse than the control systems for the Abrasion Resistance; and similar to the control systems for all other Phase II tests.
- System -9 performed well during phase one testing, but did not fare as well in Phase II testing. It performed worse than the control systems in the Repairability, Fungus Resistance, Cyclic Corrosion, and 18-Month Marine Exposure tests; but performed similar to the control systems in the remainder of the Phase II tests.

Table 4-27 Summary of Phase II Test Results as Compared to Control Coatings

Tests	*Coating Systems*									
	1	*2*	*3**	*4*	*5*	*6**	*7**	*8*	*9**	*10*
Removability		C	S			S	S	C	S	
Repairability		C	S			S	S	C	W	
Abrasion Resistance		C	B			S	W	C	S	
Gravelometer		C	W			B	S	C	S	
Fungus Resistance		C	W			S	S	C	W	
Accelerated Weathering (Gloss Retention)		C	S			S	S	C	S	
Mandrel Bend		C	W			S	S	C	S	
Cyclic Corrosion		C	S			S	S	C	W	
Hypergol Compatibility	S	C	S	S	W	S	S	C	S	S
LOX Compatibility	S	C	S	S	S	S	S	C	S	S
18-Month Marine Exposure (Gloss Retention)	B	C	S	W	B	B	B	C	S	B
18-Month Marine Exposure (Color Change)	B	C	S	B	S	S	S	C	W	W
18-Month Marine Exposure (Blistering)	S	C	S	W	W	S	S	C	W	S
18-Month Marine Exposure (Visual Corrosion)	S	C	S	W	W	B	B	C	W	S
18-Month Marine Exposure (Creepage from Scribe)	S	C	S	S	S	S	S	C	W	S
18-Month Marine Exposure (Heat Adhesion)	S	C	S	S	S	S	S	C	NA	S

* Coating Systems carried on to Phase II

C = Control Coatings

B = Performance Better than Control Coatings

S = Performance Similar to Control Coatings

W = Performance Worse than Control Coatings

5. FIELD TESTING

Field evaluations demonstrate comparative field performance of candidate coating systems when applied on operating structures and were performed in conjunction with the laboratory testing.

Table 5-1 lists the field evaluations that were intended to compare the performance of candidate test coatings with current coatings when applied in an operational environment. These tests are further defined in the FTP.

Table 5-1 Field Evaluation Requirements

Test	*JTR Section*	*Test Specimen*	*Acceptance Criteria*	*References*
Ease of Application	5.1.	Field Test	Smooth coat, with acceptable appearance, no runs, bubbles or sags; Ability to cover the properly prepared/primed substrate with a single coat (one-coat hiding ability); Record Pot Life, DFT and associated issues	SSPC-PA-2
Surface Appearance	5.2.	Field Test	No streaks, blistering, voids, air bubbles, cratering, lifting, blushing, or other surface defects/irregularities; No micro-cracks observable at 10X magnification	ASTM D 523; ASTM D 2244
Dry-To-Touch (Sanding)	5.3.	Field Test	No rolling or scribing during sanding, and "easy" sanding (as evaluated by technician)	None

The table includes acceptance criteria and the reference specifications, if any, used to conduct the tests. The test and evaluation are based on the aggregate knowledge and experience of the assigned technical project personnel and prior testing where "None" appears under *Test Method References*.

During the week of August 11-18, 2005, a section of a flame bucket of an engine test stand at SSC was prepared for field application of the coating candidates and controls. A 4' wide by 50' long section was abrasively cleaned using sponge media imbedded with aluminum oxide to a *White Metal Blast Cleaning* condition (SSPC SP5) before masking 3'× 3' sections and applying the respective coating systems (Figures 5-1 and 5-2).

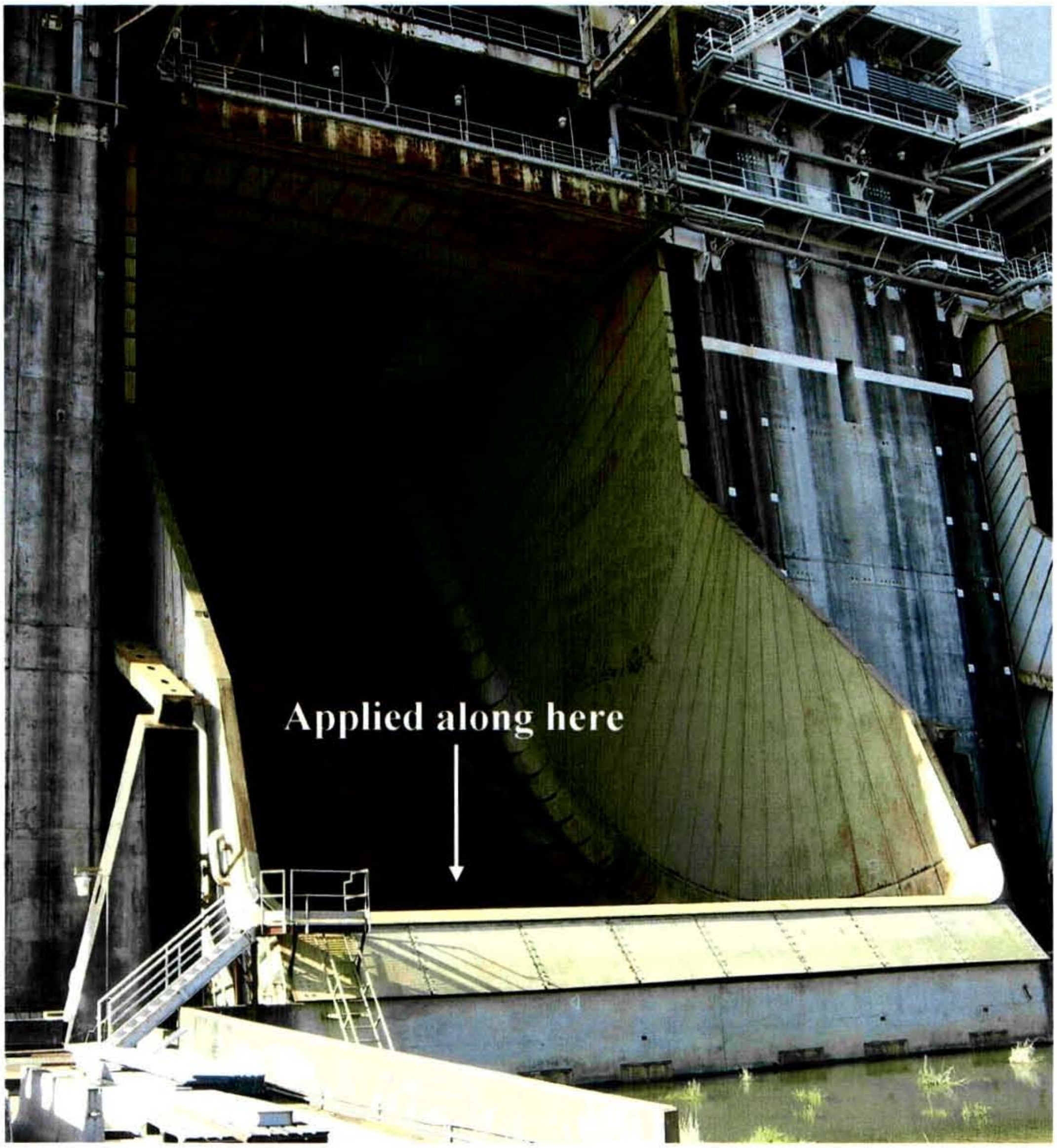


Figure 5-1 Photograph of Field Application Site at SSC

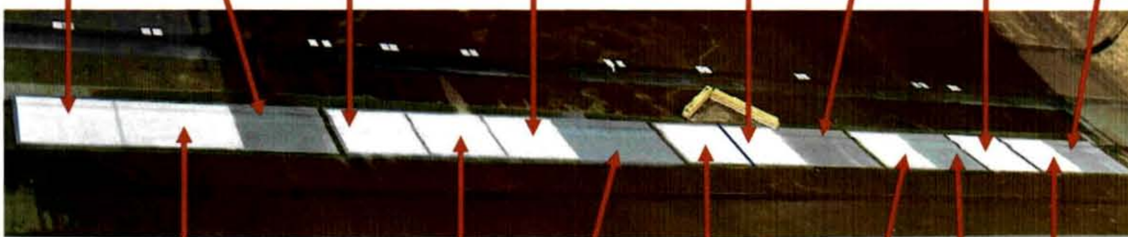


Figure 5-2 Field Coating Application Sections

The coatings were applied according to the manufacturers' recommendations on the product data sheets. Systems -2, -4, -6, and -7 required two topcoats to provide adequate coverage. Systems -9 and -10 required primer coat DFTs which exceeded manufacturer recommendations due to the severity of pitting on the surface. A summary of the applied dry film thicknesses and manufacturers' recommended ranges for each system are shown in Table 5-2.

Table 5-2 Applied and Recommended Dry Film Thicknesses for Field Testing

System	Primer		Intermediate		Topcoat	
	Applied	Range	Applied	Range	Applied	Range
1	5 mils	2-6 mils	4 mils	3-6 mils	6 mils	3-7 mils
2*	5 mils	2-6 mils	4 mils	3-6 mils	5 mils [a]	2-2.5 mils
3	4 mils	3-5 mils	none	none	6 mils	3-7 mils
4	4 mils	3-5 mils	none	none	5 mils [a]	2.5-4 mils
5	4 mils	3-5 mils	none	none	7 mils	5-8 mils
6	4 mils	2-4 mils	6 mils	4-6 mils	8 mils [a]	4-6 mils
7	4 mils	2-4 mils	6 mils	4-6 mils	5 mils [a]	2-3 mils
8*	4 mils	2-4 mils	3 mils	2-3 mils	6 mils	4-6 mils
9	2 mils	1.2-1.4 mils	2 mils	1.2-1.4 mils	1 mils	0.75 -1 mil
10	6 mils	2.5-4 mils	6 mils	4-8 mils	3 mils	2-3 mils

* Control Coating
[a] Sum of two coats applied

Inspections (including photodocumentation) were performed to evaluate the coatings 24 ± 3 hours after application and at six-month (March 2006) and twelve-month (August 2006) intervals. Additionally, coating condition surveys were performed and color and gloss measurements were recorded.

5.1. Coating Condition

The six-month visual coating condition survey was performed on the coatings at SSC on March 7, 2006. The evaluation was an examination of Surface Appearance including observation of any coating defects, color readings, and gloss readings. The results of the field evaluation were consistent with laboratory testing. Those coatings that had not performed as well in the laboratory tests were not performing as well as the other coatings in the field either. One coating exhibited blistering and many showed significant drops in color and gloss measurements.

The final (12-month) visual coating condition survey was performed on the coatings at SSC on September 26, 2006. Each coating system was found to exhibit good performance characteristics. The only failure occurred with System -4, where the topcoat had blistered and revealed the zinc primer underneath. In the scribed area, all systems show signs of corrosion in the scribe, but no signs of creepage or coating delamination due to undercutting were evident.

5.2. Gloss Retention

Gloss measurements were performed on the unexposed surfaces using a properly calibrated BYK Gardner Tri-Gloss portable gloss meter at the 60° angle. Measurements were taken in three spots on the coating surface and averaged. The initial, six-month, and final twelve-month data is presented in Table 5-3.

Table 5-3 Results of Gloss Retention from SSC Field Testing

System	*Initial Gloss* (GU's)	*6-month Gloss* (GU's)	*12-month Gloss* (GU's)	*Final Gloss Retention*
1	82.3	55.1	60.2	73%
2*	79.1	47.3	36.0	46%
3	81.2	36.4	30.2	37%
4	83.1	22.8	19.7	24%
5	46.2	17.6	18.6	40%
6	65.1	22.2	21.4	33%
7	56.8	12.6	11.0	19%
8*	57.3	21.6	15.2	27%
9	7.4	5.0	5.3	72%
10	70.8	38.9	30.3	43%

* Control Coating

As shown in the table, all of the coating systems exhibited a significant reduction in gloss. Compared to Control System -2, only two of the coatings retained a higher percentage of gloss; Systems -1 and -9 retained the highest gloss of 73% and 72%, respectively. When compared to Control System -8, all the remaining coating systems met or exceeded the controls performance, except for Systems -4 and -7 which only retained 24% and 19% gloss, respectively, as shown in Figure 5-3.

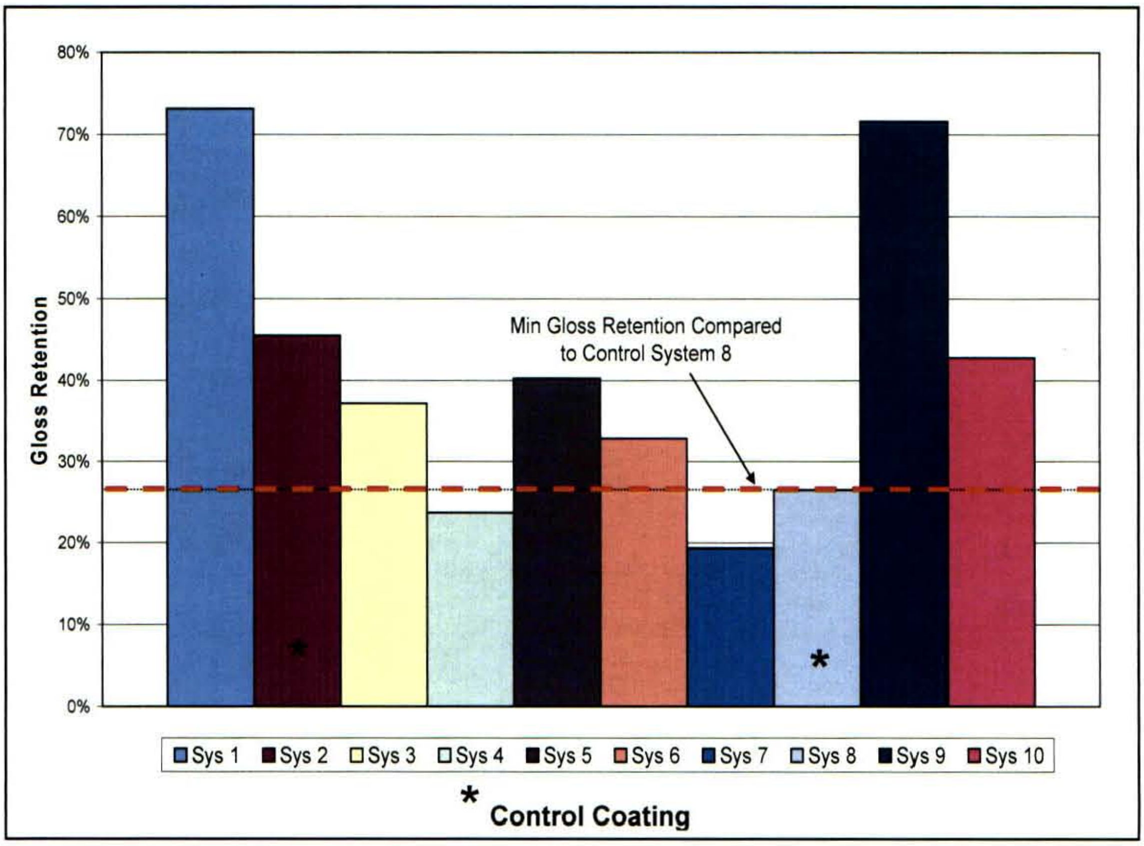


Figure 5-3 Results of Gloss Retention from SSC Field Testing

5.3. Color Retention

Color measurements were recorded at ambient temperatures (20°- 25° C) on a ColorTec-PCM handheld portable color meter using the CIE L*a*b* format, D-65 illuminant, and a 10° observer. A single number indicator of overall color change (ΔE) was calculated by the taking the square root of the sum of the squares of the color difference of the three dimensions of color space as stated in Equation 1. Delta E values for the field coatings at SSC are shown in Table 5-4.

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

where:

L_i = initial Lightness value

L_f = final Lightness value

a_i = initial Red/Green value

a_f = final Red/Green value

b_i = initial Blue/Yellow value

b_f = final Blue/Yellow value

Table 5-4 Results of Color Retention from SSC Field Testing

System	*6 Month ΔE*	*12 Month ΔE*
1	0.6	1.0
2	0.8	1.1
3	2.0	1.9
4	1.9	2.3
5	2.2	2.2
6	2.6	3.1
7	1.4	2.3
8	2.4	1.5
9	4.5	17.8
10	2.4	4.5

As a general rule, a delta E value of 1 is discernable with 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 the table, all of the coating systems exhibited slight variations in color, except for System -9 which experienced the largest overall color change (ΔE) of 17.8 units. Control Systems -2 and -8 maintained their color properties with delta E values of 1.1 and 1.5, respectively. As shown in Figure 5-4, all remaining systems performed within one delta E of Control System -8, except for Systems -6 and -10, which were outside of this range. The field coatings color change properties showed similar performance characteristics to the laboratory findings for each system.

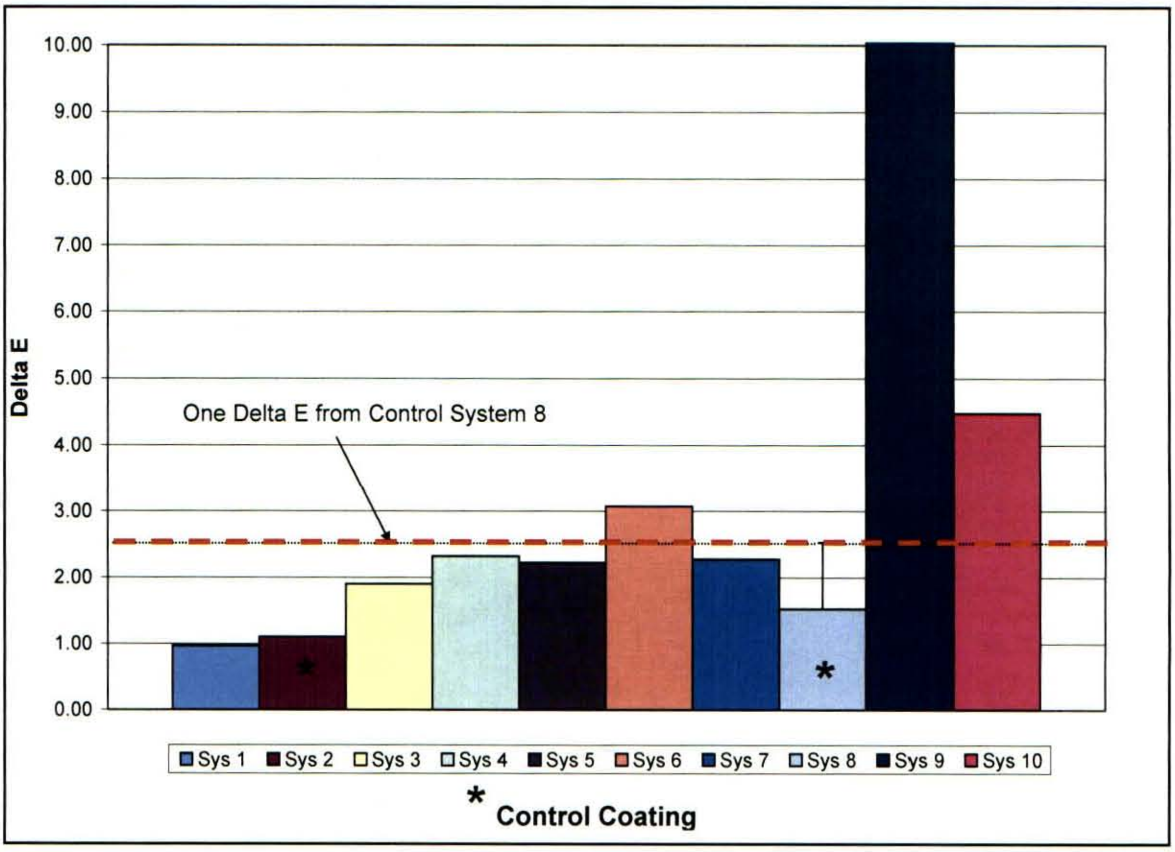


Figure 5-4 Results of Color Retention from SSC Field Testing

5.4. Summary of Field Testing Results

After a review of the field testing performance data (Table 5-5), the following results for the alternatives were found:

- System -1 had the best performance in the field with gloss and color retention better than and coating condition equal to Control Systems -2 and -8.
- System -3 performed similarly to the Control Systems in each category (coating condition, color retention, and gloss retention).
- System -5 performed similarly to the Control Systems in each category (coating condition, color retention, and gloss retention).
- System -9 had better gloss retention and similar coating condition, but worse color retention when compared to the Control Systems.
- System -6 had similar coating condition when compared to the Control Systems, but worse color retention.
- System -7 had similar coating condition when compared to the Control Systems, but worse gloss retention.
- System -10 had a similar coating condition compared to the Control Coatings, but had lower color and gloss retention.
- System -4 had the worst field performance exhibiting blistering and revealing the zinc primer underneath.

Table 5-5 Summary of Field Testing Results as Compared to Control Coatings										
Tests	***Coating Systems***									
	1	***2***	***3****	***4***	***5***	***6****	***7****	***8***	***9****	***10***
Coating Condition (after 12 months)	**S**	**C**	**S**	**W**	**S**	**S**	**S**	**C**	**S**	**S**
Gloss Retention (after 12 months)	**B**	**C**	**S**	**W**	**S**	**S**	**W**	**C**	**B**	**W**
Color Retention (after 12 months)	**B**	**C**	**S**	**S**	**S**	**W**	**S**	**C**	**W**	**W**

* Coating Systems carried on to Phase II

C = Control Coatings

B = Performance Better than Control Coatings

S = Performance Similar to Control Coatings

W = Performance Worse than Control Coatings

6. CONCLUSIONS

Each of the alternative coating systems gave the following results (summarized in Table 6-1):

- System -1
  - Phase I: Performed worse than Control Systems -2 and -8 in the Pot Life (Room Temperature), Knife, Tensile (Pull-off) Adhesion, and X-Cut Adhesion by Wet Tape tests
  - Phase II: Was not carried on to Phase II testing
  - 18-month Marine Exposure: Excellent performance (Better Color and Gloss Retention than Control Systems; Similar Corrosion Protection)
  - Field Testing: Excellent performance (Better Color and Gloss Retention than Control Systems; Similar Corrosion Protection)

- System -3
  - Phase I: Performed worse than the Control Systems in the Tensile (Pull-off) Adhesion and X-Cut Adhesion by Wet Tape tests
  - Phase II: Performed worse than the Control Systems in the Mandrel Bend, Gravelometer, and X-cut Adhesion tests (failure in these tests generally suggest a coating to be more brittle and not flexible)
  - 18-month Marine Exposure: Good performance (Equal to Control Systems)
  - Field Testing: Good performance (Equal to Control Systems)

- System -4
  - Phase I: Performed worse than the Control Systems in the Cure Time (Solvent Rubs), Cleanability, Tensile (Pull-off) Adhesion, and X-Cut Adhesion by Wet Tape tests; but better than the Control Systems in the Accelerated Storage Stability test
  - Phase II: Was not carried on to Phase II testing
  - 18-month Marine Exposure: Poor performance (Worse Color Retention, Blistering, and Corrosion than Control Systems)
  - Field Testing: Poor performance (Worse Gloss and Coating Condition than Control Systems)

- System -5
  - Phase I: Performed worse than the Control Systems in the Cure Time (Solvent Rubs), Cleanability, and Tensile (Pull-off) Adhesion tests
  - Phase II: Was not carried on to Phase II testing
  - Hypergol Compatibility: Failed
  - 18-month Marine Exposure: Poor performance (Better Gloss Retention, but worse Blistering and Corrosion than Control Systems)
  - Field Testing: Good performance (Equal to Control Systems)

- System -6
    - Phase I: Performed worse than the Control Systems only in the X-Cut Adhesion by Wet Tape test
    - Phase II: Performed equal to or better than the Control Systems
    - 18-month Marine Exposure: Excellent performance (Better Color Retention and Corrosion Protection than Control Systems)
    - Field Testing: Good performance (Worse Gloss Retention than Control Systems; Similar Corrosion Protection)

- System -7
    - Phase I: Performed worse than the Control Systems only in the Accelerated Storage Stability test
    - Phase II: Performed worse than the Control Systems only in the Abrasion Resistance test
    - 18-month Marine Exposure: Excellent performance (Better Gloss Retention and Corrosion Protection than Control Systems)
    - Field Testing: Good performance (Worse Gloss Retention than Control Systems, despite better performance in the 18-month Marine Exposure; Similar Corrosion Protection)

- System -9
    - Phase I: Performed worse than the Control Systems only in the Ease of Application test, but better than the Control Systems in the Tensile (Pull-off) Adhesion test
    - Phase II: Performed worse than the Control Systems in the Repairability, Fungus Resistance, and Cyclic Corrosion tests
    - 18-month Marine Exposure: Poor performance (Worse Color Retention, Blistering, Corrosion, and Creepage than Control Systems)
    - Field Testing: Good performance (Worse Color Retention, but better Gloss Retention and equal Coating Condition compared to Control Systems despite poor performance in the 18-month Marine Exposure)
    - System -9 was the only coating system in the test that did not contain a sacrificial protecting primer, such as an inorganic zinc primer; therefore, System -9 was not tested for heat adhesion stability (required for zinc systems in NASA-STD-5008)

NOTE: The manufacturer of System -9 has identified the Kimetsan D45 AMS MO-Zinc Rich Primer as the zinc primer to use with its topcoat for protection of structural steel. Based on the results in Phase I and the field testing, additional testing of this system incorporating the identified zinc primer is recommended.

- System -10
    - Phase I: Performed worse than the Control Systems in the Cure Time (Solvent Rubs), Cleanability, Knife, Tensile (Pull-off) Adhesion, and X-Cut Adhesion by Wet Tape tests
    - Phase II: Was not carried on to Phase II testing
    - 18-month Marine Exposure: Good performance (Better Gloss Retention, but worse Color Retention than Control Systems; Similar Coating Condition)
    - Field Testing: Good performance (Worse Gloss Retention and Color Retention than Control Systems; Similar Coating Condition)

After review of all the test results, it was determined that three (3) of the alternative coating systems (Systems -3, -6, and -7) met the requirements as identified by the stakeholders of the project and NASA-STD-5008 and will be added to the Qualified Products List (QPL).

In addition, although they were not down-selected for Phase II testing in this project, two (2) other systems (Systems -1 and -10) showed acceptable performance in the 18-Month Marine Exposure Testing and will be added to the QPL in NASA-STD-5008.

Table 6-1 Summary of Test Results as Compared to Control Coatings

Test	Coating System									
	1	2	3*	4	5	6*	7*	8	9*	10
Ease of Application	S	C	S	S	S	S	S	C	W	S
Surface Appearance	S	C	S	S	S	S	S	C	S	S
Dry-To-Touch (Sanding)	S	C	S	S	S	S	S	C	S	S
Accelerated Storage Stability	S	C	S	B	S	S	W	C	S	S
Pot Life (Heated)	B	C	B	B	B	B	B	C	B	B
Pot Life (Room Temp)	W	C	S	S	S	S	S	C	S	S
Cure Time (Solvent Rubs)	S	C	S	W	W	S	S	C	S	W
Cleanability	S	C	S	W	W	S	S	C	S	W
Knife Test	W	C	S	S	S	S	S	C	S	W
Tensile (Pull-off) Adhesion	W	C	W	W	W	S	S	C	B	W
X-Cut Adhesion by Wet Tape	W	C	W	W	S	W	S	C	S	W
Removability		C	S			S	S	C	S	
Repairability		C	S			S	S	C	W	
Abrasion Resistance		C	B			S	W	C	S	
Gravelometer		C	W			B	S	C	S	
Fungus Resistance		C	W			S	S	C	W	
Accelerated Weathering (Gloss Retention)		C	S			S	S	C	S	
Mandrel Bend		C	W			S	S	C	S	
Cyclic Corrosion		C	S			S	S	C	W	
Hypergol Compatibility	S	C	S	S	W	S	S	C	S	S
LOX Compatibility	S	C	S	S	S	S	S	C	S	S
18-Month Marine Exposure (Gloss)	B	C	S	W	B	B	B	C	S	B
18-Month Marine Exposure (Color)	B	C	S	B	S	S	S	C	W	W
18-Month Marine Exposure (Blistering)	S	C	S	W	W	S	S	C	W	S
18-Month Marine Exposure (Corrosion)	S	C	S	W	W	B	B	C	W	S
18-Month Marine Exposure (Creepage)	S	C	S	S	S	S	S	C	W	S
18-Month Marine Exposure (Heat Adhesion)	S	C	S	S	S	S	S	C	NA	S
Field Coating Condition (after 12 months)	S	C	S	W	S	S	S	C	S	S
Field Gloss Retention (after 12 months)	B	C	S	W	S	S	W	C	B	W
Field Color Retention (after 12 months)	B	C	S	S	S	W	S	C	W	W

* Coating Systems carried on to Phase II

NA = System -9 was not tested for heat adhesion stability

C = Control Coatings

B = Performance Better than Control Coatings

S = Performance Similar to Control Coatings

W = Performance Worse than Control Coatings

APPENDIX A

Coating System Application Evaluation and Inspection Report

COATING SYSTEM EVALUATION AND INSPECTION REPORT*				
DATE: **1/31/05**	PROJECT REF. NO. **System 1**		PAGE **1** OF **1**	
PROJECT NAME: **ISO Free Coatings**		INSPECTOR: **Curran**		
PRODUCT MANUFACTURER / NAME: **Carboline Carboxane 2000**				
BATCH NUMBERS: **Part A- 4K5060L/ Part B- 452250B**				
1. DESCRIPTION OF ITEMS AND /OR AREAS: **4"x6" flat and composite, 3"x6", 4"x12", 3"x5", 4"x4" flat coupons**				
2. DESCRIPTION OF WORK PERFORMED / REMARKS: **Spraying Test Coupons**				
3. ENVIRONMENTAL CONDITIONS				
TIME	**9:00**	**10:30**	**12:30**	
AIR TEMP °F	**67**	**68**	**72**	
RELATIVE HUMIDITY	**75%**	**71%**	**63%**	
DEWPOINT	**58**	**58**	**58**	
SURFACE TEMPERATURE	**64**	**64**	**70**	
4. PRE-WORK SURFACE CONDITIONS / SURFACE PREPARATION: **Spraying over Carboguard 893 Mid-coat**				
5. COATING APPLICATION				
METHOD OF APPLICATION:	START TIME **10:30**	STOP TIME **12:30**		
Conventional Spray	APPROXIMATE SQ. FT. COATED: **12**			
EQUIPMENT DESCRIPTION:	GALS COATING APPLIED: **0.5**			
Binks 2001 66ss/63pb 565 needle Fluid 12 psi/ Air 30 psi	WET FILM THICKNESS (AVG) **6-7** MILS			
EASE OF USE—(Technician Evaluation) **Easy mixing, good atomization, smooth flow. Tends to run and sag above 7 mils WFT. One coat coverage except for edges.**				
POT LIFE— **Room temperature sample not sprayable after four hours.**				
Heated sample sprayable after four hours.				
6. POST CURE INSPECTION DRY FILM THICKNESS (AVG) **6** MILS (See Attached Documentation) DRY-TO-TOUCH (SANDING) EVALUATION- **No effects** EVALUATION WITH UNAIDED EYE- **Smooth glossy finish with uniform color.** EVALUATION WITH 10X MAGNIFICATION- **No defects or irregularities observed.** GLOSS READING (per ASTM D 523) COLOR READING (per ASTM D 2244) 60° **82.3 G.U.** **(L*,a*,b*) 95.39, -1.59, 7.60** REMARKS				

COATING SYSTEM EVALUATION AND INSPECTION REPORT*				
DATE- 2/2/05	PROJECT REF. NO. System 2		PAGE 1 OF 1	
PROJECT NAME: ISO Free Coatings		INSPECTOR: Curran		
PRODUCT MANUFACTURER / NAME: Carboline Carbothane 134 HB				
BATCH NUMBERS- "A" 4K5061L/ "B" 4J2402B				
1. DESCRIPTION OF ITEMS AND /OR AREAS: 4"x6" flat and composite, 3"x6", 4"x12", 3"x5", 4"x4" flat coupons				
2. DESCRIPTION OF WORK PERFORMED / REMARKS: Spraying Test Coupons				
3. ENVIRONMENTAL CONDITIONS				
TIME	8:30	10:00	11:00	
AIR TEMP °F	62	66	74	
RELATIVE HUMIDITY	81%	72%	52%	
DEWPOINT	57	57	56	
SURFACE TEMPERATURE	66	65	70	
4. PRE-WORK SURFACE CONDITIONS / SURFACE PREPARATION:				
5. COATING APPLICATION				
METHOD OF APPLICATION: Conventional Spray	START TIME 9:00	STOP TIME 10:30		
	APPROXIMATE SQ. FT. COATED: 20			
EQUIPMENT DESCRIPTION: Binks 2001 66ss/63pb 565 needle Fluid 12 psi/ Air 50 psi	GALS COATING APPLIED: .75			
	WET FILM THICKNESS (AVG) 2.5-3.5 MILS			
EASE OF USE—Technician Evaluation Some settling in can. Good atomization, smooth flow. Two coats needed for coverage.				
POT LIFE—Technician Evaluation				
Room Temperature not sprayable after 2.5 hrs.				
Heated not sprayable after 1.5 hrs.				
6. POST CURE INSPECTION DRY FILM THICKNESS (AVG) 2.5 MILS (See Attached Documentation) DRY-TO-TOUCH (SANDING) EVALUATION- No effects EVALUATION WITH UNAIDED EYE- Slight orange peel glossy finish with uniform color. EVALUATION WITH 10X MAGNIFICATION- No defects or irregularities observed. GLOSS READING (per ASTM D 523) 60° 79.1 G.U. COLOR READING (per ASTM D 2244) (L*,a*,b*) 92.61, -2.45, 4.78 REMARKS				

COATING SYSTEM EVALUATION AND INSPECTION REPORT*			
DATE- 2/3/05	PROJECT REF. NO. System 3	PAGE 1 OF 1	
PROJECT NAME: ISO Free Coatings		INSPECTOR: Curran	
PRODUCT MANUFACTURER / NAME: Sherwin Williams Polysiloxane XLE			
BATCH NUMBERS- "A" 6403-60095/ "B" 6403-60079			
1. DESCRIPTION OF ITEMS AND /OR AREAS: 4"x6" flat and composite, 3"x6", 4"x12", 3"x5", 4"x4" flat coupons			
2. DESCRIPTION OF WORK PERFORMED / REMARKS: Spraying Test Coupons			
3. ENVIRONMENTAL CONDITIONS			
TIME	11:00	1:30	2:30
AIR TEMP °F	74	74	75
RELATIVE HUMIDITY	52%	52%	50%
DEWPOINT	56	56	53
SURFACE TEMPERATURE	70	72	76
4. PRE-WORK SURFACE CONDITIONS / SURFACE PREPARATION Direct application to zinc primer.			
5. COATING APPLICATION			
METHOD OF APPLICATION:	START TIME 1:30	STOP TIME 2:40	
Conventional Spray	APPROXIMATE SQ. FT. COATED 12		
EQUIPMENT DESCRIPTION:	GALS COATING APPLIED .5		
Binks 2001 66ss/63pb 565 needle Fluid 15 psi/ Air 80 psi	WET FILM THICKNESS (AVG) 6-7 MILS		
EASE OF USE—Technician Evaluation- A mist coat is required to prevent bubbles. Good atomization, smooth flow. Poor edge retention.			
POT LIFE—Technician Evaluation			
Room Temperature sprayable after 4 hrs.			
Heated sprayable after 4 hrs.			
6. POST CURE INSPECTION			
DRY FILM THICKNESS (AVG) 6 MILS (See Attached Documentation)			
DRY-TO-TOUCH (SANDING) EVALUATION- No effect.			
EVALUATION WITH UNAIDED EYE- Smooth glossy appearance with uniform color.			
EVALUATION WITH 10X MAGNIFICATION- No defects or irregularities observed.			
GLOSS READING (per ASTM D 523) 60° 81.2 G.U.	COLOR READING (per ASTM D 2244) (L*,a*,b*) 94.26, -2.28, 3.60		
REMARKS			

COATING SYSTEM EVALUATION AND INSPECTION REPORT*		
DATE- 2/5/05	PROJECT REF. NO. System 4	PAGE 1 OF 1
PROJECT NAME: ISO Free Coatings	INSPECTOR: Curran	
PRODUCT MANUFACTURER / NAME: Sherwin Williams Sher-Cryl HPA		
BATCH NUMBERS- 6405-18908		
1. DESCRIPTION OF ITEMS AND /OR AREAS: 4"x6" flat and composite, 3"x6", 4"x12", 3"x5", 4"x4" flat coupons		
2. DESCRIPTION OF WORK PERFORMED / REMARKS: Spraying Test Coupons		
3. ENVIRONMENTAL CONDITIONS		
TIME	1:30	2:30
AIR TEMP °F	64	70
RELATIVE HUMIDITY	55%	43%
DEWPOINT	47	46
SURFACE TEMPERATURE	68	68
4. PRE-WORK SURFACE CONDITIONS / SURFACE PREPARATION Direct application to zinc primer.		
5. COATING APPLICATION		
METHOD OF APPLICATION: Conventional Spray	START TIME 1:30 STOP TIME 2:10 APPROXIMATE SQ. FT. COATED 12	
EQUIPMENT DESCRIPTION: Binks 2001 66ss/63pb 565 needle Fluid 15 psi/ Air 50 psi	GALS COATING APPLIED 1 WET FILM THICKNESS (AVG) 7-8 MILS	
EASE OF USE—Technician Evaluation- Easy mixing (one component, water-based). Good atomization, smooth flow with one coat coverage after required mist coat.		
POT LIFE—Technician Evaluation		
Room Temperature sprayable after 4 hrs. no gel after 6 hrs.		
Heated- N/A		
6. POST CURE INSPECTION DRY FILM THICKNESS (AVG) 3-4 MILS (See Attached Documentation) DRY-TO-TOUCH (SANDING) EVALUATION- No effect. EVALUATION WITH UNAIDED EYE- Smooth semi-gloss appearance with uniform color. Remains Tacky for extended periods. EVALUATION WITH 10X MAGNIFICATION- Small crater-like anomalies observed on surface of Coating, not through to the primer or substrate. GLOSS READING (per ASTM D 523) 60° 49.4 G.U. COLOR READING (per ASTM D 2244) (L*,a*,b*) 93.76, -2.57, 4.26 REMARKS		

COATING SYSTEM EVALUATION AND INSPECTION REPORT*

DATE- **2/11/05** | PROJECT REF. NO. **System 5** | PAGE **1** OF **1**

PROJECT NAME: **ISO Free Coatings** | INSPECTOR: **Curran**

PRODUCT MANUFACTURER / NAME: **Sherwin Williams Fast-Clad HB**

BATCH NUMBERS- **6403-47894**

1. DESCRIPTION OF ITEMS AND /OR AREAS: **4"x6" flat and composite, 3"x6", 4"x12", 3"x5", 4"x4" flat coupons**

2. DESCRIPTION OF WORK PERFORMED / REMARKS: **Spraying Test Coupons**

3. ENVIRONMENTAL CONDITIONS

TIME	**8:30**	**10:00**
AIR TEMP °F	**73**	**65**
RELATIVE HUMIDITY	**16%**	**19%**
DEWPOINT	**24**	**23**
SURFACE TEMPERATURE	**62**	**60**

4. PRE-WORK SURFACE CONDITIONS / SURFACE PREPARATION

Direct application to zinc primer.

5. COATING APPLICATION

METHOD OF APPLICATION:	START TIME **9:00** STOP TIME **9:45**
Conventional Spray	APPROXIMATE SQ. FT. COATED **12**
EQUIPMENT DESCRIPTION:	GALS COATING APPLIED **.75**
Binks 2001 66ss/63pb 565 needle Fluid 15 psi/ Air 50 psi	WET FILM THICKNESS (AVG) **12-15** MILS

EASE OF USE—Technician Evaluation- **Easy mixing (one component, water-based). Good atomization, smooth flow with one coat coverage after required mist coat.**

POT LIFE—Technician Evaluation

Room Temperature sprayable after 4 hrs. no gel after 6 hrs.

Heated- N/A

6. POST CURE INSPECTION

DRY FILM THICKNESS (AVG) **7-8** MILS (See Attached Documentation)

DRY-TO-TOUCH (SANDING) EVALUATION- **No effect.**

EVALUATION WITH UNAIDED EYE- **Smooth semi-gloss appearance with uniform color. Remains Tacky for extended periods.**

EVALUATION WITH 10X MAGNIFICATION- **Small crater-like anomalies observed on surface of Coating, not through to the primer or substrate.**

GLOSS READING (per ASTM D 523) 60° **46.2 G.U.**

COLOR READING (per ASTM D 2244) **(L*,a*,b*) 93.74, -2.11, 2.92**

REMARKS

COATING SYSTEM EVALUATION AND INSPECTION REPORT*				
DATE- **2/22/05**	PROJECT REF. NO. **System 6**		PAGE **1** OF **1**	
PROJECT NAME: **ISO Free Coatings**		INSPECTOR: **Curran**		
PRODUCT MANUFACTURER / NAME: **International Interfine 979**				
BATCH NUMBERS- **"A" SYA 046/ "B" SYB 000**				
1. DESCRIPTION OF ITEMS AND /OR AREAS: **4"x6" flat and composite, 3"x6", 4"x12", 3"x5", 4"x4" flat coupons**				
2. DESCRIPTION OF WORK PERFORMED / REMARKS: **Spraying Test Coupons**				
3. ENVIRONMENTAL CONDITIONS				
TIME	**10:00**	**11:00**		
AIR TEMP °F	**69**	**71**		
RELATIVE HUMIDITY	**79%**	**75%**		
DEWPOINT	**63**	**63**		
SURFACE TEMPERATURE	**70**	**70**		
4. PRE-WORK SURFACE CONDITIONS / SURFACE PREPARATION **Applied over Interseal 670 HS tie coat.**				
5. COATING APPLICATION				
METHOD OF APPLICATION:	START TIME **10:00** STOP TIME **11:00**			
Conventional Spray	APPROXIMATE SQ. FT. COATED **12**			
EQUIPMENT DESCRIPTION:	GALS COATING APPLIED **.3**			
Binks 2001 66ss/63pb 565 needle Fluid 15 psi/ Air 50 psi	WET FILM THICKNESS (AVG) **6-7** MILS			
EASE OF USE—Technician Evaluation- **Easy mixing, good flow, good atomization with one coat coverage.**				
POT LIFE—Technician Evaluation				
Room Temperature sprayable after 4 hrs.				
Heated sprayable after 4 hrs.				
6. POST CURE INSPECTION DRY FILM THICKNESS (AVG) **4-6** MILS (See Attached Documentation) DRY-TO-TOUCH (SANDING) EVALUATION- **No effect.** EVALUATION WITH UNAIDED EYE- **Slight orange peel glossy finish with uniform color.** EVALUATION WITH 10X MAGNIFICATION- **No defects or irregularities observed.** GLOSS READING (per ASTM D 523) COLOR READING (per ASTM D 2244) 60° **(L*,a*,b*) 93.93, -2.41, 2.43** **65.1 G.U.** REMARKS				

COATING SYSTEM EVALUATION AND INSPECTION REPORT*				
DATE- 2/22/05	PROJECT REF. NO. System 7		PAGE 1 OF 1	
PROJECT NAME: ISO Free Coatings		INSPECTOR: Curran		
PRODUCT MANUFACTURER / NAME: International Interfine 878				
BATCH NUMBERS- "A" SZA000/ "B" SZB056				
1. DESCRIPTION OF ITEMS AND /OR AREAS: 4"x6" flat and composite, 3"x6", 4"x12", 3"x5", 4"x4" flat coupons				
2. DESCRIPTION OF WORK PERFORMED / REMARKS: Spraying Test Coupons				
3. ENVIRONMENTAL CONDITIONS				
TIME	11:00	12:00	1:00	
AIR TEMP °F	71	75	75	
RELATIVE HUMIDITY	75%	64%	67%	
DEWPOINT	63	62	64	
SURFACE TEMPERATURE	70	74	74	
4. PRE-WORK SURFACE CONDITIONS / SURFACE PREPARATION Applied over Interseal 670 HS tie coat.				
5. COATING APPLICATION				
METHOD OF APPLICATION: Conventional Spray	START TIME 11:30 STOP TIME 12:30 APPROXIMATE SQ. FT. COATED 12			
EQUIPMENT DESCRIPTION: Binks 2001 66ss/63pb 565 needle Fluid 15 psi/ Air 50 psi	GALS COATING APPLIED .5 WET FILM THICKNESS (AVG) 3-4 MILS			
EASE OF USE—Technician Evaluation- Easy mixing, good flow, good atomization with one coat coverage.				
POT LIFE—Technician Evaluation				
Room Temperature sprayable after 4 hrs.				
Heated sprayable after 4 hrs.				
6. POST CURE INSPECTION DRY FILM THICKNESS (AVG) 3-4 MILS (See Attached Documentation) DRY-TO-TOUCH (SANDING) EVALUATION- No effect. EVALUATION WITH UNAIDED EYE- Slight orange peel glossy finish with uniform color. EVALUATION WITH 10X MAGNIFICATION- No defects or irregularities observed. GLOSS READING (per ASTM D 523) COLOR READING (per ASTM D 2244) 60° (L*,a*,b*) 94.78, -1.95, 2.20 56.8 G.U. REMARKS				

COATING SYSTEM EVALUATION AND INSPECTION REPORT*					
DATE- 2/28/05	PROJECT REF. NO. System 8			PAGE 1 OF 1	
PROJECT NAME: ISO Free Coatings			INSPECTOR: Curran		
PRODUCT MANUFACTURER / NAME: Devoe Devathane 134 HB					
BATCH NUMBERS- "A" 359B3501/ "B" 359C0910					
1. DESCRIPTION OF ITEMS AND /OR AREAS: 4"x6" flat and composite, 3"x6", 4"x12", 3"x5", 4"x4" flat coupons					
2. DESCRIPTION OF WORK PERFORMED / REMARKS: Spraying Test Coupons					
3. ENVIRONMENTAL CONDITIONS					
TIME	8:30	9:30	10:30	11:30	
AIR TEMP °F	70	68	68	70	
RELATIVE HUMIDITY	57%	63%	60%	56%	
DEWPOINT	54	55	53	53	
SURFACE TEMPERATURE	70	67	67	69	
4. PRE-WORK SURFACE CONDITIONS / SURFACE PREPARATION Applied over Devran 201 epoxy tie coat.					
5. COATING APPLICATION					
METHOD OF APPLICATION: Conventional Spray	START TIME 9:00 STOP TIME 11:00 APPROXIMATE SQ. FT. COATED 12				
EQUIPMENT DESCRIPTION: Binks 2001 66ss/63pb 565 needle Fluid 25 psi/ Air 60 psi	GALS COATING APPLIED .75 WET FILM THICKNESS (AVG) 7-8 MILS				
EASE OF USE—Technician Evaluation- Easy mixing, good flow, good atomization with one coat coverage.					
POT LIFE—Technician Evaluation					
Room Temperature sprayable after 4 hrs.					
Heated not sprayable after 2 hrs.					
6. POST CURE INSPECTION DRY FILM THICKNESS (AVG) 5-6 MILS (See Attached Documentation) DRY-TO-TOUCH (SANDING) EVALUATION- No effect. EVALUATION WITH UNAIDED EYE- Smooth glossy appearance with uniform color. EVALUATION WITH 10X MAGNIFICATION- No defects or irregularities observed. GLOSS READING (per ASTM D 523) 60° 57.3 G.U. COLOR READING (per ASTM D 2244) (L*,a*,b*) 96.51, -1.92, 1.46 REMARKS					

COATING SYSTEM EVALUATION AND INSPECTION REPORT*				
DATE- **3/22/05**	PROJECT REF. NO. **System 9**		PAGE **1** OF **1**	
PROJECT NAME: **ISO Free Coatings**		INSPECTOR: **Curran**		
PRODUCT MANUFACTURER / NAME: **AquaSurTech D45-AMS White**				
BATCH NUMBERS- **none**				
1. DESCRIPTION OF ITEMS AND /OR AREAS: **4"x6" flat and composite, 3"x6", 4"x12", 3"x5", 4"x4" flat coupons**				
2. DESCRIPTION OF WORK PERFORMED / REMARKS: **Spraying Test Coupons**				
3. ENVIRONMENTAL CONDITIONS				
TIME	**9:30**	**10:30**	**11:30**	
AIR TEMP °F	**75**	**76**	**77**	
RELATIVE HUMIDITY	**84%**	**78%**	**68%**	
DEWPOINT	**70**	**69**	**65**	
SURFACE TEMPERATURE	**75**	**75**	**75**	
4. PRE-WORK SURFACE CONDITIONS / SURFACE PREPARATION **Applied over D45-20 Medium Base primer.**				
5. COATING APPLICATION				
METHOD OF APPLICATION:	START TIME **10:30** STOP TIME **12:30**			
Conventional Spray (gravity cup)	APPROXIMATE SQ. FT. COATED **12**			
EQUIPMENT DESCRIPTION:	GALS COATING APPLIED **.33**			
Binks 96G 66ss/66 sd 565 needle Fluid (gravity)/ Air 40 psi	WET FILM THICKNESS (AVG) **2** MILS			
EASE OF USE—Technician Evaluation- **Coating not viscous enough to reach the recommended 2 mils wft. Reached recommended thickness by spraying three mist coats to avoid runs and sags.**				
POT LIFE—Technician Evaluation				
Room Temperature sprayable after 4 hrs. no gelling after 6 hrs.				
Heated- N/A.				
6. POST CURE INSPECTION DRY FILM THICKNESS (AVG) **1- 1.5** MILS (See Attached Documentation) DRY-TO-TOUCH (SANDING) EVALUATION- **No effect.** EVALUATION WITH UNAIDED EYE- **Smooth semi-gloss appearance with uniform color.** EVALUATION WITH 10X MAGNIFICATION- **No defects or irregularities observed.** GLOSS READING (per ASTM D 523) COLOR READING (per ASTM D 2244) 60° **N/A** **N/A** REMARKS				

COATING SYSTEM EVALUATION AND INSPECTION REPORT*			
DATE- **3/24/05**	PROJECT REF. NO. **System 9**	PAGE **1** OF **1**	
PROJECT NAME: **ISO Free Coatings**		INSPECTOR: **Curran**	
PRODUCT MANUFACTURER / NAME: **AquaSurTech D45-AMS Clear**			
BATCH NUMBERS			
1. DESCRIPTION OF ITEMS AND /OR AREAS: 4"x6" flat and composite, 3"x6", 4"x12", 3"x5", 4"x4" flat coupons			
2. DESCRIPTION OF WORK PERFORMED / REMARKS: Spraying Test Coupons			
3. ENVIRONMENTAL CONDITIONS			
TIME	**8:00**	**9:00**	
AIR TEMP °F	**71**	**72**	
RELATIVE HUMIDITY	**53%**	**53%**	
DEWPOINT	**53**	**53**	
SURFACE TEMPERATURE	**70**	**70**	
4. PRE-WORK SURFACE CONDITIONS / SURFACE PREPARATION			
Applied on D45-AMS White top coat			
5. COATING APPLICATION			
METHOD OF APPLICATION:	START TIME **8:30** STOP TIME **9:00**		
Conventional Spray (gravity cup)	APPROXIMATE SQ. FT. COATED **12**		
EQUIPMENT DESCRIPTION:	GALS COATING APPLIED **.33**		
Binks 96G 66ss/66 sd 565 needle Fluid (gravity)/ Air 40 psi	WET FILM THICKNESS (AVG) **2-3** MILS		
EASE OF USE—Technician Evaluation- **Coating not viscous enough to reach the recommended 2 mils wft. Reached recommended thickness by spraying three mist coats to avoid runs and sags.**			
POT LIFE—Technician Evaluation			
Room Temperature sprayable after 4 hrs. no gelling after 6 hrs.			
Heated- N/A.			
6. POST CURE INSPECTION DRY FILM THICKNESS (AVG) **0.7-1.0** MILS (See Attached Documentation) DRY-TO-TOUCH (SANDING) EVALUATION- **No effects.** EVALUATION WITH UNAIDED EYE- **Smooth semi-gloss appearance with uniform color.** EVALUATION WITH 10X MAGNIFICATION- **No defects or irregularities observed.** GLOSS READING (per ASTM D 523) COLOR READING (per ASTM D 2244) 60° **(L*,a*,b*) 94.10, -1.89, 2.54** **7.4 G.U.** REMARKS			

COATING SYSTEM EVALUATION AND INSPECTION REPORT*			
DATE- **3/11/05**	PROJECT REF. NO. **System 10**		PAGE **1** OF **1**
PROJECT NAME: **ISO Free Coatings**		INSPECTOR: **Curran**	
PRODUCT MANUFACTURER / NAME- **Ameron PSX 1001**			
BATCH NUMBERS- **LR2004 120277**			
1. DESCRIPTION OF ITEMS AND /OR AREAS: 4"x6" flat and composite, 3"x6", 4"x12", 3"x5", 4"x4" flat coupons			
2. DESCRIPTION OF WORK PERFORMED / REMARKS: Spraying Test Coupons			
3. ENVIRONMENTAL CONDITIONS			
TIME	**12:00**	**1:00**	
AIR TEMP °F	**70**	**72**	
RELATIVE HUMIDITY	**40%**	**41%**	
DEWPOINT	**46**	**47**	
SURFACE TEMPERATURE	**70**	**70**	
4. PRE-WORK SURFACE CONDITIONS / SURFACE PREPARATION Applied over Amercoat 383H tie coat			
5. COATING APPLICATION			
METHOD OF APPLICATION: **Conventional Spray**	START TIME **12:00** STOP TIME **1:00**		
	APPROXIMATE SQ. FT. COATED **12**		
EQUIPMENT DESCRIPTION: **Binks 2001 66ss/63pb 565 needle Fluid 5 psi/ Air 50 psi**	GALS COATING APPLIED **.33**		
	WET FILM THICKNESS (AVG) **5-6** MILS		
EASE OF USE—Technician Evaluation- Easy mixing (one-component). **Low viscosity causes runs and sags. Sprayed 1 mil mist coat 20 minutes prior to full application of 5-6 mils wft.**			
POT LIFE—Technician Evaluation			
Room Temperature sprayable after 4 hrs.			
Heated sprayable after 4 hrs.			

6. POST CURE INSPECTION

DRY FILM THICKNESS (AVG) **2-3** MILS (See Attached Documentation)

DRY-TO-TOUCH (SANDING) EVALUATION- **No effect.**

EVALUATION WITH UNAIDED EYE- **Smooth glossy appearance with uniform color.**

EVALUATION WITH 10X MAGNIFICATION- **No defects or irregularities observed.**

GLOSS READING (per ASTM D 523) COLOR READING (per ASTM D 2244)

60° **(L*,a*,b*) 96.60, -1.80, 2.42**

70.8 G.U.

REMARKS

APPENDIX B

Binks Air Nozzle Guide
Fluid Nozzle Guide
Nozzle and Needle Selection Chart

Air Nozzle Identification Guide

Low CFM And Low Viscosity Materials

AIR NOZZLE	TYPE	REMARKS	CFM at 50 PSI	MAXIMUM PATTERN
63P	PE	Low CFM Capacity, Medium to Narrow Fan Width	5.1	5"
66S	SE	Low CFM Capacity, Siphon Nozzle	5	9"

Medium Viscosity Material

AIR NOZZLE	TYPE	REMARKS	CFM at 50 PSI	MAXIMUM PATTERN
63PB	PE	An excellent "general purpose" nozzle, used with wide range of materials	14.3	14"
63PH-1	PE	High volume delivery nozzle, anti "fogging," wide fan width use with high solids materials, very wide pattern	15.5	18"
63PR	PE	High production nozzle	15.5	18"
64PA	PE	Used for vitreous enamels and other abrasive materials	18.2	13"
66SD-3	PE	Best air nozzle for adhesive applications	15.4	9"
66PE	PE	High production, high volume delivery nozzle	15	17"
66PH	PE	Used with high solids, vitreous enamels	16.4	16"
66SD	PE	An excellent "general purpose" siphon nozzle, use with wide range of materials	12.1	11"

High Viscosity Materials

AIR NOZZLE	TYPE	REMARKS	CFM at 50 PSI	MAXIMUM PATTERN
67PB	PE	An excellent "general purpose" nozzle for heavier viscosities of materials.	14.9	12"
67PD	PE	Used for Zinc rich and other abrasive coatings	15	15"
68PB	PE	An excellent "general purpose" nozzle where a high volume and heavier viscosity materials are required	14.1	12"
66SK	PE	An excellent "general purpose" siphon nozzle, wide pattern with higher fluid, delivery, used with wide range of materials	15.2	13"

Internal Mix Air Nozzles

AIR NOZZLE	TYPE	REMARKS	CFM at 50 PSI	MAXIMUM PATTERN
101	PI	Tungsten Carbide, Used with highly abrasive materials	6.8	11"
190	PI	Tungsten Carbide, Used with road marking materials	11.5	9"
200	PI	Primarily used for multi color applications	5.2	14"
201	PI	Primarily used for light text materials	6.8	11"
206	PI	Primarily used for multi color applications, light texture	9.5	19"
390ss	PI	SS, used with road marking materials on truck mount guns, water-based paint	11.5	9"
391ss	PI	SS, used with road marking materials on truck mount guns, water-based paint	10.5	11"
709ss	PI	Primarily used with push behind line stripers	5.75	8"

Note: PE - Pressure External SE - Siphon External PI - Pressure Internal * For other Air nozzles see charts on page 20

Fluid Nozzle Identification Guide

Flow Rates for Fluid Nozzles

	FLUID NOZZLE	ID SIZE IN. (MM)	FLOW RATE or MATERIAL
Pressure Feed			
	63ss	.028" (0.7)	Up to 12 oz./min.
	63Ass	.040" (1.0)	Up to 20 oz./min.
	63Bss	.046" (1.2)	Up to 25 oz./min.
	63Css	.052" (1.4)	Up to 28 oz./min.
	64VT	.064" (1.6)	Abrasive enamels
	66ss	.070" (1.8)	40 oz./min. and over
	67ss	.086" (2.2)	Heavy-body materials
	67VT	.086" (2.2)	Abrasive/Heavy-body materials
	68ss	.110" (2.8)	Heavy-body materials
Siphon Feed			
	66ss	.070 (1.8)	Up to 12 oz./min.

Fluid Nozzle Orifice Size

NOZZLE NUMBER	ORIFICE SIZE (INCHES)	(MM) ORIFICE SIZE	NOZZLE NUMBER	ORIFICE SIZE (INCHES)	(MM) ORIFICE SIZE
JA	.043	1.1	61ss	.022	.6
J2ss	.043	1.1	62ss	.022	.6
			63ss	.028	.7
33ss	.040	1.0	63Ass	.040	1.0
33Bss	.046	1.2	63Bss	.046	1.2
36ss	.070	1.8	63Css	.052	1.3
38ss	.086	2.2	63CVT‡	.052	1.3
44ss	.187	4.7	64VT‡	.064	1.6
45ss	.250	6.4	65ss	.059	1.5
46ss	.312	7.9	66ss	.070	1.8
47ss	.375	9.5	67ss	.086	2.2
49ss	.500	12.7	67VT‡	.086	2.2
			68ss	.110	2.8
57ss	.218	5.56	68VT‡	.110	2.8
58ss	.281	7.1	69Bss	.172	4.4
59Ass	.171	4.3			
59Bss	.218	5.5	76ss	.040	1.0
59Css	.281	7.7	77ss	.052	1.3
			78ss	.070	1.8
			794ss	.040	1.0

Nozzle and Needle Selection Chart

Type of Fluid to be Sprayed	Fluid x Air Nozzles	Nozzle Type	CFM at 30 PSI	CFM at 50 PSI	CFM at 70 PSI	Max. Pattern at 8"	Fluid Needle Numbers for Spray Gun Models: 95 SL	95	95A & 95 AR	2001	21
VERY THIN	63ss x 63P	PE	4.5	7.5	10	5	863	663	763	563	263
14-16 secs. Zahn 2 Cup	63Bss x 63PB	PE	9	14.3	20	14	863A	663A	763A	563A	263A
Wash primers, dyes,	66ss x 66SD	SE	7.9	12.1	—	10.5	865	665	765	565	265
stains, solvents,	66ss x 66SK	SE	11	15.2	19.5	13	865	665	765	565	265
water, inks	63Bss x 200	PI	3.1	5.2	6.4	12	863A	663A	763A	563A	263A
THIN											
16-20 secs. Zahn 2 Cup	63Ass x 63P	PE	5.1	8.37	12.2	11	863A	663A	763A	563A	263A
Sealer, lacquers,	63Bss x 63PE	PE	9.5	15	20	13	863A	663A	763A	563A	263A
primers, inks, lubricants	66ss x 66SK	SE	11	15.2	19.5	13	865	665	765	565	265
zinc chromates, acrylics	63Bss x 200	PI	3.1	5.2	6.4	12	863A	663A	763A	563A	263A
MEDIUM											
19-30 secs. Zahn 2 Cup	63Bss x 63PB	PE	9	14.3	20	14	863A	663A	763A	563A	263A
Synthetic enamels,	63Css x 63PE	PE	9.5	15	20	13	863A	663A	763A	563A	263A
varnishes, shellacs, fillers,	66ss x 66SD	SE	7.9	12.1	—	11	865	665	765	565	265
primers, epoxies,	66ss x 66SK	SE	11	15.2	19.5	13	865	665	765	565	265
urethanes, lubricants,	63Css x 200	PI	3.1	5.2	6.4	12	863A	663A	763A	563A	263A
wax emulsions, enamels											
HEAVY											
(Cream-like)	67ss x 67PB	PE	9.5	14.9	19.5	12	867	667	767	567	267
Over 28 secs.	68ss x 68PB	PE	9.5	14.1	19.1	12	868	668	768	568	268
No. 4 Ford Cup	67ss x 206	PI	6	9.5	13	15	867	667	767	567	267
VERY HEAVY	68ss x 68PB	PE	9.5	14.1	19.1	12	868	668	768	568	268
Texture coatings,	68ss x 206	PI	6.2	9.8	13.2	15	868	668	768	568	268
Road marking paint	59Ass x 244	PI	7.8	11.5	15.2	12	859	659	759	559	259
	59Ass x 245	PI	7.8	11.5	15.2	6	859	659	759	559	259
	59Bss x 251	PI	7.8	11.5	15.2	12	859	659	759	559	259
	59Bss x 252	PI	7.8	11.5	15.2	6	859	659	759	559	259
	59Css x 262	PI	7.3	11	14.7	6	859	659	759	559	259
	68ss x 206	PI	6.2	9.8	13.2	15	868	668	768	568	268
ADHESIVES											
Waterbase white vinyl glues	63Bss x 66SD-3	PE	7.9	12.1	16.2	4	863	663	763	563	263
Solvent base, neoprenes	67ss x 67PB	PE	9.5	14.1	19.1	12	867	667	767	567	267
(contact cement)	66ss x 66SD-3	PE	7.9	12.1	16.2	10	865	--	--	--	--
CERAMICS											
Similar abrasive materials,	67VT x 67PD	PE	10	15	20	15	867VT	667VT	767VT	567VT	267VT
glazes, engobes,	68VT x 68PB	PE	9.5	14.1	19.1	12	868VT	668VT	768VT	568VT	268VT
porcelain enamel											
BUFFING COMPOUNDS	64VT x 64PA	PE	12.1	15	21	13	864VT	664VT	764VT	--	264VT
	67VT x 67PD	PE	10	15	20	15	867VT	667VT	767VT	--	267VT
CONCRETE CURING	66ss x 200	PI	3.1	5.2	6.4	15	865	665	765	565	265
COMPOUNDS	67ss x 206	PI	6	9.5	13	18	867	667	767	567	267
	68ss x 206	PI	6.2	9.8	13.2	20	868	668	768	568	268
MULTICOLOR PAINTS	66ss x 200	PI	3.1	5.2	—	12	865	665	765	565	265
	67ss x 206	PI	6	9.5	—	15	867	667	767	567	267
TEFLONS	63Ass x 63PB	PE	9	14.3	20.1	10	863A	663A	763A	563A	263A
	66ss x 66SD	PE	7.9	12.1	—	7	865	665	765	565	265
HAMMERS	63ss x 63PB	PE	9	14.3	—	14	863A	663A	763A	563A	263A
	66ss x 63PB	PE	9	14.3	—	14	865	665	765	565	265
	66ss x 66SD	PE	7.9	12.1	—	7	865	665	765	565	265
WRINKLE ENAMELS	63Css x 63PB	PE	9	14.3	20	10	863A	663A	763A	563A	263A
	66ss x 63PB	PE	9	14.3	20	10	865	665	765	565	265
ZINC RICH COATINGS	66ss x 67PD	PE	12	18	24	15	865	665N	765	565N	--
	67VT x 67PB	PE	9.5	14.1	19.1	12	867VT	667VT	767VT	567VT	267VT
SPATTER	66ss x 66PD	PE	3@15psi	—	—	—	865	665	765	565	265
VEILING	794ss x 793	PE	3@15psi	—	—	—	894	694	792	590	294
DISTRESS	794ss x 797	PE	3@15psi	—	—	—	894	694	792	590	294
EXTRUSION	66xss extrusion tip		—	—	—	—	--	--	--	565	--

Note: PE - Pressure External SE - Siphon External PI - Pressure Internal

APPENDIX C

Baseline Color and Gloss Data

Baseline Gloss Data							
Coupon Number	System	20°	60°	85°	Average 20°	Average 60°	Average 85°
93174	1	31.9	80.9	85.5	41.0	82.3	88.4
93175		45.4	86.3	94.2			
93176		42.0	79.9	83.3			
93177		44.7	81.9	90.6			
93188	2*	32.0	82.8	80.3	29.9	79.1	73.6
93189		28.0	85.9	71.4			
93190		34.2	75.1	71.4			
93191		25.4	72.7	71.3			
93204	3	34.2	82.1	89.0	34.0	81.2	89.2
93205		34.5	80.8	89.3			
93206		33.5	81.3	88.9			
93207		33.6	80.6	89.7			
93220	4	49.0	84.7	92.5	49.4	83.1	91.2
93221		53.6	84.6	92.0			
93222		54.5	85.1	92.2			
93224		40.5	78.1	88.1			
93238	5	9.6	36.4	46.0	9.5	46.2	62.1
93239		8.7	47.5	62.0			
93240		10.1	52.0	72.6			
93241		9.6	49.1	67.8			
39	6	16.4	58.9	54.8	18.1	65.1	66.2
40		16.9	66.1	65.7			
41		17.6	64.0	68.0			
42		21.3	71.6	76.0			
49	7	17.4	65.3	71.5	14.5	56.8	58.8
52		13.9	51.5	55.2			
53		12.4	53.4	49.9			
54		14.2	57.0	58.8			
19	8*	12.9	54.3	57.2	13.6	57.3	55.4
21		13.4	57.6	58.4			
22		12.3	56.5	43.1			
23		15.6	60.8	62.9			
92677	9	1.6	7.4	9.8	1.6	7.4	9.6
92678		1.6	7.3	10.0			
92679		1.6	7.6	9.9			
92684		1.7	7.3	8.8			
92700	10	38.7	91.0	86.3	19.9	70.8	67.4
92702		14.0	70.6	69.1			
92703		17.8	69.1	66.7			
92704		8.9	52.3	47.4			

* Control Coating

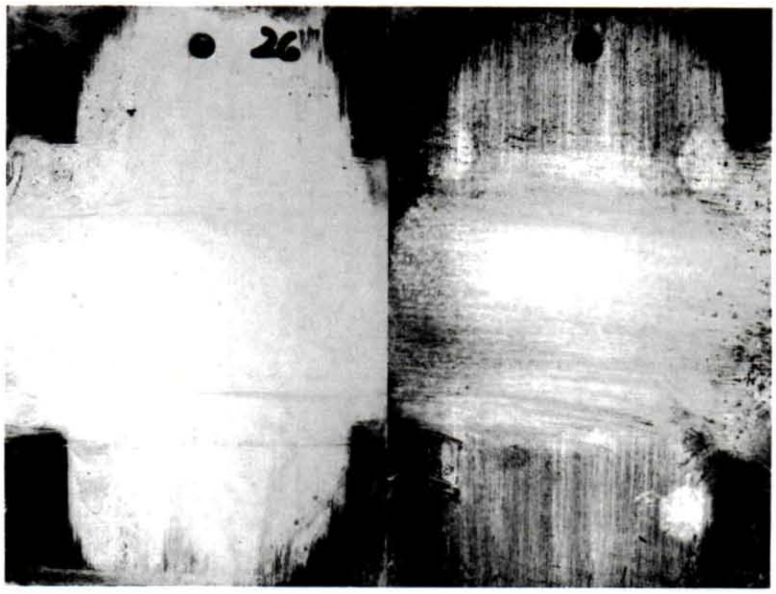
Baseline Color Data							
Coupon Number	***System***	***Color Coordinates***			***Avg. Color Coordinates***		
		L*	***a****	***b****	***L****	***a****	***b****
93174	1	95.18	-1.64	7.29	95.39	-1.59	7.60
93175		95.14	-1.85	7.75			
93176		95.9	-1.23	7.92			
93177		95.32	-1.65	7.42			
93188	2*	92.73	-2.4	4.73	92.61	-2.45	4.78
93189		92.53	-2.55	4.68			
93190		92.51	-2.46	4.56			
93191		92.68	-2.39	5.15			
93204	3	94.11	-2.52	3.9	94.26	-2.28	3.60
93205		94.11	-2.61	4.11			
93206		94.19	-2.32	3.55			
93207		94.64	-1.67	2.83			
93220	4	93.66	-2.63	4.01	93.76	-2.57	4.26
93221		93.97	-2.43	4.1			
93222		93.91	-2.46	4.24			
93224		93.51	-2.77	4.69			
93238	5	94.59	-2.38	2.29	93.74	-2.11	2.92
93239		93.71	-1.76	2.67			
93240		93.29	-2.34	3.44			
93241		93.36	-1.94	3.28			
39	6	93.84	-2.14	1.94	93.93	-2.41	2.43
40		94.35	-1.98	2.12			
41		93.63	-2.68	2.49			
42		93.9	-2.84	3.16			
49	7	94.16	-2.64	2.47	94.78	-1.95	2.20
52		94.82	-1.18	2.07			
53		95.18	-1.85	2.22			
54		94.96	-2.11	2.02			
19	8*	96.39	-1.81	1.16	96.51	-1.92	1.46
21		96.74	-1.85	1.17			
22		96.78	-1.44	1.2			
23		96.11	-2.58	2.32			
92677	9	94.04	-2.29	3.42	94.10	-1.89	2.54
92678		94.24	-1.71	2.64			
92679		94.2	-1.55	1.89			
92684		93.9	-1.99	2.2			
92700	10	96.71	-1.74	2.06	96.60	-1.80	2.42
92702		96.56	-1.07	2.01			
92703		96.7	-1.93	2.39			
92704		96.43	-2.45	3.22			

* Control Coating

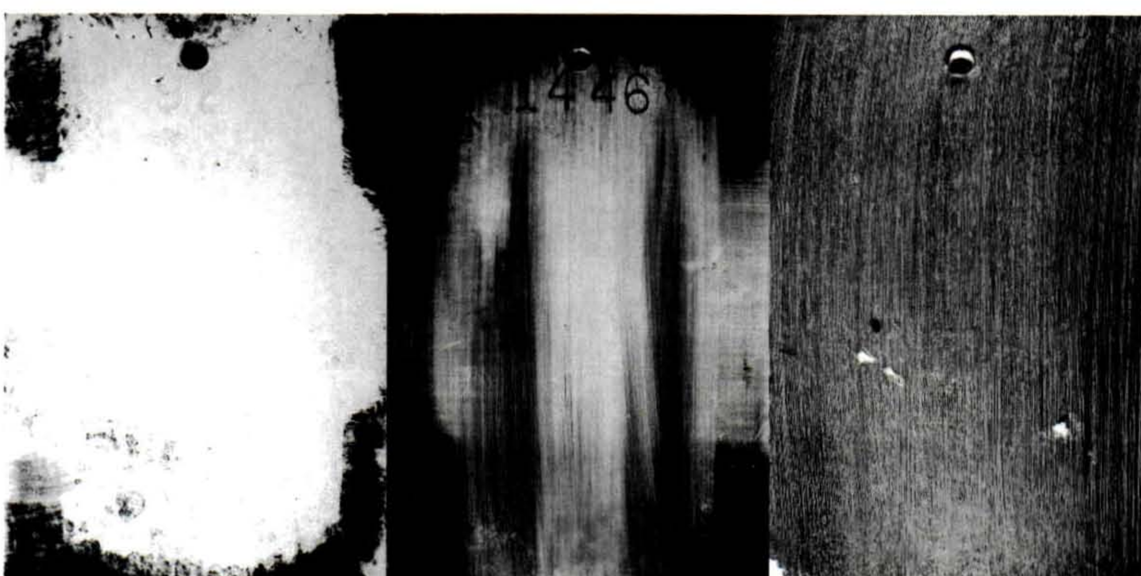
APPENDIX D

Cleanability Test Photographs

Cleanability Photographs



System 1 **System 2***



System 3 **System 4** **System 5**

* Control Coating

Cleanability Photographs

System 6

System 7

System 8*

System 9

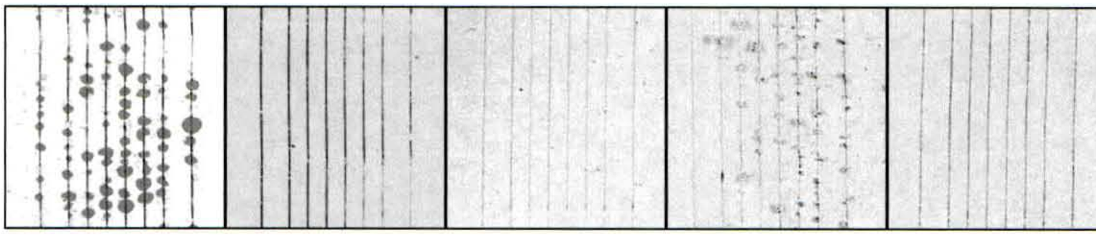
System 10

* Control Coating

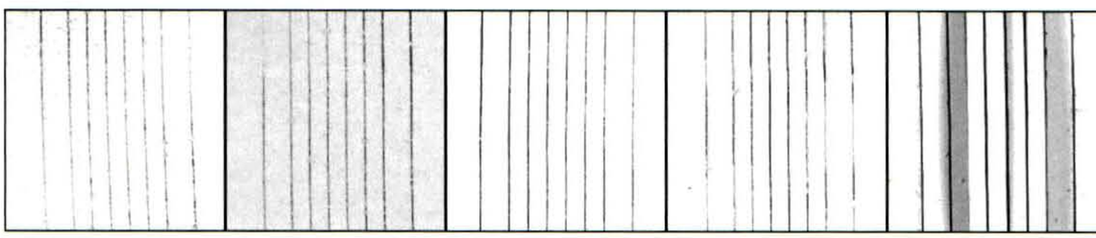
APPENDIX E

Knife Adhesion Test Photographs

Knife Adhesion



System 1 **System 2*** **System 3** **System 4** **System 5**



System 6 **System 7** **System 8*** **System 9** **System 10**

* Control Coating

APPENDIX F

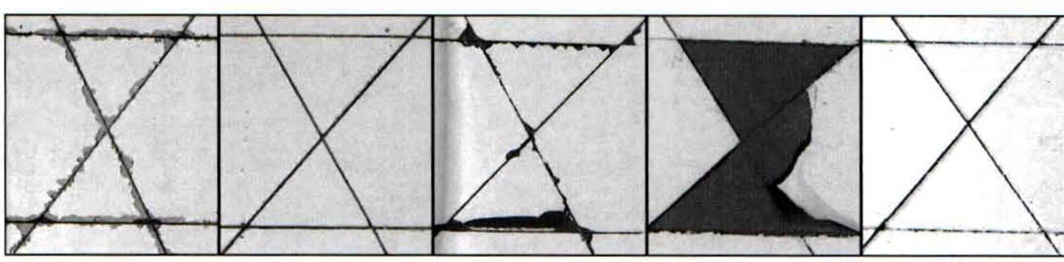
Tensile Adhesion and Wet Tape Adhesion Test Photographs

Dolly Tensile Adhesion Photographs

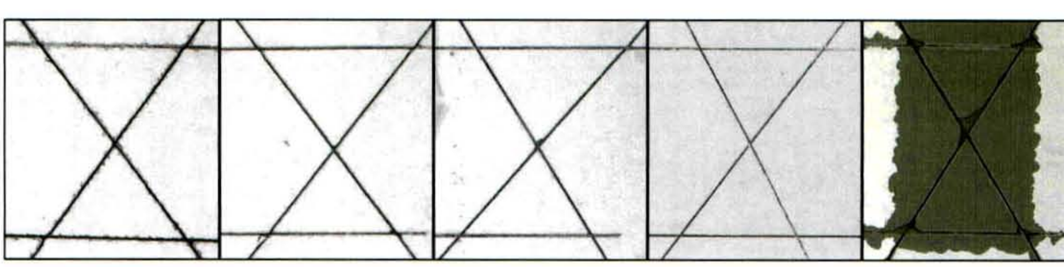
System 1 System 2* System 3 System 4 System 5

System 6 System 7 System 8* System 9 System 10

Wet Tape Adhesion Photographs



System 1 System 2* System 3 System 4 System 5



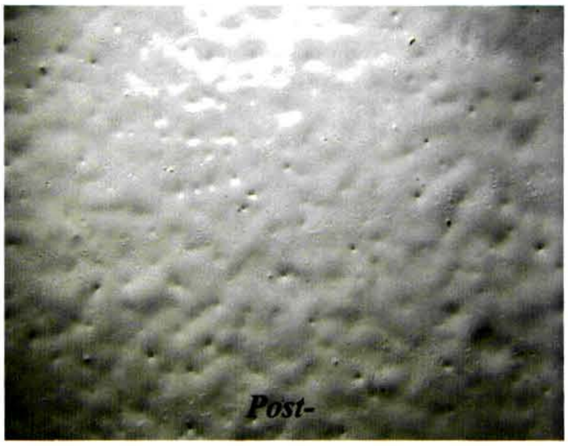
System 6 System 7 System 8* System 9 System 10

* Control Coating

APPENDIX G

Fungus Resistance Test Photographs and Lab Report

System 2 (Control Coating)



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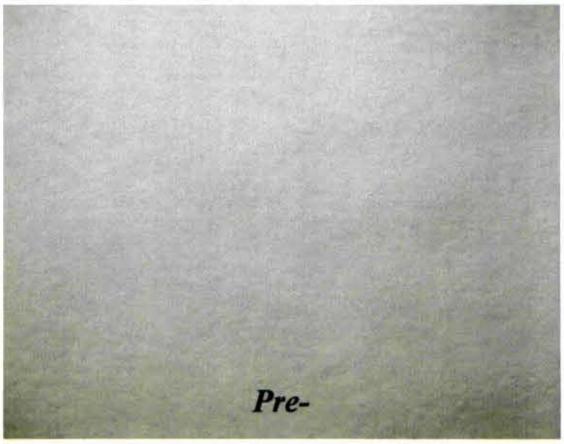

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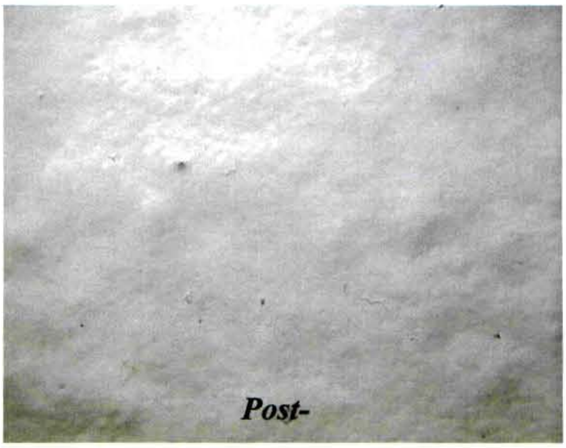
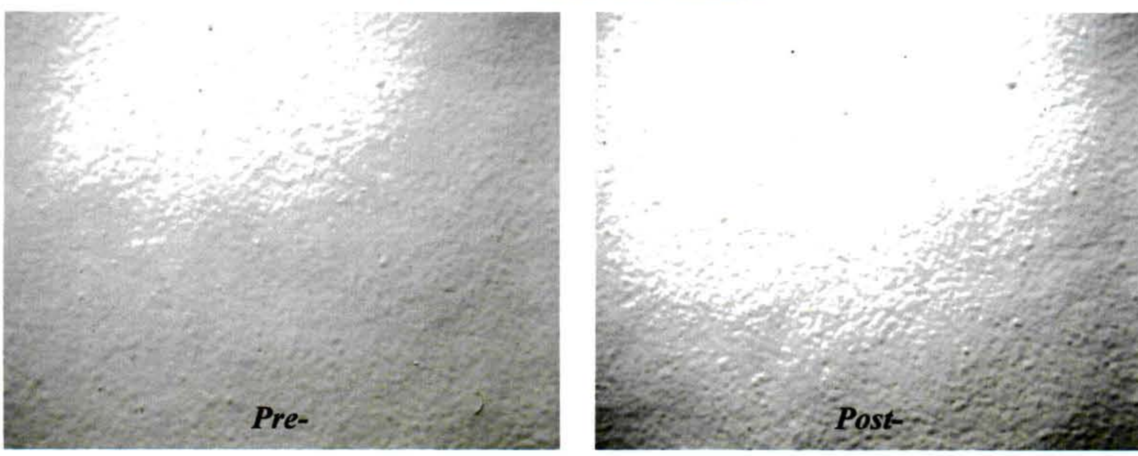


System 7

System 8 (Control Coating)



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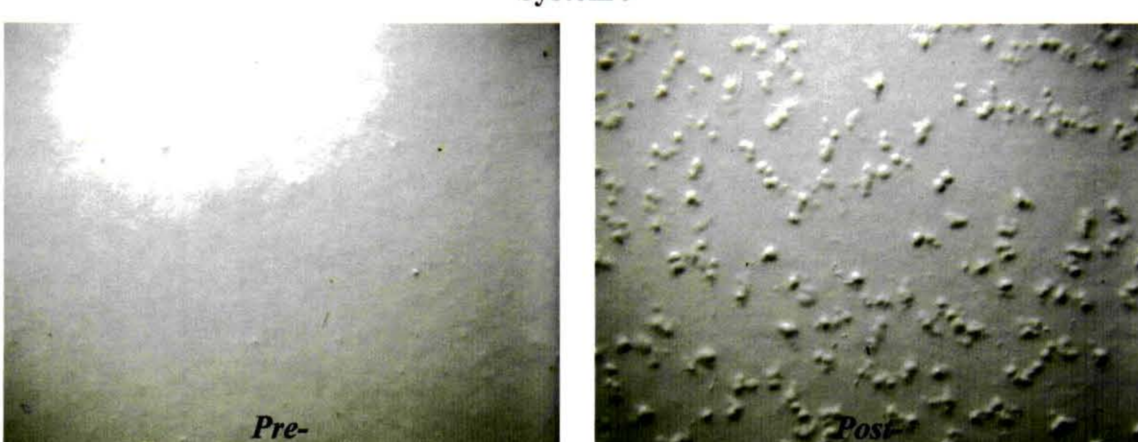
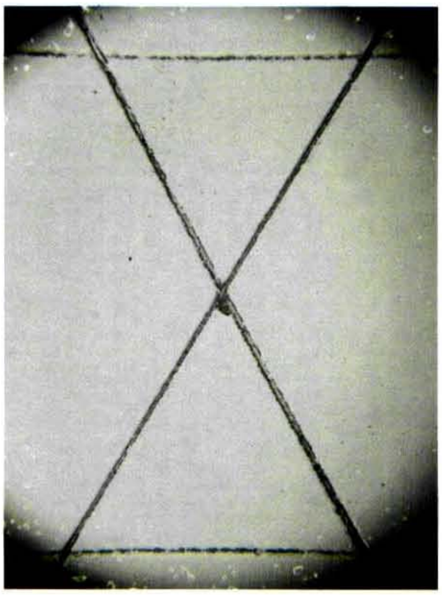
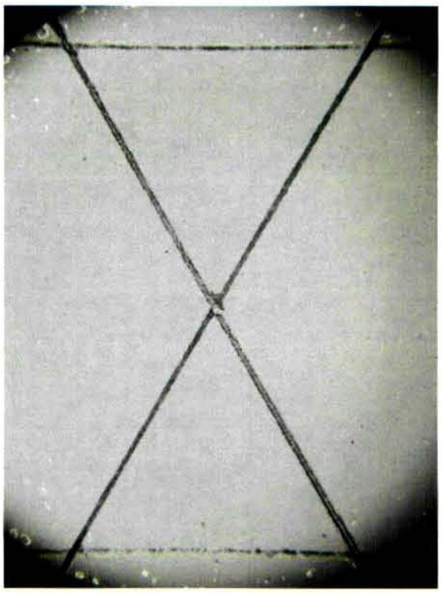


System 2 (Control Coating)

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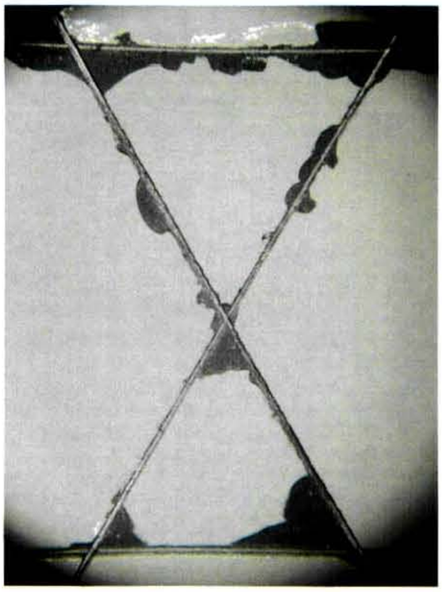
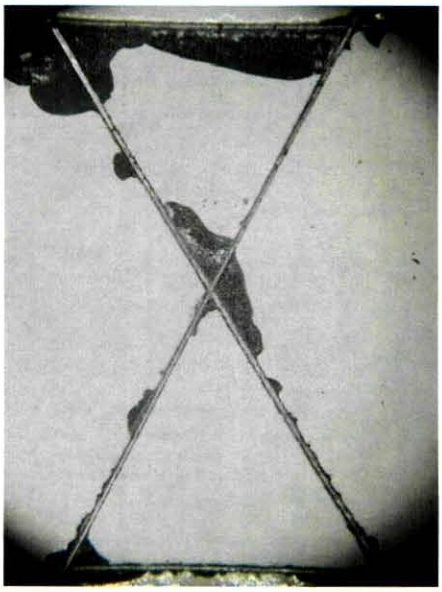

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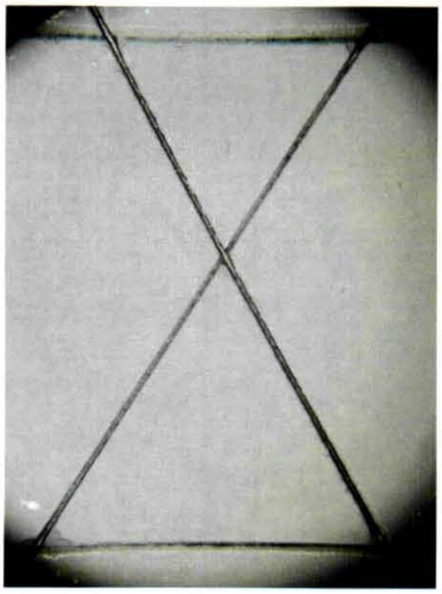
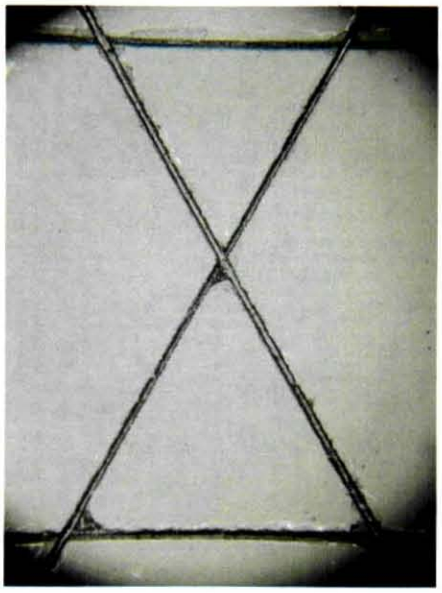

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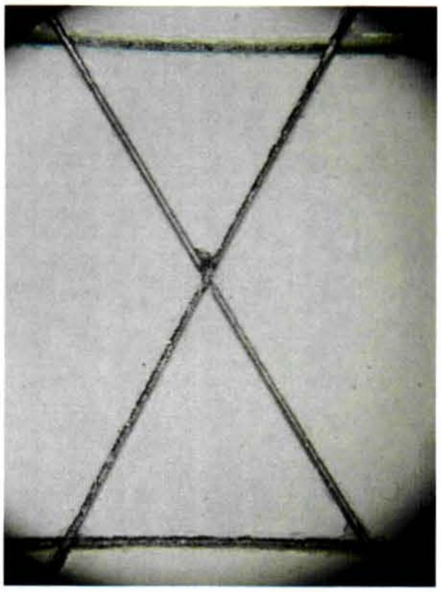
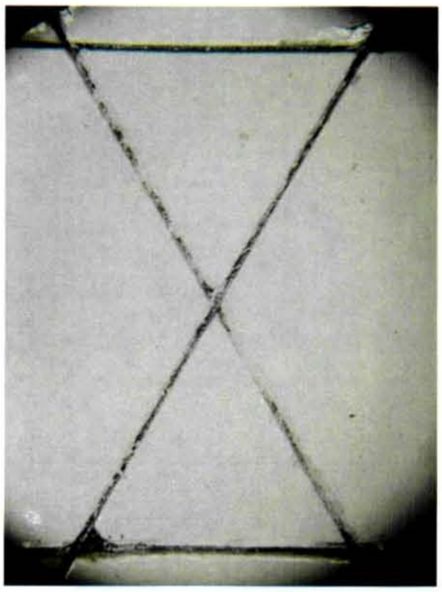
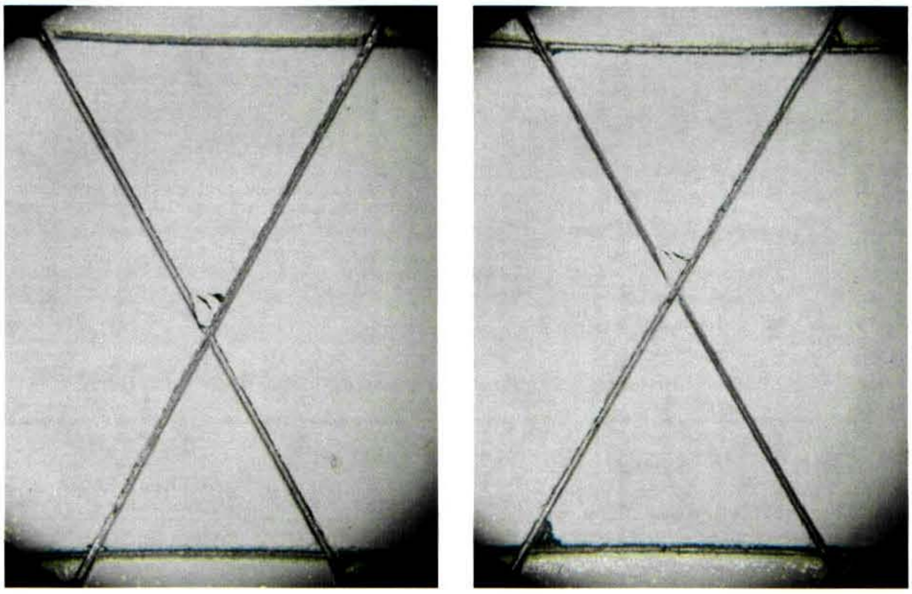
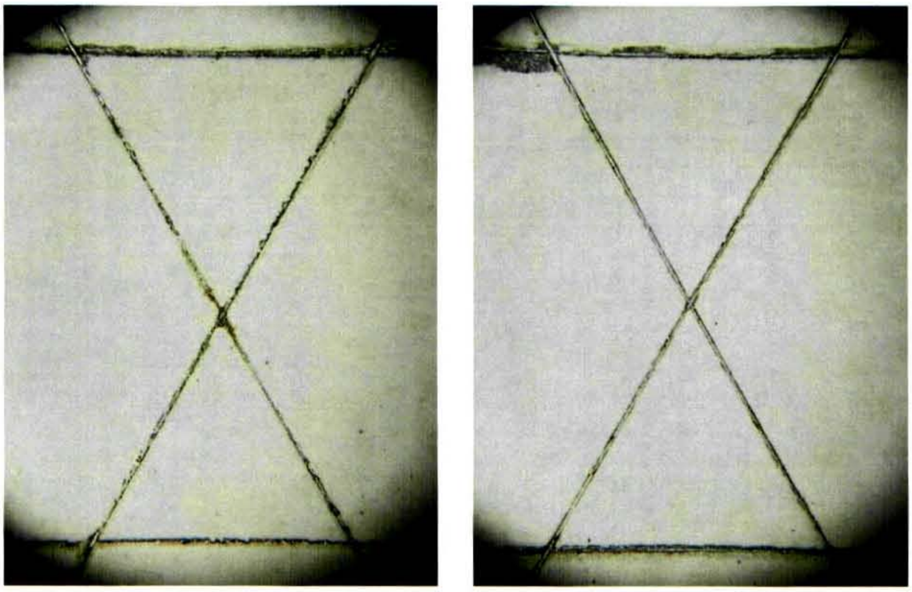



System 8 (Control Coating)



System 9



VISION · VALUE · INTEGRITY

The Bionetics Corporation
Life Science Services Contract
Mail Code: BIO-4
Kennedy Space Center, FL 32899-0001
Phone 321 867-7709 • Fax 321 867-7743
www.bionetics.com

September 20, 2006
BIO-4-06-088

TO: J. Curran/ Artic Slope Research Corp

FROM: R. Sumner/BIO-4

SUBJECT: Fungus Resistance Testing performed for Artic Slope Research Corp.

BACKGROUND / DESCRIPTION AND SCOPE OF WORK

The KSC Environmental Microbiology Laboratory operated by Bionetics performed Fungus Resistance testing on 6 coating systems provided by Artic Slope Research Corp. The testing was performed to measure the extent to which the coatings will support fungal growth. ASRC will determine what effect the fungal growth had on the coating systems.

ASRC provided 4 coupons (4" x 8" coated metal tiles) for each of the 6 coating systems to be tested. Bionetics exposed 3 coupons from each system to test conditions while retaining one coupon unexposed as a control as shown in Table A. below:

Table A.

Coating System	Test - Numbers	Control - Number
System 2	57, 58, 59	56
System3	109, 110, 111	112
System 6	227, 228, 229	230
System 7	288, 289, 290	291
System 8	308, 309, 310	311
System 9	353, 354, 355	356

METHODOLOGY

Testing was performed according to Method 508.5 (*Fungus*) of MIL_STD_810F (*Department of Defense Test Method Standard for Environmental Considerations and Laboratory Tests*, issued 2000, last changed 2003) with modifications to include using the five fungal species listed below:

Aspergillus niger (ATCC* #16404)
Aspergillus flavus (ATCC #10124)
Aspergillus versicolor (ATCC #11730)
Penicillium fungiculosum (ATCC #96014)
Chaetomium globosum (ATCC #58948)

*American Type Culture Collection

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Page 2 of 4

Fungal subcultures were prepared on Sabourauds Dextrose Agar for the Aspergillus and Penicillium species. Chaetomium globosum was cultured on filter paper strips overlaid on Mineral Salts Agar (Appendix A.). Subcultures were incubated for 12 days at 30 +/-1.0^{0}C.

Spore suspensions were then prepared by harvesting spores from the fresh subcultures. 10 milliliters of a sterile wash solution consisting of de ionized water and 0.05 grams of Sodium Lauryl Sulfate was pored onto each culture, agitated slightly and the resulting suspension was poured off into individual Erlenmeyer flasks containing 45 milliliters of sterile water and 65 +/- 5 glass beads (5 millimeter diameter). The flasks were shaken and the contents were filtered through glass wool, centrifuged, suspended and filtered 3 additional times. After the final filtration, the spores were suspended in Mineral Salts solution (Appendix A.), counted with a hemocytometer, and adjusted to a final concentration of 1 x 10^6 +/- 0.20 spores per milliliter. Individual spore suspension concentrations are given in Table B.

Table B.

Fungal Spores	Final Concentration / milliliter
Aspergillus niger	0.90 x 10^6
Aspergillus flavus	0.92 x 10^6
Aspergillus versicolor	1.05 x 10^6
Penicillium fungiculosum	1.10 x 10^6
Chaetomium globosum	0.95 x 10^6

Each spore suspension was checked for viability by inoculating plates of Sabourauds Dextrose Agar (Chaetomium spore suspension was placed on paper strips overlaid on mineral salts agar) and checked for growth after 7 days of incubation at 30.0 +/- 1.0^0 C.

A mixed spore suspension was prepared by combining 5.0 milliliters of each of the previously prepared individual viable suspensions and was used to inoculate the test coupons and control cotton strips.

The environmental chamber was set to maintain a temperature of 30.0 +/- 1.0^0 C, humidity of 95 +/- 5% (at maximum setting), and an air velocity of 1.0 meters per second. The test coupons were placed on trays along with cotton strips (used for a positive growth control). Test coupons and cotton control strips were pre-incubated in the preset chamber for 4 hours prior to inoculation with the mixed spore suspension. A nebulizer was used to spray the mixed spore suspension onto the coupons and cotton strips.

The cotton strips were observed for fungal growth after 7 days. Fungal growth was considered to be covering greater than 90% of the cotton strips.

The incubation were continued an addition 77 days. Test coupons were then held at room temperature until they were decontaminated and returned to ASRC.

September 20, 2006
BIO-4-06-088
Page 3 of 4

RESULTS

At ten days after inoculation, the cotton control strips showed good growth over nearly all the exposed surface. The test coupons, however, showed no sign of fungal growth as reflected in picture files and Table C. At the end of the incubation period, fungal growth was observed on most of the test coupons as well as seen in the post test pictures and referenced in Table D. Fungal growth appeared to be only on the surface of the coupons not invading or penetration the coatings.

Table C.

DAY 10	TEST SYSTEM	OBSERVATION	PICTURE FILE
	Cotton Control Strips	Good Growth	
	System 2	No growth observed	SYS - 2
	System3	No growth observed	SYS - 3
	System 6	No growth observed	SYS - 6
	System 7	No growth observed	SYS - 7
	System 8	No growth observed	SYS - 8
	System 9	No growth observed	SYS - 9

Table D.

DAY 84	TEST SYSTEM	OBSERVATION	PICTURE FILE
	Cotton Control Strips	Heavy Growth	
	System 2	Moderate to Heavy Growth	SYS - 2
	System3	Light Growth	SYS - 3
	System 6	Heavy Growth	SYS - 6
	System 7	Very Heavy Growth	SYS - 7
	System 8	None to Light Growth	SYS - 8
	System 9	Moderate growth	SYS - 9

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APPENDEX A.

Mineral Salts Solution:

	Quantity
Potassium dihydrogen orthophosphate	0.7 gram
Potassium monohydrogen orthophosphate	0.7 gram
Magnesium sulfate heptahydrate	0.7 gram
Ammonium nitrate	1.0 gram
Sodium chloride	0.005 gram
Ferrous sulfate heptahydrate	0.002 gram
Zinc sulfate monohydrate	0.002 gram
Distilled water	1000 milliliters

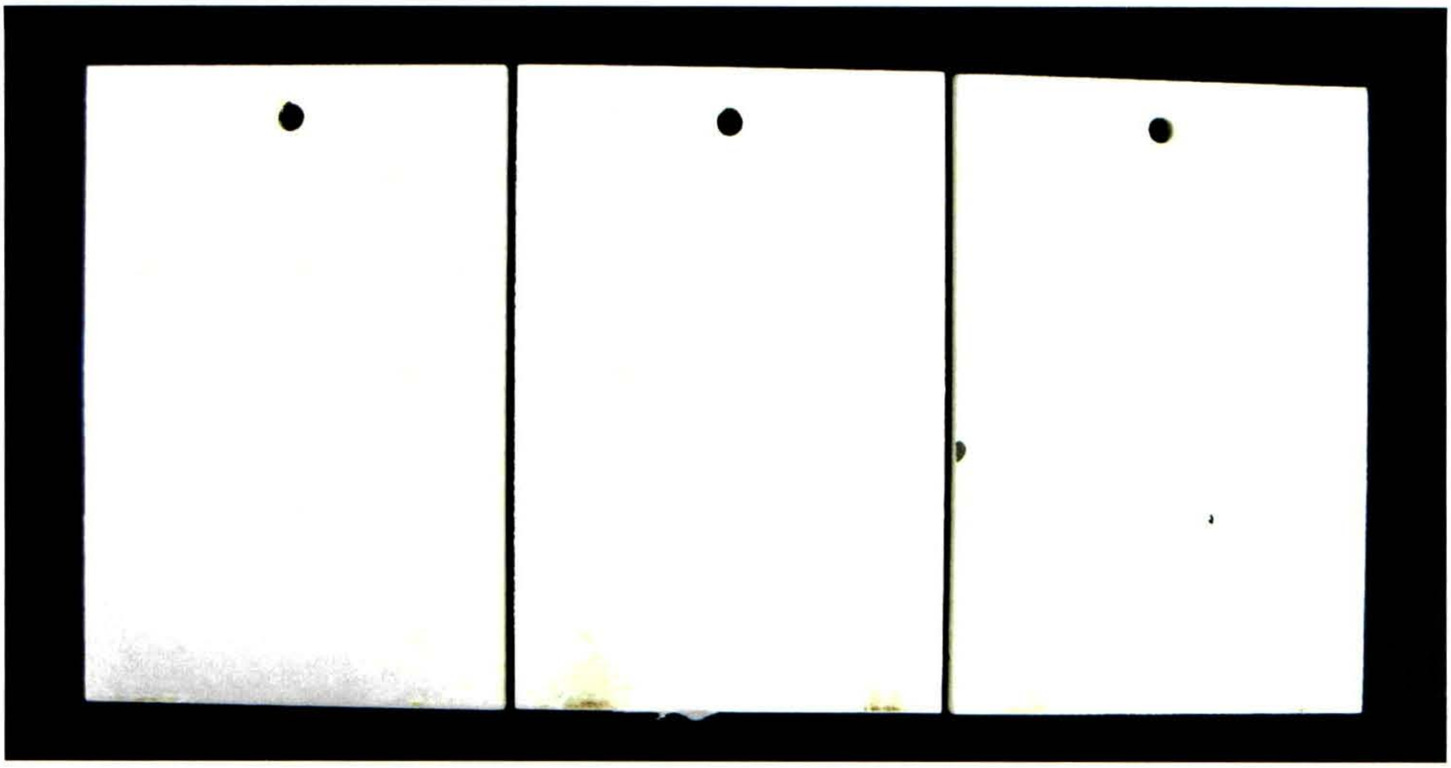
Mineral Salts Agar:

	Quantity
Bacteriological Agar	15 grams
Mineral Salts Solution	1000 milliliters

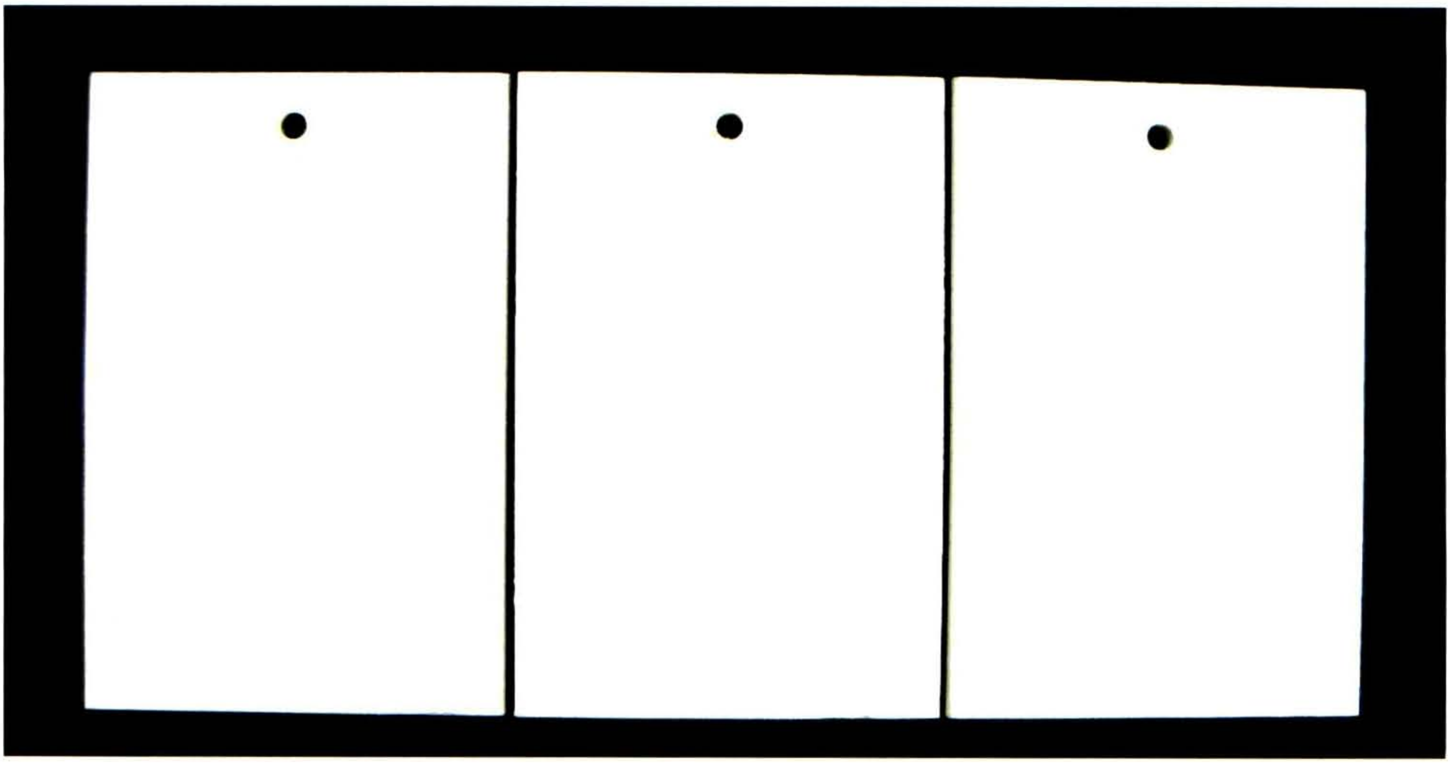
APPENDIX H

Cyclic Corrosion Test Photographs

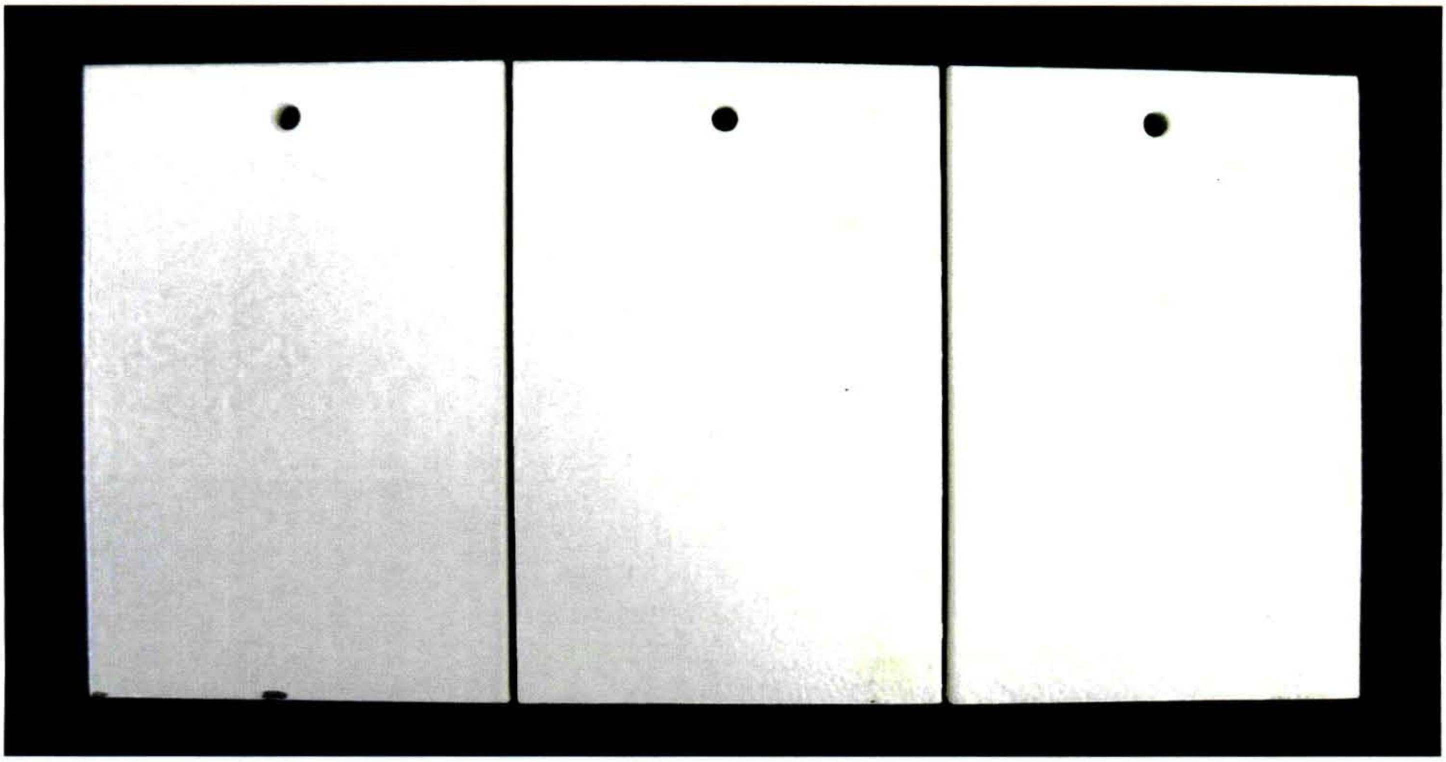
System 2 (Control Coating)



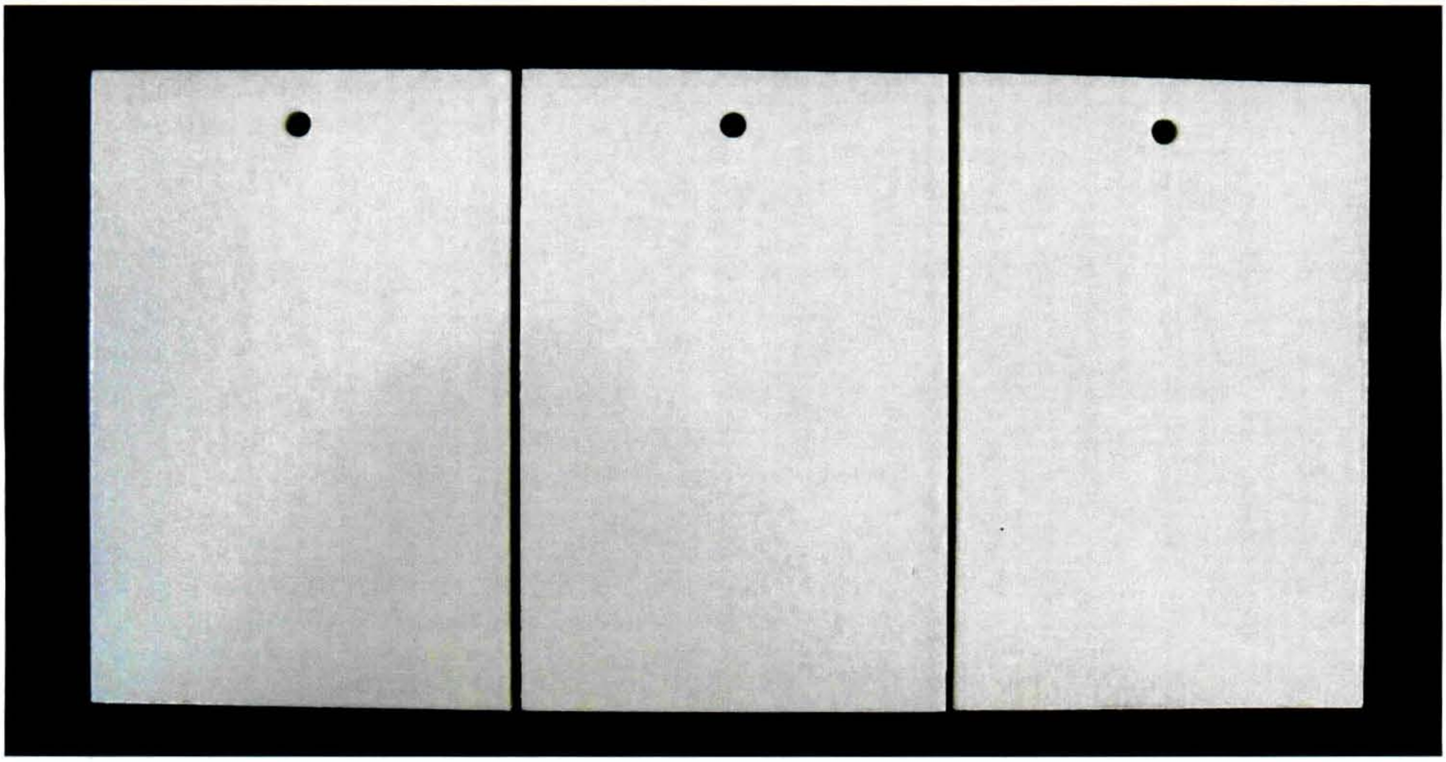
System 3



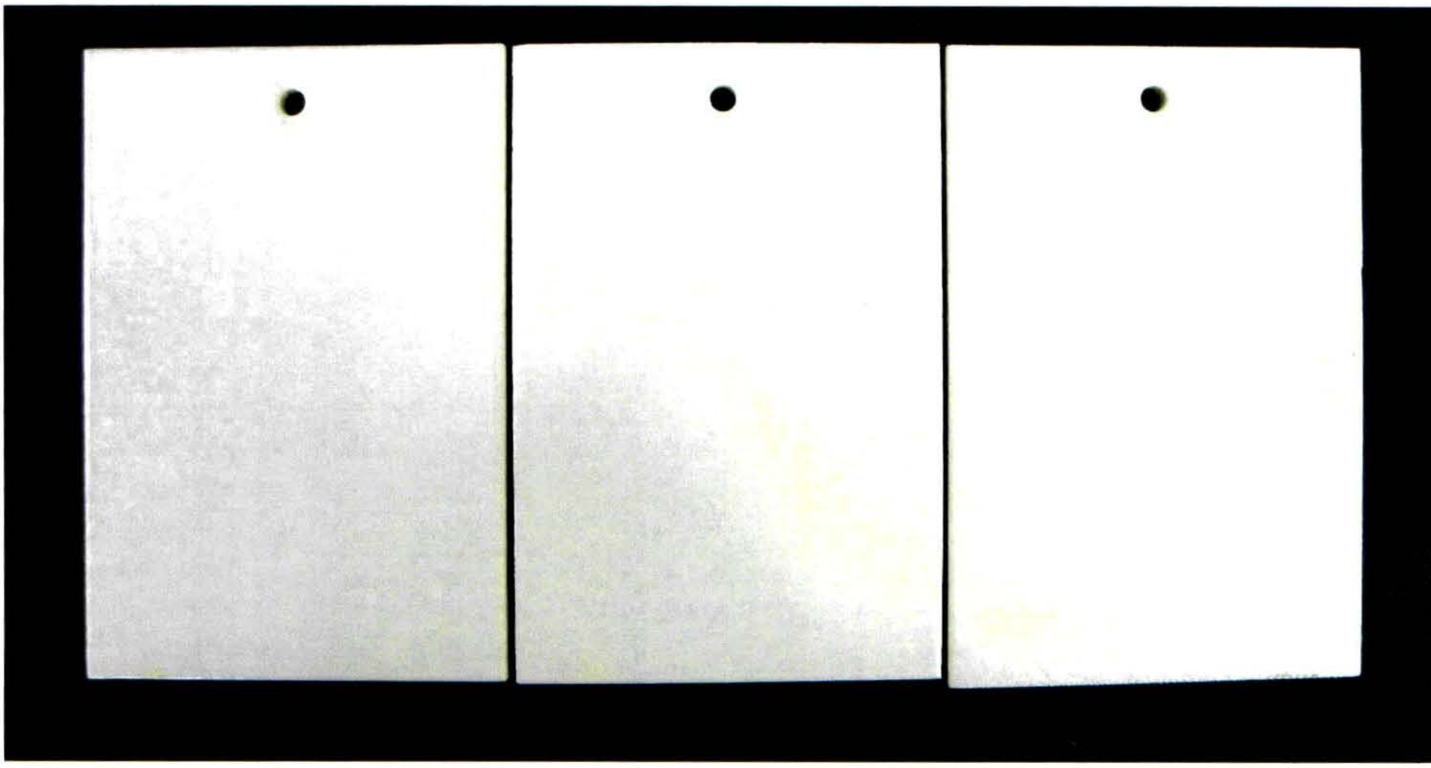
System 6



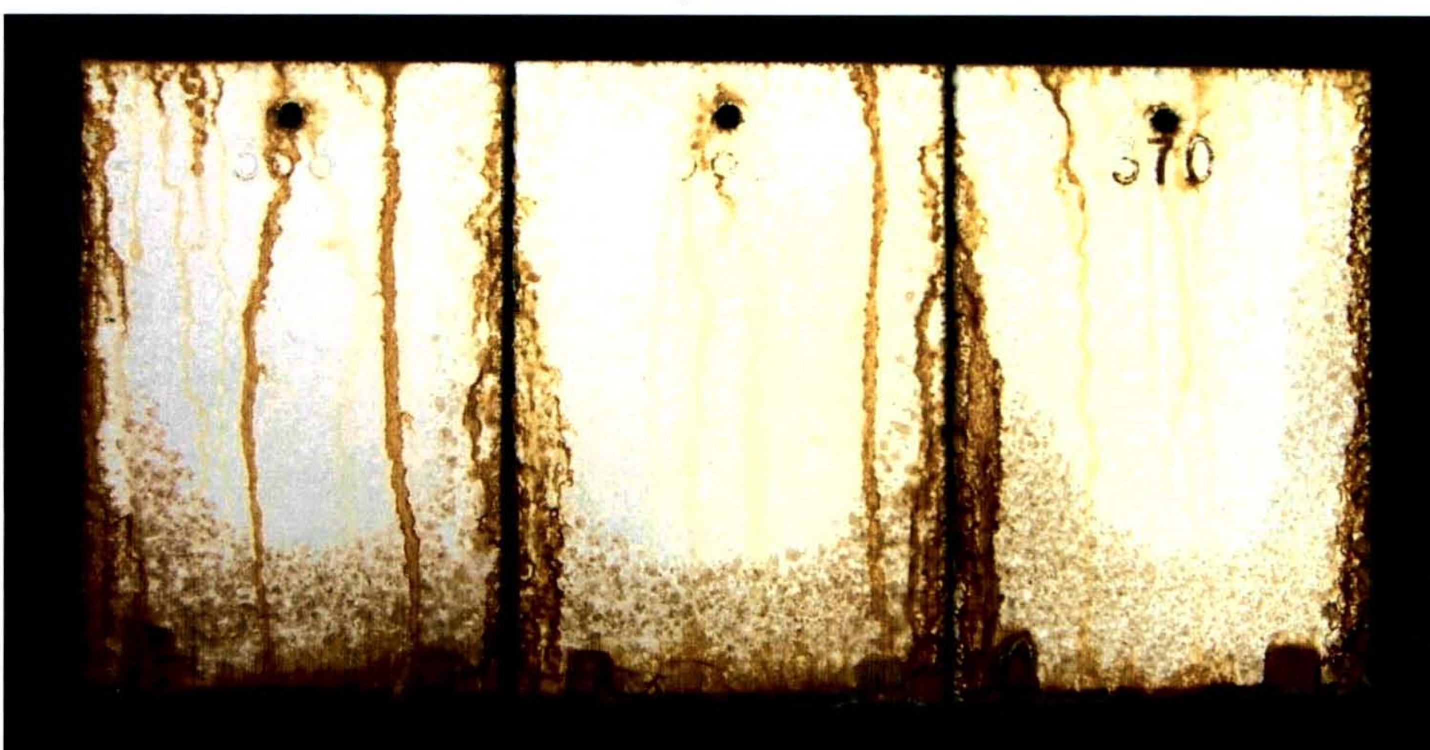
System 7



System 8 (Control Coating)



System 9



APPENDIX I

NASA KSC-MSL-2005-0560 LOX Compatibility Report
And
NASA KSC-MSL-2005-0559 Hypergol Reactivity Report

NASA
Center Operations Directorate
Materials Science Laboratory
Kennedy Space Center, Florida

February 6, 2006

KSC-MSL-2005-0560

SUBJECT: LOX Testing of Ten New Paint Coating Systems

CUSTOMER: Jerry Curran/ASRC-20/867-9486

1. FOREWORD

   Customer developed ten new paint coatings as part of hazardous material reduction effort for protective coatings, and requested their LOX impact testing.

2. PROCEDURES AND RESULTS

   2.1 Test samples were prepared by the customer per NASA-STD-6001 Test 13A Mechanical Impact in Ambient Pressure LOX.

   2.2 Tests were performed at WSTF. See page 2 for test results.

PRIMARY INVESTIGATOR: ______________________________
Rupert Lee/YA-F2-T

TEST: Liquid Oxygen (LOX) Mechanical Impact at 72 ft-lbs.

TEST METHOD: NASA-STD-6001, Test 13A.

REFERENCE DOCUMENTATION:

Item	Number of reactions	Number of tests	Type of reactions	Pass Fail	WSTF Report
Carboxane 2000	2	2	A, B, C	Fail	05-40127
Carbothane 134HG	2	2	A, C	Fail	05-40128
Polysiloxane XLE	2	3	A, B, C	Fail	05-40129
Sher-Cryl HPA	2	3	A, B, C	Fail	05-40130
Fast Clad HB	2	2	A, B, C	Fail	05-40131
Interfine 979	2	2	A, B, C	Fail	05-40132
Interfine 878	2	2	A, B, C	Fail	05-40133
Devthane 359	2	2	A, B, C	Fail	05-40134
Kimetsan D45	2	2	A, B, C	Fail	05-40135
PSX 1001	2	2	A, C	Fail	05-40136

Test Temperature: -183 °C
Test Pressure: 12.4 psia

Note:
A = flash
B = noise
C = charring or discoloration
D = melting
E = test chamber temperature increase
F = test chamber pressure increase
G = deformation or stains on the cup or pin due to a reaction

<u>ACCEPTANCE CRITERIA</u>:

One of the two following conditions must be met:

1) Twenty samples must be without reaction.
2) If impact energy is 72 ft-lbs and one (1) sample out of 20 reacts, 40 additional samples are tested. All 40 must be without reaction.

NASA
Center Operations Directorate
Materials Science Laboratory
Kennedy Space Center, Florida

December 5, 2005

KSC-MSL-2005-0559

SUBJECT: Ten Paint Coatings

CUSTOMER: Jerry Curran/ASRC-20

3. FOREWORD

Customer requested hypergol compatibility testing of ten paint coatings applied on aluminum substrates.

4. PROCEDURES AND RESULTS

Hypergol ignition testing for casual contact per MTB-175-88 (Wiltech). All coatings except Fast Clad HB passed the acceptance criteria for ignition hazard. See page 2 for test results.

PRIMARY INVESTIGATOR: ______________________________
Rupert Lee/YA-F2-T

TEST: Potential for Hypergolic Ignition

TEST METHOD: MTB-175-88, Exothermic Reaction (Temperature Rise) and Reactivity Tests, 1 sample each, ten (10) minute exposure.

Item	Chemical	Temperature Change (°C)	Reactivity Rating	Pass/Fail
Carboxane 2000	MMH	0.9 °C@ 10 min	Not significant	Pass
	N_2H_4	1.2 °C@ 4 min	Not significant	Pass
	N_2O_4	NA	Slight to moderate	Pass
Carbothane 134 HG	MMH	0.3 °C@ 10 min	Slight to moderate	Pass
	N_2H_4	0.7 °C@ 4 min	Not significant	Pass
	N_2O_4	NA	Slight to moderate	Pass
Polysiloxane XLE	MMH	1.1 °C@ 10 min	Not significant	Pass
	N_2H_4	0.7 °C@ 2 min	Not significant	Pass
	N_2O_4	NA	Slight to moderate	Pass
Sher Cryl HPA	MMH	1.1 °C@ 10 min	Slight to moderate	Pass
	N_2H_4	0.7 °C@ 4 min	Not significant	Pass
	N_2O_4	NA	Slight to moderate	Pass
Fast Clad HB	MMH	3.2 °C@ 8 min	NA	Fail
	N_2H_4	0.9 °C@ 10 min	Not significant	Pass
	N_2O_4	NA	Not significant	Pass
Interfine 979	MMH	1.3 °C@ 4 min	Not significant	Pass
	N_2H_4	0.6 °C@ 2 min	Not significant	Pass
	N_2O_4	NA	Slight to moderate	Pass
Interfine 878	MMH	2.7 °C@ 6 min	Not significant	Pass
	N_2H_4	1.6 °C@ 8 min	Not significant	Pass
	N_2O_4	NA	Slight to moderate	Pass
Devoe Devthane 359	MMH	0.5 °C@ 4 min	Slight to moderate	Pass
	N_2H_4	1.2 °C@ 4 min	Not significant	Pass
	N_2O_4	NA	Slight to moderate	Pass
Kimetsan D45	MMH	1.1 °C@ 10 min	Not significant	Pass
	N_2H_4	0.9 °C@ 2 min	Not significant	Pass
	N_2O_4	NA	Slight to moderate	Pass
PSX 1001	MMH	0.4 °C@ 4 min	Not significant	Pass
	N_2H_4	0.4 °C@ 2 min	Not significant	Pass
	N_2O_4	NA	Slight to moderate	Pass

Note: Temperature rise is not measured in N_2O_4 due to evaporative cooling effect.

SAFETY ACCEPTANCE CRITERIA:

Four reactivity ratings: Not significant (no visible change), Slight to moderate, Significant (complete dissolution or unsuitable for intended use), and Ignition. The first two are considered acceptable. Significant will be weighed by the customer. Ignition is unacceptable.

A material shall exhibit a temperature rise no greater than 2.8 °C when exposed to liquid N_2H_4, MMH, UDMH or AEROZINE-50.

There shall be no penetration through the material when exposed to liquid N_2O_4, N_2H_4, MMH, UDMH or AEROZINE-50.

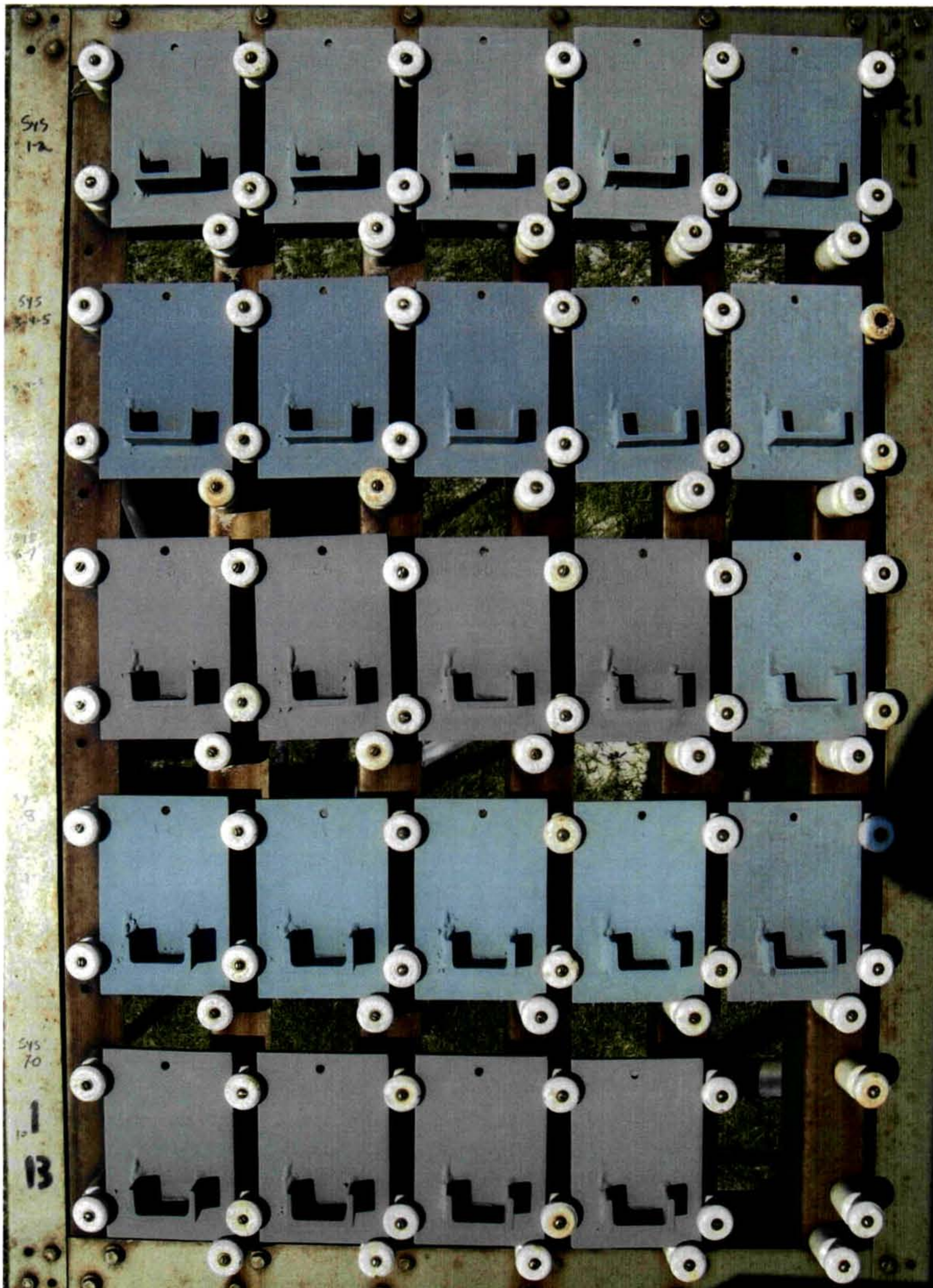
APPENDIX J

Beach Exposure Test Rack Layout Diagrams and Photographs

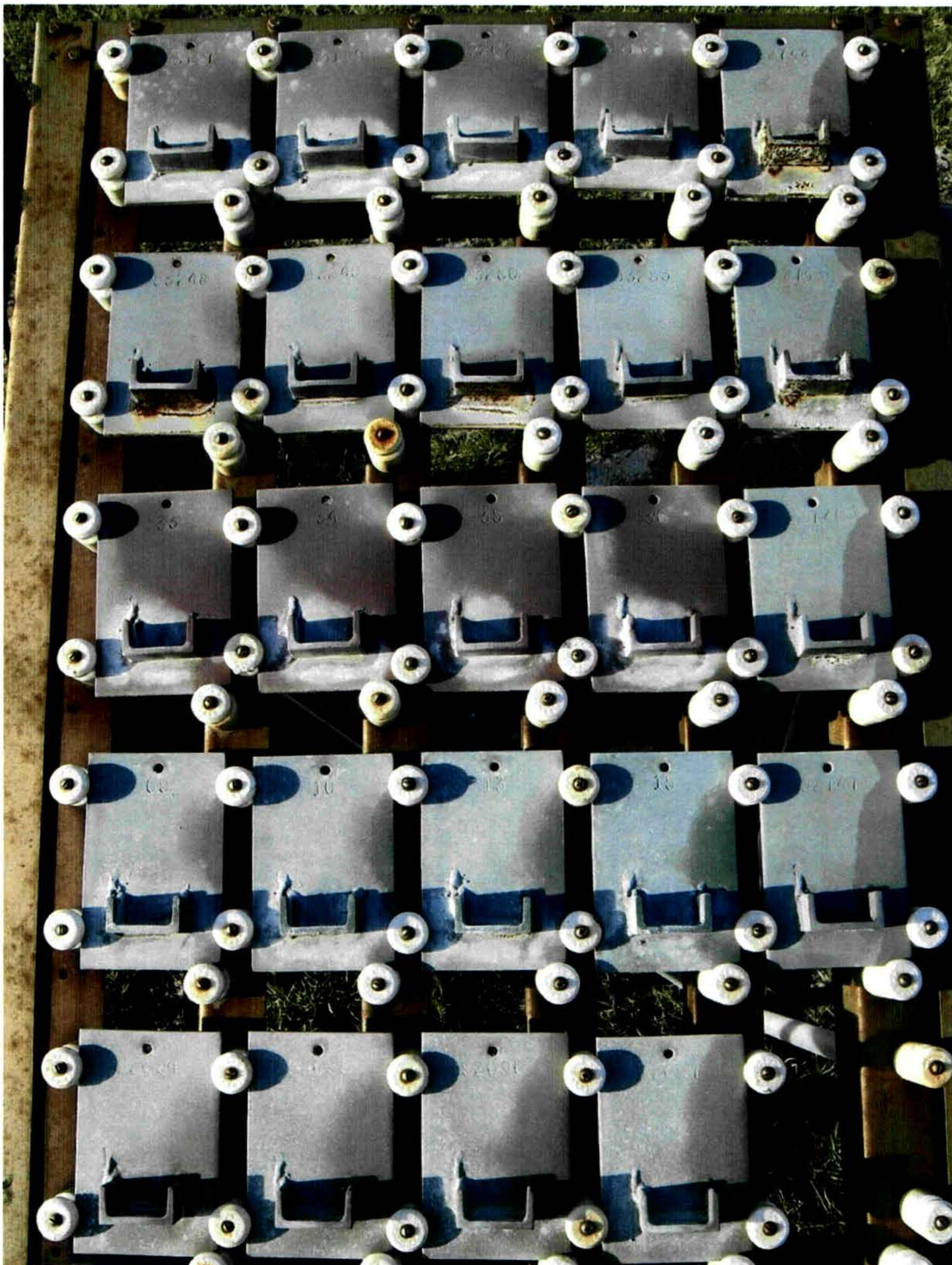
STUDY: Iso-Free Coatings RACK #:1-B DATE: 4/20/05 EXPOSURE: Normal (Zinc Only)

	A	B	C	D	E
5	93197 SYS 1-2	93199 SYS 1-2	93202 SYS 1-2	93203 SYS 1-2	92744 SYS 3-4-5
4	93248 SYS 3-4-5	93249 SYS 3-4-5	93250 SYS 3-4-5	93253 SYS 3-4-5	92745 SYS 3-4-5
3	33 SYS 6-7	34 SYS 6-7	35 SYS 6-7	36 SYS 6-7	92746 SYS 3-4-5
2	09 SYS 8	10 SYS 8	13 SYS 8	15 SYS 8	92747 SYS 3-4-5
1	92694 SYS 10	92695 SYS 10	92696 SYS 10	92697 SYS 10	EMPTY

Initial Condition



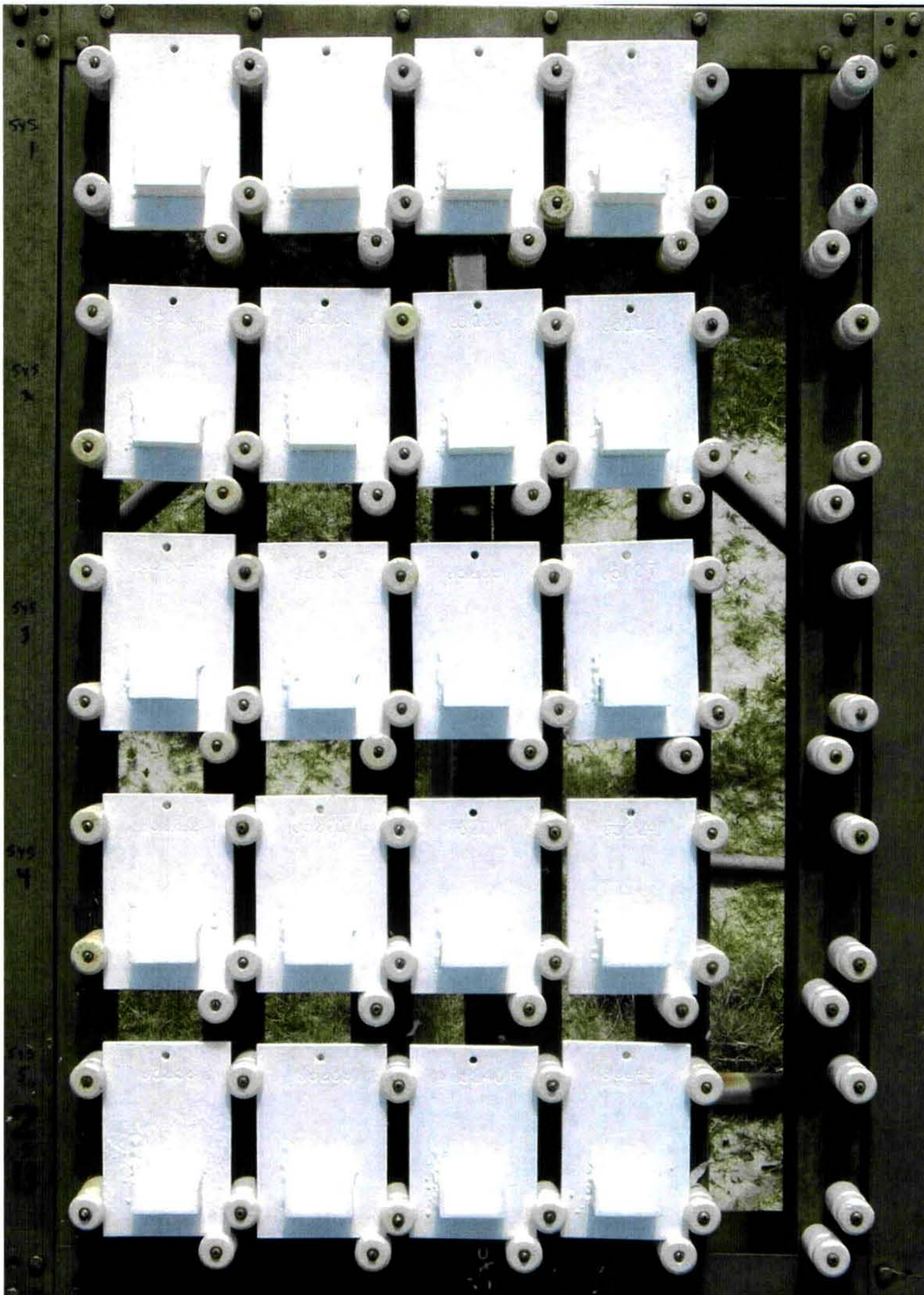
18-Month Exposure



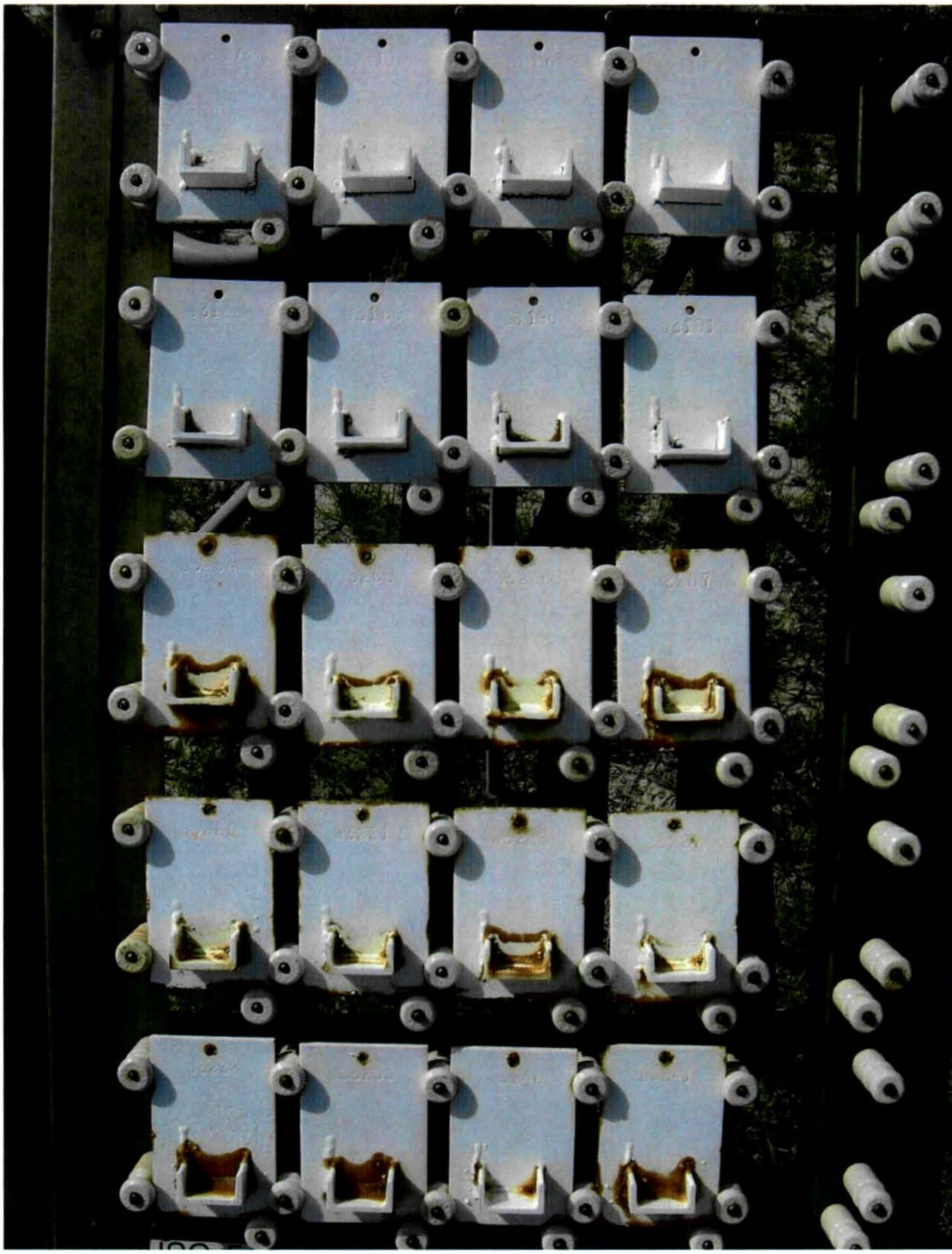
STUDY: Iso-Free Coatings RACK #:2-B DATE: 4/20/05 EXPOSURE: Normal

	A	B	C	D	E
5	93174 SYS 1	93175 SYS 1	93176 SYS 1	93177 SYS 1	EMPTY
4	93188 SYS 2	93189 SYS 2	93190 SYS 2	93191 SYS 2	EMPTY
3	93204 SYS 3	93205 SYS 3	93206 SYS 3	93207 SYS 3	EMPTY
2	93220 SYS 4	93221 SYS 4	93222 SYS 4	93224 SYS 4	EMPTY
1	93238 SYS 5	93239 SYS 5	93240 SYS 5	93241 SYS 5	EMPTY

Initial Condition



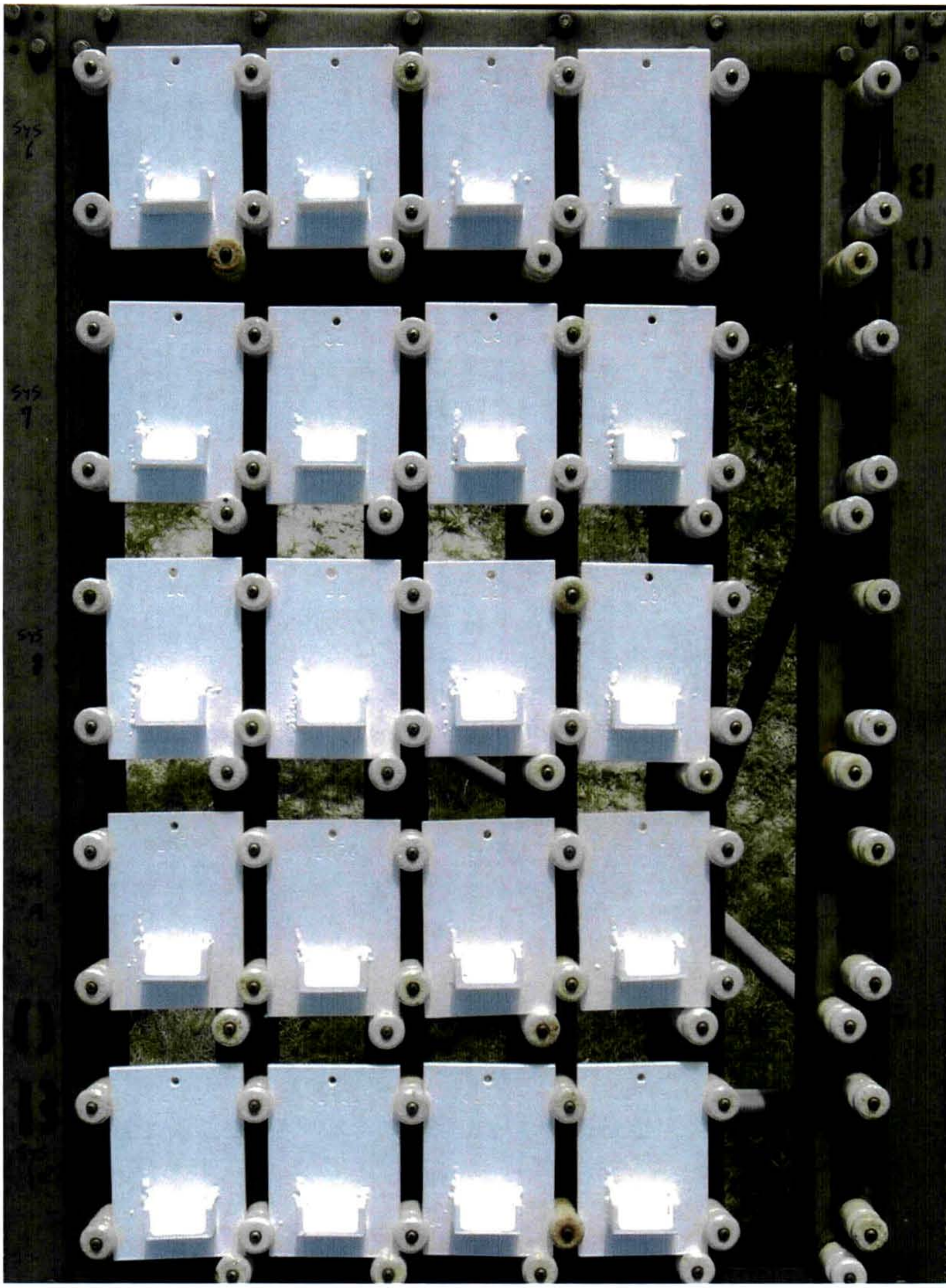
18-Month Exposure



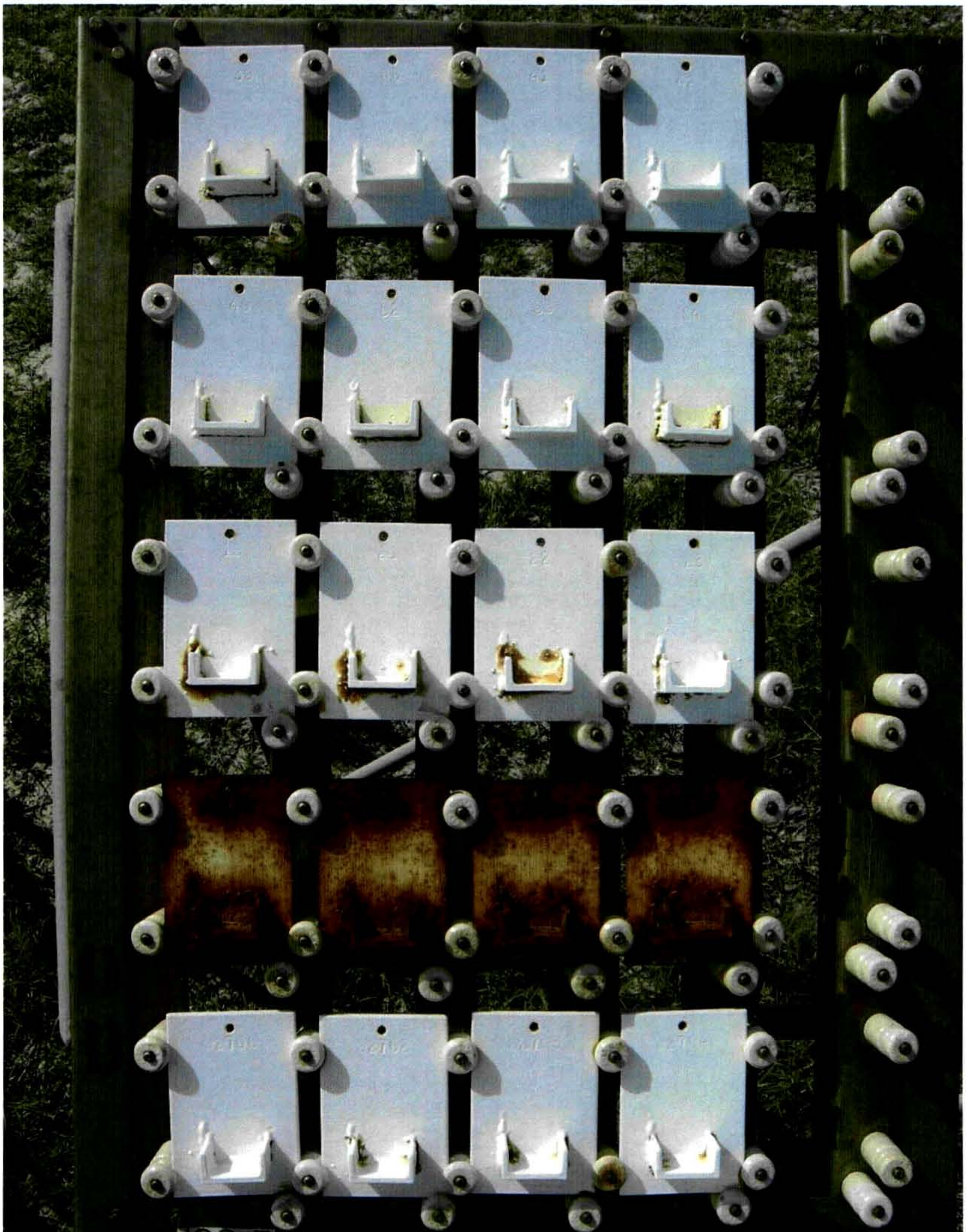
STUDY: Iso-Free Coatings RACK #:0-B DATE: 4/20/05 EXPOSURE: Normal

	A	B	C	D	E
5	39 SYS 6	40 SYS 6	41 SYS 6	42 SYS 6	EMPTY
4	49 SYS 7	52 SYS 7	53 SYS 7	54 SYS 7	EMPTY
3	19 SYS 8	21 SYS 8	22 SYS 8	23 SYS 8	EMPTY
2	93677 SYS 9	93678 SYS 9	93679 SYS 9	93684 SYS 9	EMPTY
1	92700 SYS 10	92702 SYS 10	92703 SYS 10	92704 SYS 10	EMPTY

Initial Condition



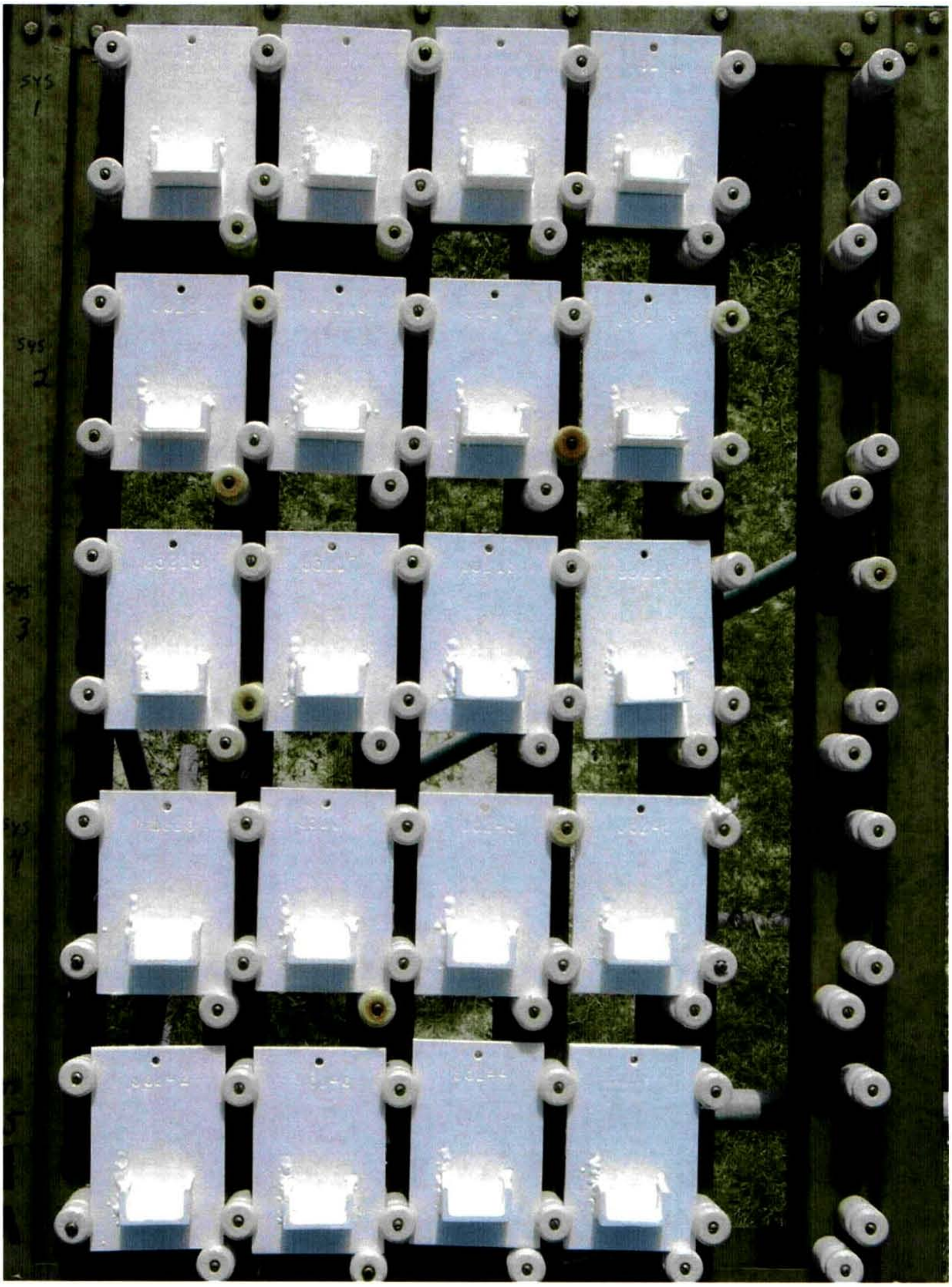
18-Month Exposure



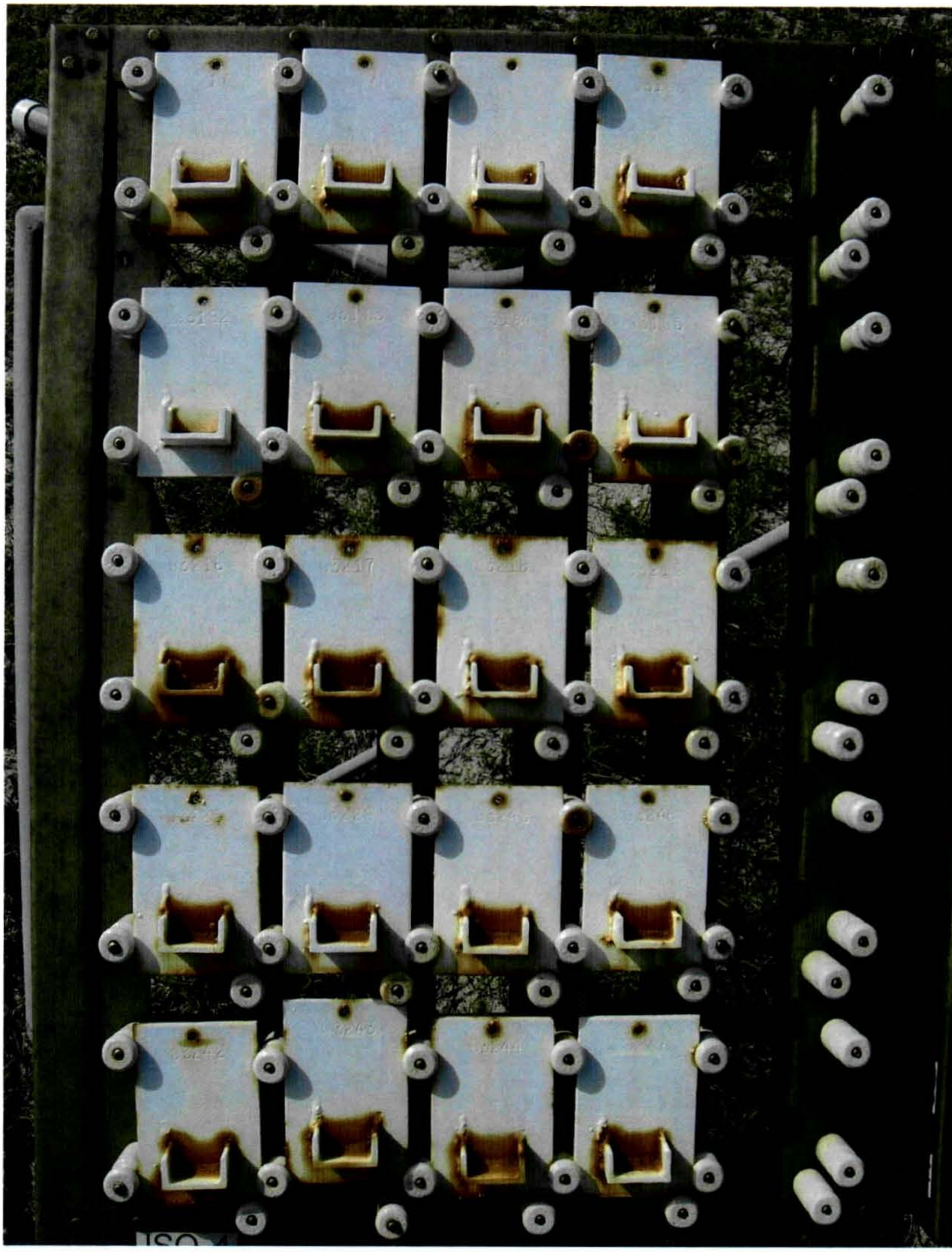
STUDY: Iso-Free Coatings RACK #:1-A DATE: 4/20/05 EXPOSURE: Acid

	A	B	C	D	E
5	93178 SYS 1	93179 SYS 1	93180 SYS 1	93185 SYS 1	EMPTY
4	93192 SYS 2	93193 SYS 2	93194 SYS 2	93195 SYS 2	EMPTY
3	93216 SYS 3	93217 SYS 3	93218 SYS 3	93219 SYS 3	EMPTY
2	93225 SYS 4	93229 SYS 4	93245 SYS 4	93246 SYS 4	EMPTY
1	93242 SYS 5	93243 SYS 5	93244 SYS 5	93247 SYS 5	EMPTY

Initial Condition



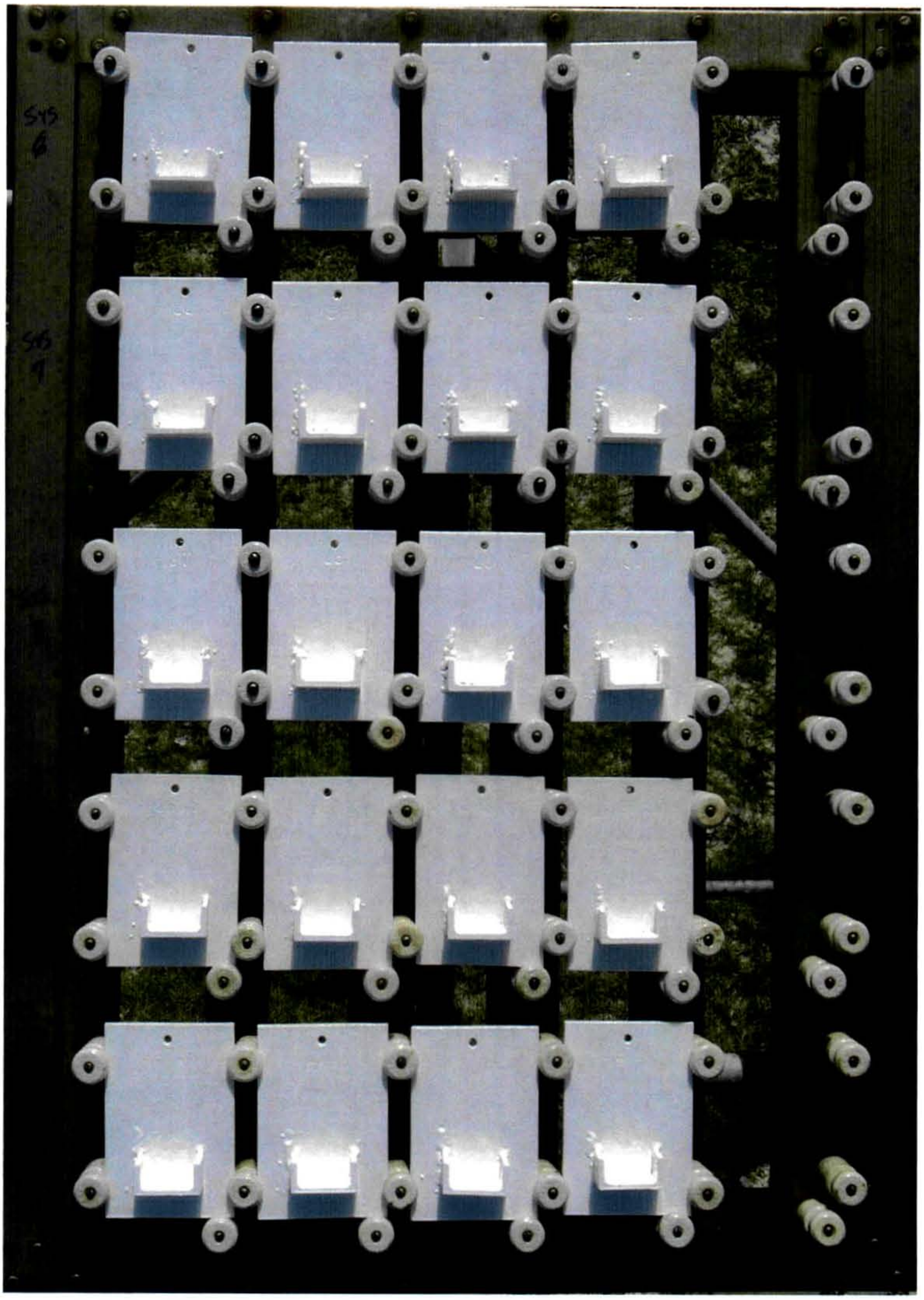
18-Month Exposure



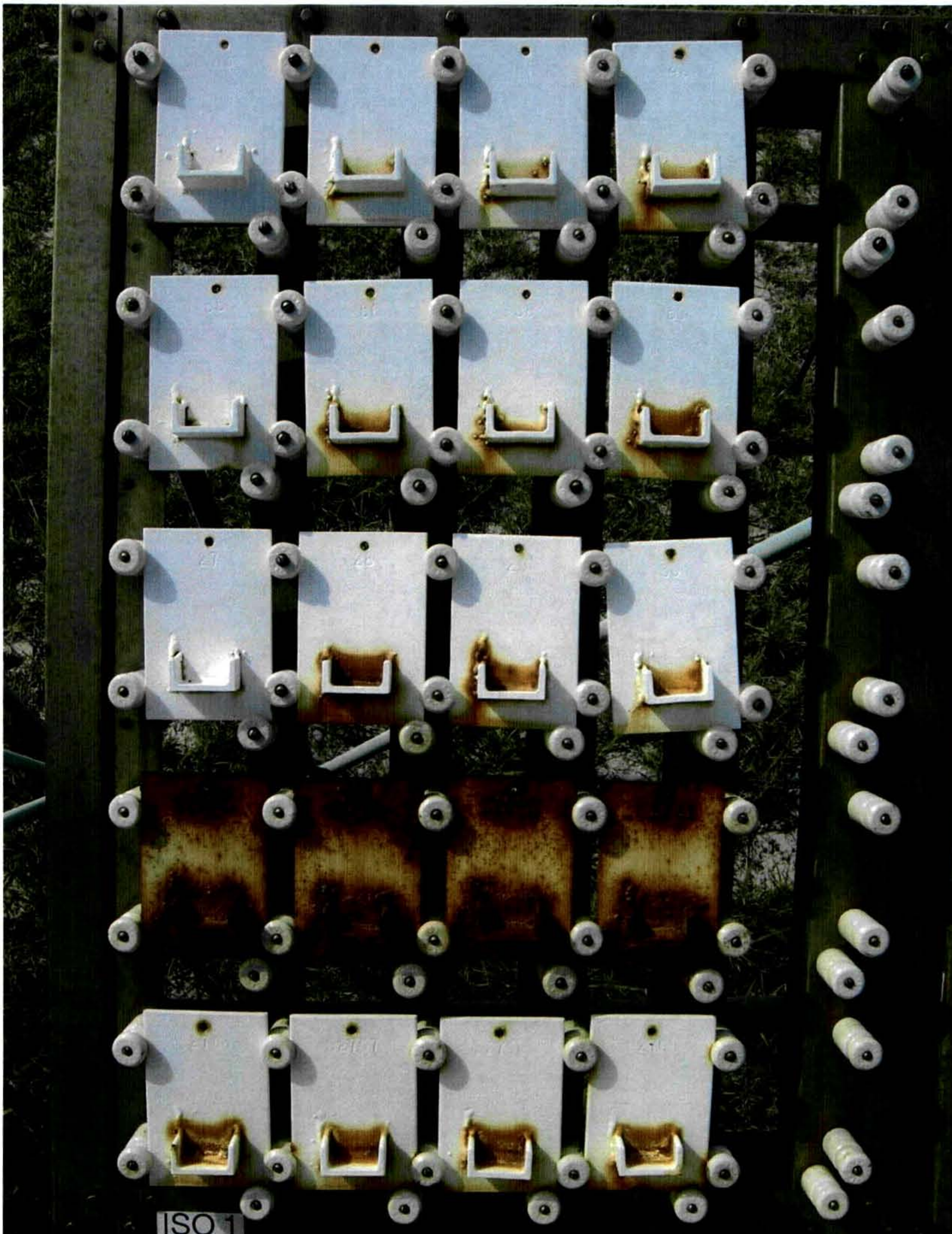
STUDY: Iso-Free Coatings RACK #:2-A DATE: 4/20/05 EXPOSURE: Acid

	A	B	C	D	E
5	43 SYS 6	44 SYS 6	45 SYS 6	46 SYS 6	EMPTY
4	55 SYS 7	56 SYS 7	58 SYS 7	59 SYS 7	EMPTY
3	27 SYS 8	28 SYS 8	29 SYS 8	30 SYS 8	EMPTY
2	92685 SYS 9	92689 SYS 9	92690 SYS 9	93257 SYS 9	EMPTY
1	92706 SYS 10	92707 SYS 10	92708 SYS 10	92709 SYS 10	EMPTY

Initial Condition



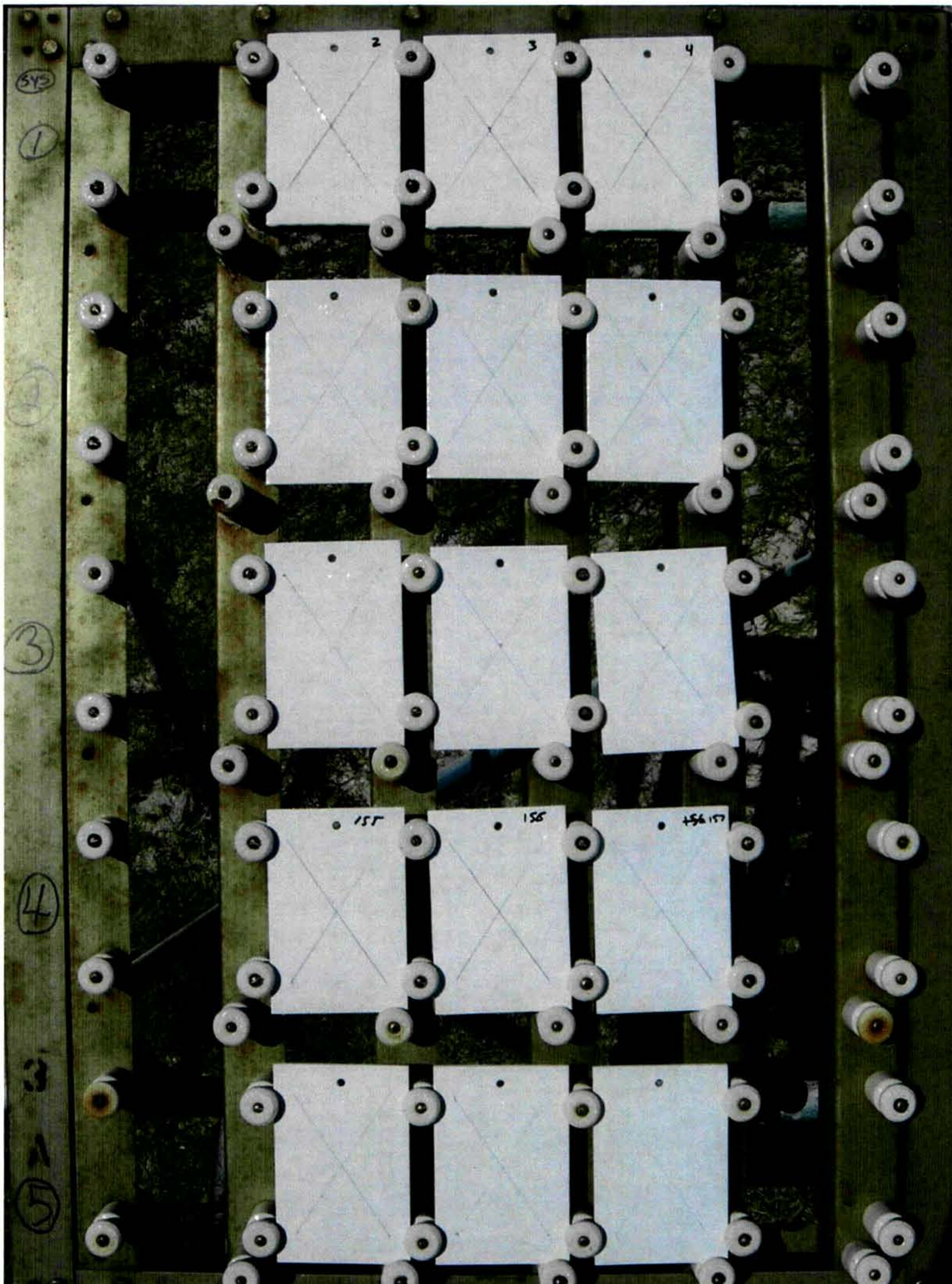
18-Month Exposure



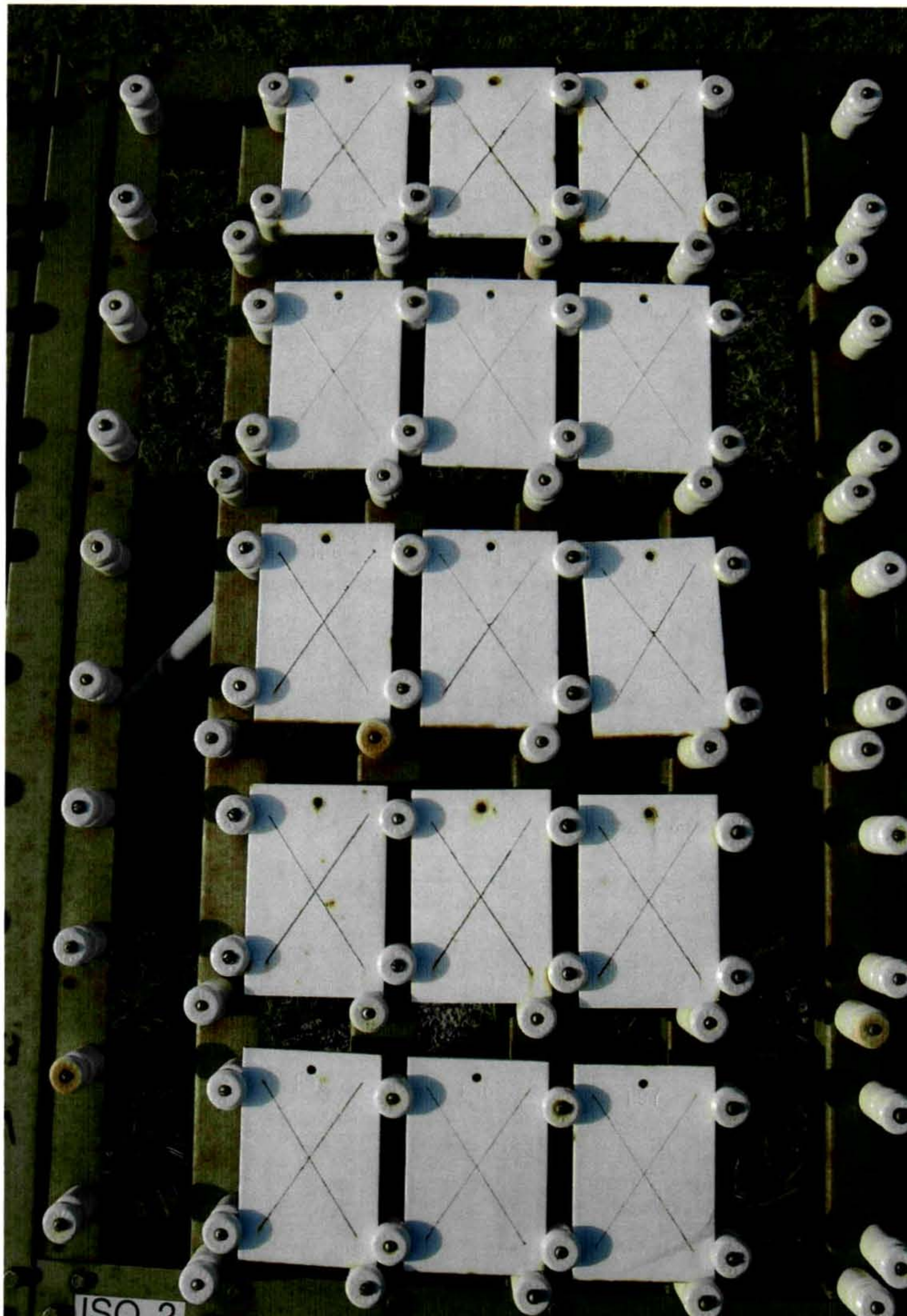
STUDY: Iso-Free Coatings RACK #:3-A DATE: 4/20/05 EXPOSURE: Normal- Scribe

	A	B	C	D	E
5	EMPTY	2 SYS 1	3 SYS 1	4 SYS 1	EMPTY
4	EMPTY	82 SYS 2	83 SYS 2	84 SYS 2	EMPTY
3	EMPTY	120 SYS 3	121 SYS 3	122 SYS 3	EMPTY
2	EMPTY	155 SYS 4	156 SYS 4	157 SYS 4	EMPTY
1	EMPTY	195 SYS 5	196 SYS 5	197 SYS 5	EMPTY

Initial Condition



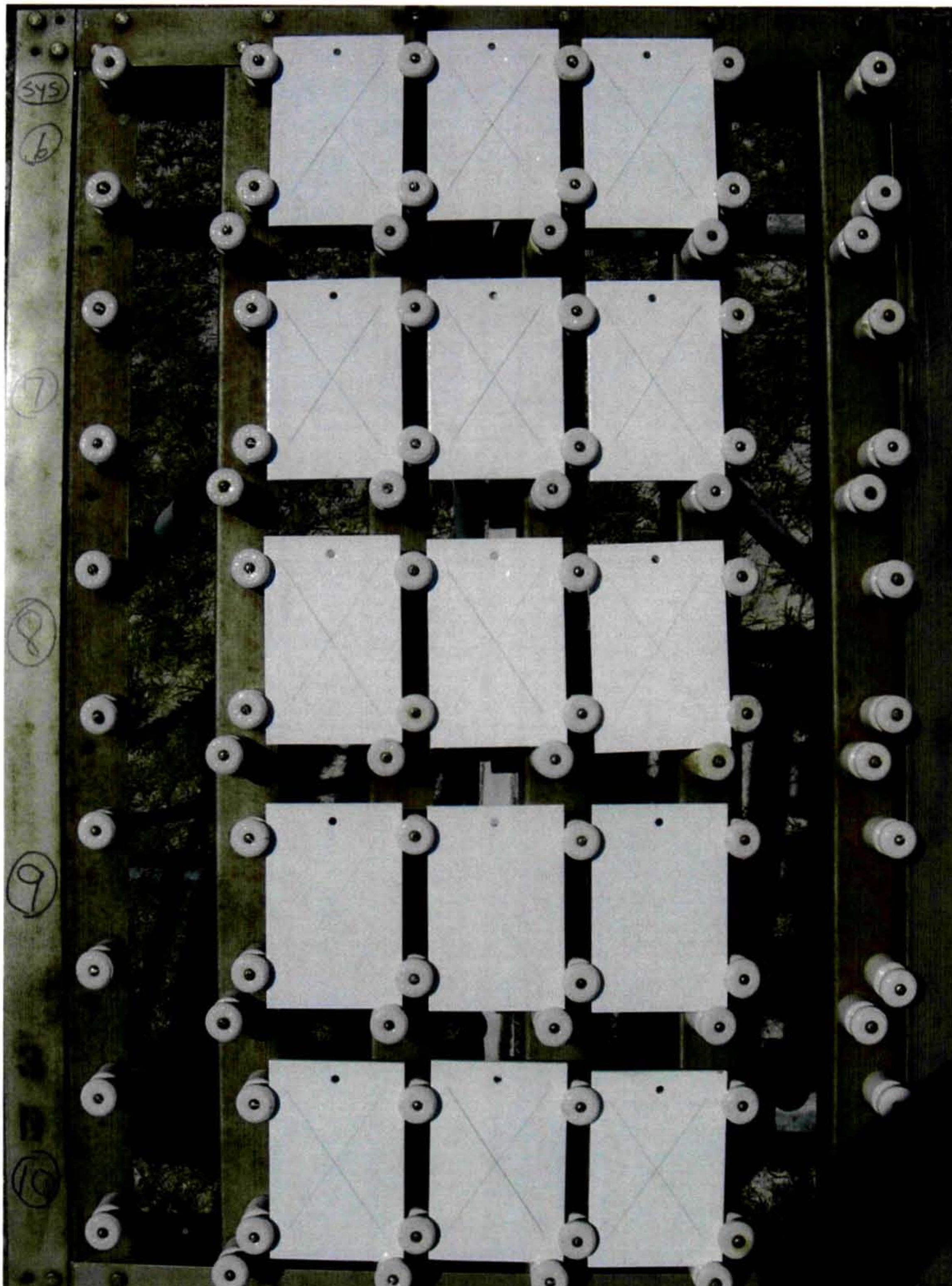
18-Month Exposure



STUDY: Iso-Free Coatings RACK #:3-B DATE: 4/20/05 EXPOSURE: Normal- Scribe

	A	B	C	D	E
5	EMPTY	257 SYS 6	258 SYS 6	259 SYS 6	EMPTY
4	EMPTY	292 SYS 7	293 SYS 7	294 SYS 7	EMPTY
3	EMPTY	332 SYS 8	333 SYS 8	334 SYS 8	EMPTY
2	EMPTY	379 SYS 9	380 SYS 9	382 SYS 9	EMPTY
1	EMPTY	419 SYS 10	420 SYS 10	421 SYS 10	EMPTY

Initial Condition



18-Month Exposure