FINAL REPORT

Joint DoD Demonstration and Validation of Magnesium-Rich Primer Coating Technology

ESTCP Project WP-0731

Dr. Craig J. Price
Rachel M. Naumann
Elizabeth A. Shell
Naval Air Systems Command

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Commander
Attn: Code 434, Bldg. 2188
NAVAIRSYSCOMHQ
47123 Buse Road
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14. ABSTRACT
The relative performance of the Mg-rich primer, as compared to control coatings, is highly variable depending on the pretreatment. In some instances, the Mg-rich primer out-performs both the non-chromate and the chromate controls. However, over military-qualified pretreatments, the Mg-rich is not as good as the control coatings. In addition, poor performance was observed when the Mg-rich was tested without a topcoat. Also, relatively poor performance was observed in acidic salt fog, similar to that seen in early Mg-rich primer testing in the early 1970's. The ultimate goal is to produce a commercial non-chromate product that exceeds the performance of the currently qualified non-chromate primers regardless of surface preparation. While improvements to the Mg-rich primer over the past several years have led to increased performance, the Mg-rich primers still fall short of this goal.

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List of Acronyms and Symbols

AA.......................................Aluminum Alloy
AFB....................................Air Force Base
AFRL ....Air Force Research Laboratory
ANAC ....AkzoNobel Aerospace Coatings
AQMD ....Air Quality Management Districts
ASTM ....American Society for Testing and Materials
CCC....................................Chromate Conversion Coating
Cl..Class
CRES..................................Corrosion Resistant Steel
CFR ....Code of Federal Regulations
COTS ....Commercial-Off-The-Shelf
CPVC ....Critical Pigment Volume Concentration
CTIO ....Coatings Technology Integration Office
DFAR.................................Defense Federal Acquisition Regulations
DFT ....Dry Film Thickness
DI ....Deionized
DoD....................................Department of Defense
ESOH ....Environmental, Safety, and Occupational Health
EO ....Executive Order
EPA ....Environmental Protection Agency
ESTCP................................Environmental Security Technology Certification Program
HAFB.................................Hill Air Force Base, Ogden UT
HazMat...............................Hazardous Materials
HVLP ....High Volume Low Pressure
JTP ....Joint Test Protocol
KSC....................................Kennedy Space Center
LP-CRADA........................Limited Purpose Cooperative Research and Development Agreement
MEK...................................Methyl Ethyl Ketone
MgRP ....Magnesium-Rich Primer
MIL-PRF............................Military Performance Specification
MSDS.................................Material Safety Data Sheet
NADC ....Naval Air Development Center
NAVAIR............................Naval Air Systems Command
NAWC-AD ....Naval Air Warfare Center-Aircraft Division
NCAP.................................Non-Chromate Aluminum Pretreatment
NDSU.................................North Dakota State University
OSHA.................................Occupational Safety and Health Administration
PEL ....Permissible Exposure Limit
PI..Principal Investigator
POC....................................Point of Contact
PPE.....................................Personal Protective Equipment
ppm ....Parts per Million
RCRA.................................Resource Conservation and Recovery Act
SCE ....Standard Calomel Electrode

TCP ....Trivalent Chromium Pretreatment
TWA ....Time Weighted Average
Ty ....Type
UDRI...................................University of Dayton Research Institute
USAF ....United States Air Force
USCG..................................United States Coast Guard

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In addition, we would like to thank Joel Johnson and Mike Spicer from AFRL for initiating this project and for coordinating testing done at AFRL. Patrick Adams at AkzoNobel Aerospace Coatings provided the commercial Mg-rich versions presented in this report.

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Executive Summary

There has been a newfound interest in magnesium-rich primers, and the possibility that they may be viable replacements for primers that contain hexavalent chromium. The magnesium-rich primer functions via a galvanic mechanism to protect aluminum substrates from corrosion – akin to the protection offered to steel substrates by zinc-rich primers. Extensive testing prior to this project, and throughout its execution, have led to several iterative improvements to the formulation and marked increase in the corrosion performance. While these improvements have increased the performance of the magnesium-rich primer such that they perform better than other non-hexavalent chromium primers and even hexavalent chromium primers in certain situations, they are not equivalent across the board. Accordingly, since the performance of the magnesium-rich primer was not shown to be equivalent to currently-qualified hexavalent chromium alternatives, the demonstration/validation portion of this project was canceled.

Therefore, a key performance objective of this project – product testing – was not met. The performance objectives of "commercial-off-the-shelf procurement" and "ease of use" were met successfully. Since no field demonstrations were performed, the "hazardous material reduction" objective was not tested.

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1.0 INTRODUCTION

1.1 Background

Hexavalent chromium has long been an indispensable component of corrosion-preventing coating systems. Although hexavalent chromium compounds (chromates) offer outstanding corrosion protection, they are known carcinogens and an Environmental Protection Agency (EPA) priority pollutant [1]. The Occupational Safety and Health Administration (OSHA) recently lowered the acceptable exposure limits for chromates [2], and as a result, they are a major source of exposure to hazardous chemicals and their use has increasingly been discouraged. In addition, an April 2009 Under Secretary of Defense Memorandum strongly urged the Department of Defense to reduce the use of hexavalent chromium [3] and recent changes to the Defense Federal Acquisition Regulations (DFAR)[4] state that contractors must receive specific permission from the Contracting Officer if their deliverables contain hexavalent chromium.

Aerospace and Department of Defense (DoD) personnel currently use primers to enhance the corrosion resistance and paint adhesion performance of aluminum substrates. These coatings typically contain hexavalent chromium compounds in the corrosion-prevention scheme. The risk of worker exposure to these carcinogenic chemicals, the potential liabilities due to accidental leaks to the environment, and waste disposal issues are making the use of chromate-based primers cost prohibitive. Some users have already banned or severely limited the use of these materials at their facilities and on their platforms [5]. Lower permissible exposure limits (PELs) for chromate species will make it very difficult for users to meet exposure regulations – especially during corrosion maintenance and de-paint operations – in a cost-effective manner. A few viable primers without hexavalent chromium are available commercially; however they do not prevent corrosion as well as their chromate counterparts.

Although research and development into non-chromate technologies by academia, industry, and government laboratories has progressed appreciably over the past fifteen years, the lack of an effective benign replacement has resulted in the continued use of chromates. Many of these alternatives still rely upon the presence of chromium (III) or (VI) somewhere in the total coating system (i.e., either the primer or surface treatment). Furthermore, none of these systems to date have matched or outperformed the corrosion protection capabilities of the current chromate conversion coating (CCC)/strontium chromate pigmented primer combinations used on most aluminum structures. The use of metal-rich primer technology seeks to provide a fully non-chromate protection system that meets or exceeds these goals.

Similar to the use of zinc rich primers for steel substrates, these metal-rich primers offer sacrificial corrosion protection whereby the metal particles in the coating are oxidized preferentially to the substrate. These coatings are typically formulated such that the metal particles are in good electrical contact with each other and with the surface to be protected. In particular, the use of magnesium-rich (Mg-rich) primers for the protection of aluminum substrates has enjoyed a recent resurgence [6]. The overall performance of the Mg-rich primer is comparable in some respects to other non-chromate systems. However, some deficiencies have been noted that must be remedied before the Mg-rich primer can become widely used. Recent attempts to improve the performance of the Mg-rich primer have failed to match the performance of the other non-chromate primers.

This project was originally proposed by the Air Force Research Lab (AFRL) and awarded in 2007, with the stated purpose to paint aircraft and conduct field demonstration and validation testing of the Mg-rich primer by the fall of 2008. However, early lab testing showed decreased performance of the Mg-rich and the field trial was delayed indefinitely until the performance could be improved. In 2009, the original principal investigator was no longer available to lead the project, and cognizance for the project was transferred to the Naval Air Systems Command (NAVAIR) Naval Air Warfare Center – Aircraft Division (NAWC-AD). NAWC-AD did not believe that the performance of the currently-available Mg-rich products warranted field trials and therefore, directed the remaining project funds towards improving the formulation.

1.2 Objective of the Demonstration

The objective of this project was to evaluate and demonstrate novel non-chromium, Mg-rich primers that are environmentally friendly and potentially have higher performance compared to legacy non-chromium primers. The ultimate technical goal of this project was to validate performance of the proposed coating system during depot level rework, while demonstrating environmental and life cycle cost benefits of the technology.

Hexavalent chromium compounds, which are toxic and carcinogenic, were targeted to be reduced or eliminated in this project. A reduction or elimination of hexavalent chromium would allow compliance with federal, state, and local regulations while drastically reducing user liability and risk in the life cycle of the platform or parts being coated. Table 1 summarizes the target hazardous materials (HazMat), current processes, applications, and specifications, affected programs, and candidate parts/substrates.

Table 1: Target Hazardous Material Summary

Target Hazmat	Current Process	Applications	Current Specifications	Affected Programs	Candidate Parts and Substrates
Chromium (VI) compounds (chromates)	HVLP spraying; conventional spraying;	Aluminum alloy and steel finishing	MIL-PRF-23377; MIL-PRF-85582	**USAF:** C-130, F-15 **Army:** H-60 **Marine Corps:** C-130 **Navy:** H-53, H-60, V-22, P-3, P-8, F/A-18 **USCG:** HH-60	Any aluminum, or aluminum alloy part or substrate requiring enhanced corrosion resistance

The main challenge for any non-chromate primer is matching the technical performance of chromate primers in a cost-effective manner. Evaluation of laboratory coupon testing (Phase I) results showed that the Mg-rich primer did not perform as well as other non-chromate primers. Top laboratory performing alternatives were to have been applied at user facilities to user-defined test platform or parts (Phase II). The coatings were to undergo field testing at each demonstration facility based on the needs of the user. However, Phase II of the project was canceled in light of poor laboratory performance of the Mg-rich primer.

1.3 Regulatory Drivers

Hexavalent chromium emissions are controlled by federal agencies like the Environmental Protection Agency (EPA) and by state and local environmental agencies such as the California Air Quality Management Districts (AQMD). These agencies classify hexavalent chromium as hazardous and restrict emissions through local rules as well as regulations such as the Clean Air Act, the Clean Water Act, and the Resource Conservation and Recovery Act (RCRA). In addition, Department of Defense directives [3] and Executive Orders (EOs) [7] call for a reduction in the amount of hazardous waste generated at government facilities and direct reductions in the use of HazMat whenever feasible. Recent changes to the DFAR [4] force contractors to receive specific permission before delivering a product that contains more that 0.1% hexavalent chromium.

In February 2006, OSHA reduced the permissible exposure limit (PEL) for chromates an order of magnitude from 52 $\mu g/m^3$ to 5 $\mu g/m^3$ as an 8 hour time weighted average (TWA). There is an exception to this rule for aerospace applications, where a PEL of 25 $\mu g/m^3$ is allowed in paint hangers. The significant health risks posed from occupational exposure to hexavalent chromium originally led OSHA to propose a PEL reduction to 1 $\mu g/m^3$. However, it was concluded the lowest PEL that was both economically and technically feasible for compliance was 5 $\mu g/m^3$ and personal protective equipment (PPE) is required to ensure no worker is exposed to more than this level of chromates.

Due to current environmental and health issues associated with hexavalent chromium based primers, there is a need to develop an innovative and cost effective replacement technology that addresses the multiple health, safety, and compliance issues associated with the current systems while maintaining military readiness for national defense. The replacement of hexavalent chromium-based primer coatings at the users' facilities with less toxic compositions will strongly support compliance with federal, state, and local laws and regulations as well as directly support DoD and other government directives to reduce the use of hazardous materials.

2.0 DEMONSTRATION TECHNOLOGY

2.1 Technology Description

Over the past several years, much effort has been focused on finding viable alternatives to chromates for the coatings industry due to federal, state and local environmental agencies calling for a reduction of hexavalent chromium. Naval Aviation, as well as the Air Force, Army Aviation and US Coast Guard (USCG), are interested in replacing primers based on hexavalent chromium, such as those currently qualified to MIL-PRF-23377 or MIL-PRF-85582, with new primer coatings that contain environmentally-preferred materials. Although significant progress has been made in implementing high-performance solutions for corrosion prevention, a major technology gap still exists for transition of non-chromium primer and paint materials to use in the field.

Several alternatives have been investigated, but unfortunately, none have possessed the technical performance of the chromate coatings. One approach is to employ a sacrificial metal-rich primer in the overall protection scheme, like the use of zinc-rich coatings for steel substrates to provide galvanic corrosion protection. In galvanic protection systems, the metal in the coating acts as an anode (more negative electrical potential) and oxidizes preferentially to the substrate. The substrate acts as a cathode (more positive electrical potential), and is protected from corrosion at the sacrifice of the anodic metal in the coating. Magnesium is more anodic than aluminum and its alloys in the galvanic series (Figure 1), thereby giving it the ability to cathodically protect aluminum substrates. When Mg-rich primers are formulated, small particles of magnesium metal are added at, or even beyond, the critical pigment volume concentration (CPVC). The high loading of the magnesium particles ensures that nearly all of the metal particles are in electrical contact with each other and with the substrate. The electrical contact of metal particles is a key requirement in this corrosion protection mechanism, establishing the anode/cathode relationship described above (Figure 2)[a]. If successful, the Mg-rich primer could serve as a drop-in replacement for current chromate primers.

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a. Figure 2 shows a conversion coating in the overall coating system stack-up. Some users believe that a conversion coating is not necessary or even degrades the performance of the Mg-Rich primer. However, it is included in this schematic because NAVAIR testing has always shown better performance with a chemical conversion coating or anodized pretreatment, compared to other surface pretreatments or no pretreatment at all. See Section 6.4 below.

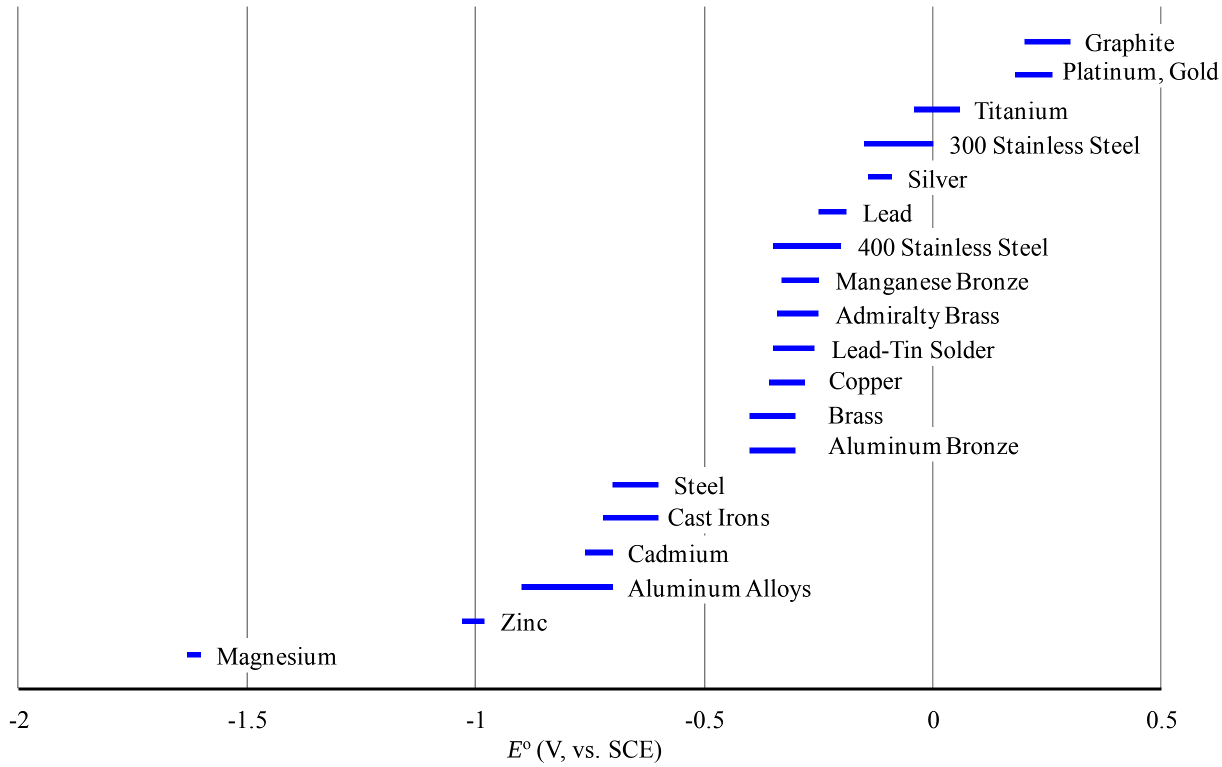


Figure 1: The electrochemical series versus the standard calomel electrode (SCE).

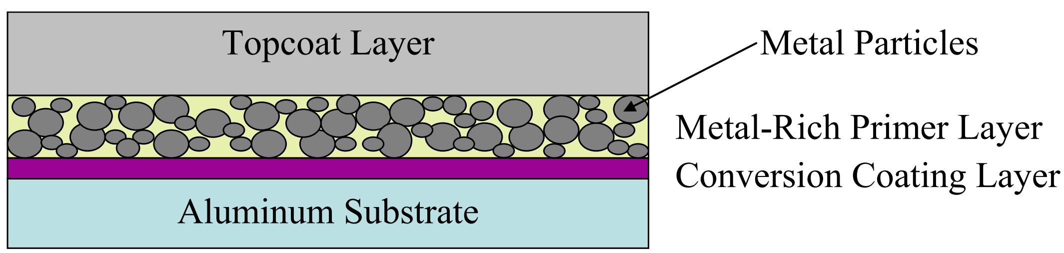


Figure 2: A schematic of metal rich primers over an aluminum substrate.

2.2 Technology Development

Mg-rich primers were studied by the Navy in the early 1970's [8], but were abandoned due to poor performance when not protected by a topcoat, especially in acidic salt fog testing. However, they have enjoyed a recent resurgence thanks to researchers at NDSU [6]. AkzoNobel Aerospace Coatings (ANAC) licensed the NDSU technology and has worked to improve the coating, eventually leading to a commercial version of the primer. An overview of the recent developments with Mg-rich primers is provided in Table 2.

Table 2: Recent Mg-Rich Chronology

2004	NDSU developed prototype formulation • Used 100+ μm Mg particles and a five component resin system • Performed well in B 117 and cyclic salt spray testing • ANAC licensed technology • Worked to address surface roughness, compliance, and usability issues
2005-2007	ANAC produced several experimental formulations (XP-406 and XP-417) • Used smaller Mg particle size, optimized pigment volume concentration • Lowered VOC levels • Improved flexibility with new resin system
2007-2008	ANAC produced Aerodur® 2100 MgRP • Included orange pigment for contrast ratio, suspected of lowering corrosion performance
2008-2009	Re-baseline reformulation due to ESTCP lab results • ANAC produced Aerodur® 2100 MgRP 002
2009-present	Improved corrosion performance, ESTCP-funded field testing delayed indefinitely • ANAC produced Aerodur® 2100 MgRP 003

Early experimental versions from ANAC were tested at the Air Force Research Lab (AFRL) and the Naval Air Systems Command (NAVAIR) in 2006. ANAC's first experimental version of the primer, XP-406, began testing at NAVAIR while ANAC was working to reformulate the primer based on early AFRL results. The second generation experimental primer, XP-417, was also tested extensively at both DoD labs with outdoor exposures, standard American Society of Testing and Materials (ASTM) test procedures and military specification test protocols.

The XP-406 performed well in several tests. Figure 3 shows the primer on aluminum alloy (AA) 2024 after a 4000 hour exposure to ASTM B 117 neutral salt fog. There is very little corrosion product on the panels, regardless of pretreatment (for a description of pretreatment procedures, please see Section 5.3 on page 28). However, when tested to failure on AA 2219, clear differences were seen with pretreatment (Figure 4). Hexavalent chromium pretreatment performed the best, followed by trivalent chromium pretreatment (TCP), with the panel that did not receive any chemical pretreatment performing the worst.

MIL-DTL-81706 Type I – Hexavalent Chromium (Alodine 1200S) | No Chemical Pretreatment (Scotch Brite Abraded) | MIL-DTL-81706 Type II – Trivalent Chromium (Alodine T5900)

Figure 3: XP-406 on AA 2024, without a topcoat, after 4000 hrs. ASTM B 117.

MIL-DTL-81706 Type I – Hexavalent Chromium | No Chemical Pretreatment | MIL-DTL-81706 Type II – Trivalent Chromium

Figure 4: XP-406 on AA 2219 without a topcoat after 4000 hrs. ASTM B 117 neutral salt fog.

When exposed to acidic salt fog per ASTM G 85, Annex 4 the performance of the Mg-rich primer was lower. ASTM G 85 acidic salt fog calls for periodic injection of SO_2 gas into the test chamber and more closely mimics the environment aboard an aircraft carrier. After exposure to acidic salt fog for 1200 hours, the coating was buckling and, in some cases, delaminating from the panel completely (Figure 5). However, during outdoor exposure, the XP-406 exhibited “self corrosion” whereby the magnesium particles in the coating corrode away, leaving the panel protected only by the conversion coating. Figure 6 shows a test panel after 8 months exposure at the Kennedy Space Center (KSC) site (see page 26 for a description of the KSC site). The magnesium in the coating is starting to self corrode, and the shiny aluminum test panel is visible over portions of the sample. Originally, it was hypothesized that since these primers are not formulated to withstand exposure to UV light, that the UV may have caused the polymer matrix to degrade, thereby causing the magnesium particles to be physically released from the coating. However, chromate and non-chromate control primers that employ almost identical resin systems did not exhibit the same effect.

MIL-DTL-81706 Type I – Hexavalent Chromium (Alodine 1200S)

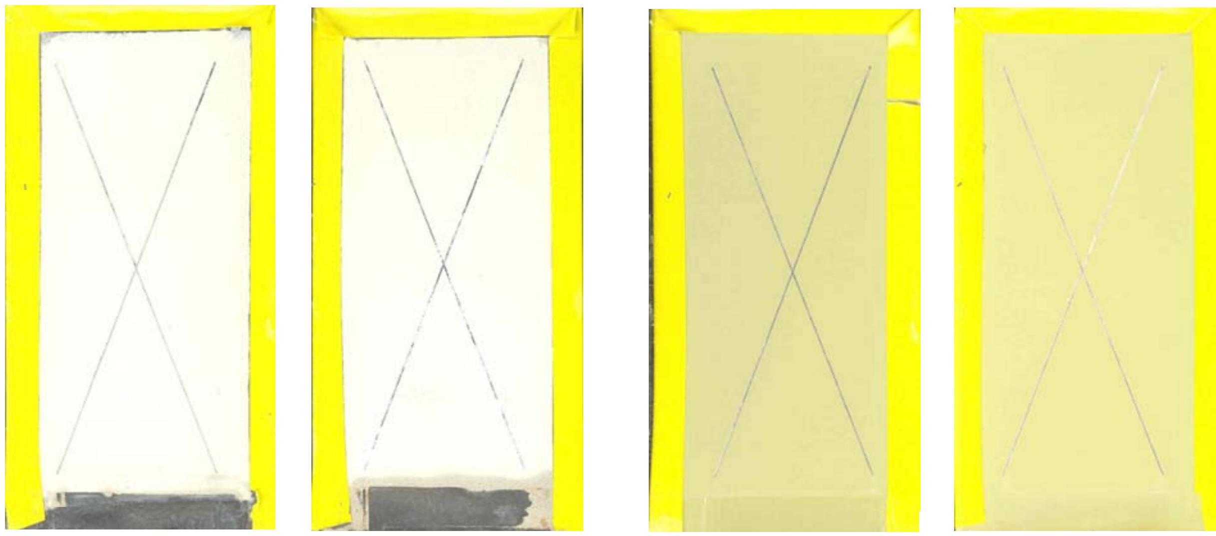
No Chemical Pretreatment (Scotch Brite Abraded)

MIL-DTL-81706 Type II – Trivalent Chromium (Alodine T5900)

Figure 5: XP-406 on AA 2024, without a topcoat, after 1200 hrs. ASTM G 85 acidic salt fog.

Figure 6: XP-406 on AA 2024 without a topcoat after 8 months exposure at KSC.

The second generation XP-417 also performed very well in neutral salt fog testing on multiple aluminum alloys. Again, there is very little corrosion product visible on either AA 2024 or 7075 after 5000 hours (Figure 7). The Mg-rich primer performs well compared to the chromate primer at this exposure length to ASTM B 117. In addition, the XP-417 outperformed chromate controls in filiform corrosion tests (Figure 8). However, like the XP-406, the XP-417 had problems with acidic salt fog testing. Large ruptures through the coating were first observed beginning at 675 hours exposure and they grew in size throughout the test (Figure 9). After testing, the coating was stripped from the panels to check for substrate damage. Figure 10 shows large pits in the aluminum substrate directly under the coating ruptures.



AA2024-T3 AA7075-T6 AA2024-T3 AA7075-T6

Mg-Rich Primer

MIL-PRF-23377, Class C2
Hexavalent Chromium Primer

Figure 7: XP-417 and chromate controls without a topcoat after 5000 hrs. ASTM B 117.

Mg-Rich Primer

MIL-PRF-23377 Class C2
Hexavalent Chromium Primer

Figure 8: XP-417 and chromate control after filiform corrosion testing per ASTM D 2803.

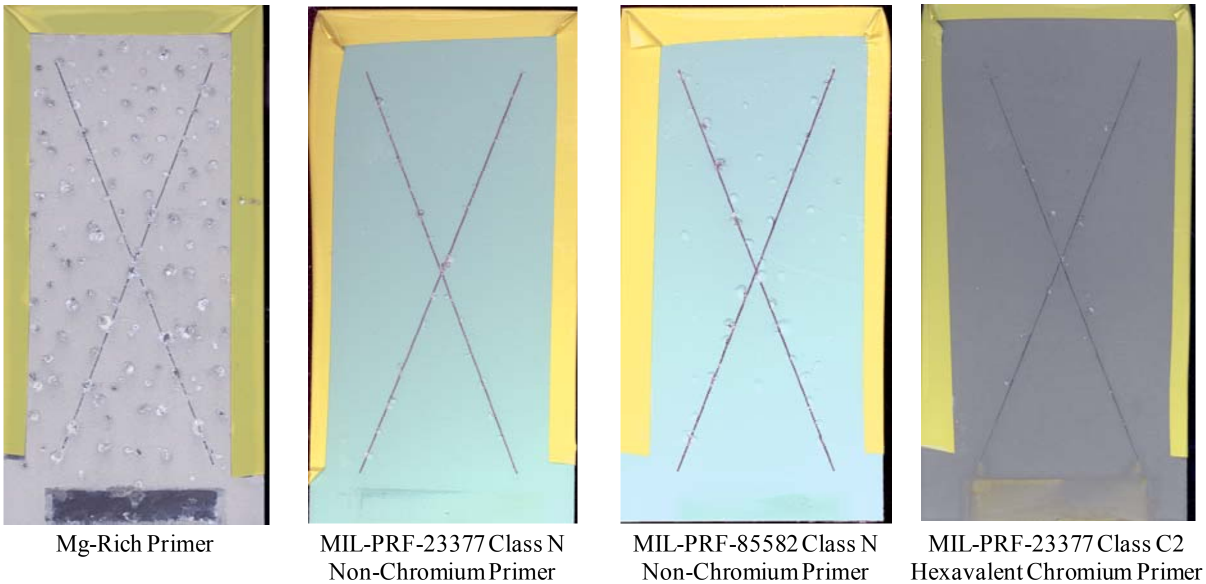


Figure 9: The XP-417 and other control coatings on AA 7075-T6 after 1500 hrs. ASTM G 85.

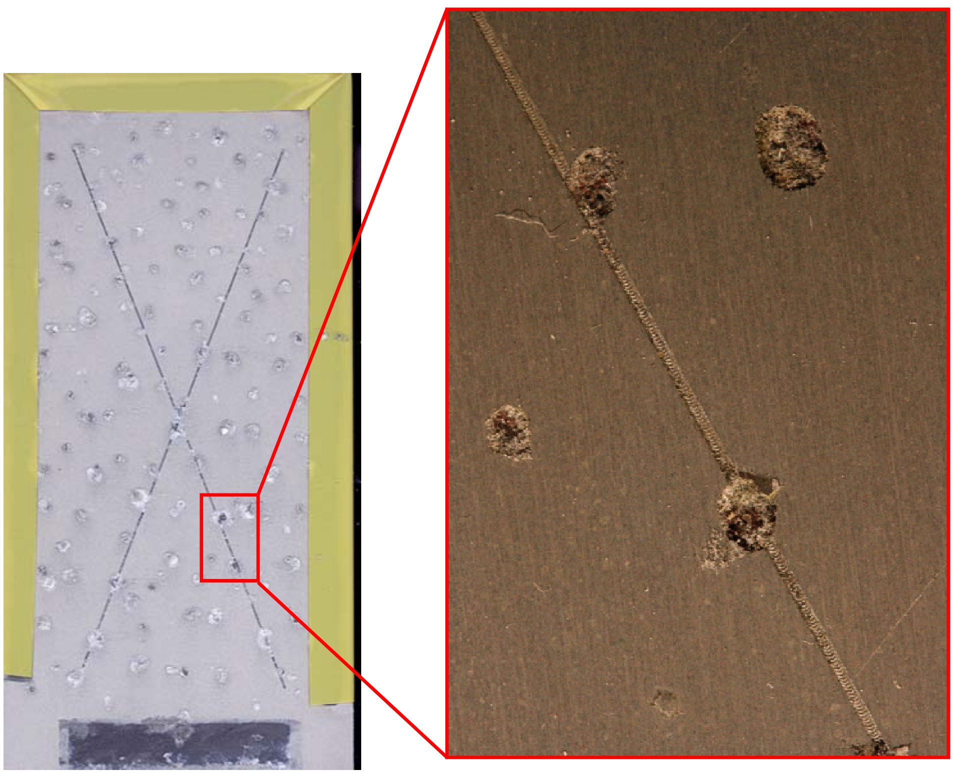
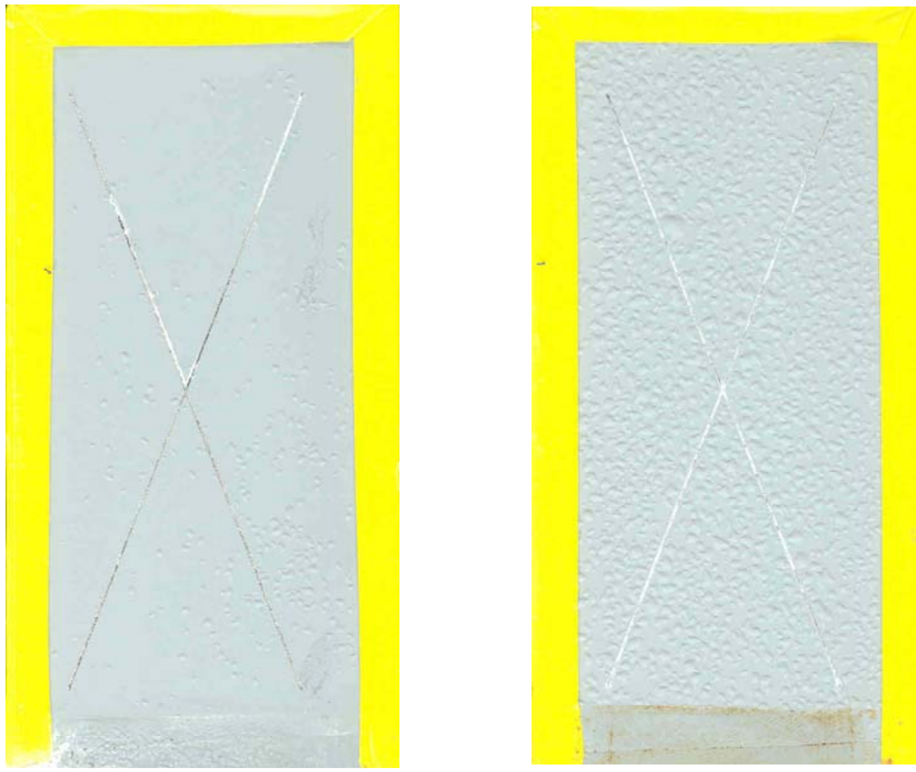


Figure 10: A close-up view of the panel shown in Figure 9 after removal of the coating.

In addition, the XP-417 showed decreased performance when topcoated. This is typical of metal-rich primers, as the added barrier of the topcoat slows down water penetration into the primer. This, in turn, slows dissolution and subsequent migration of the corrosion inhibitor to the damage site. However, this mechanism only applies to traditional corrosion inhibitors and cannot explain why the Mg-rich shows degraded performance when topcoated. Recent work [9] has focused on the added resistance of the topcoat, which then degrades the electrical performance of the entire coating system and decreases the ability of the system to protect the underlying substrate. Figure 11 and Figure 12 show the XP-417 Mg-rich primer after 2000 hours and 5000 hours exposure to ASTM B 117 neutral salt fog. After 2000 hours – the exposure required by the applicable specifications – the coating is performing well on AA 2024. However, the AA 7075 panel has white corrosion products filling the scribe and undercutting is beginning at the scribe line. At 5000 hours of exposure, both test panels are covered in small blisters, although the AA 7075 is affected significantly more. Again, the panels are stripped to evaluate the substrate under the coating. These panels exhibit general surface corrosion under the blistered coating, particularly directly under each individual blister (Figure 13).

AA2024-T3 AA7075-T6

Figure 11: XP-417 with a topcoat after 2000 hrs. ASTM B 117 neutral salt fog.



AA2024-T3 AA7075-T6

Figure 12: XP-417 with a topcoat after 5000 hrs. ASTM B 117 neutral salt fog.

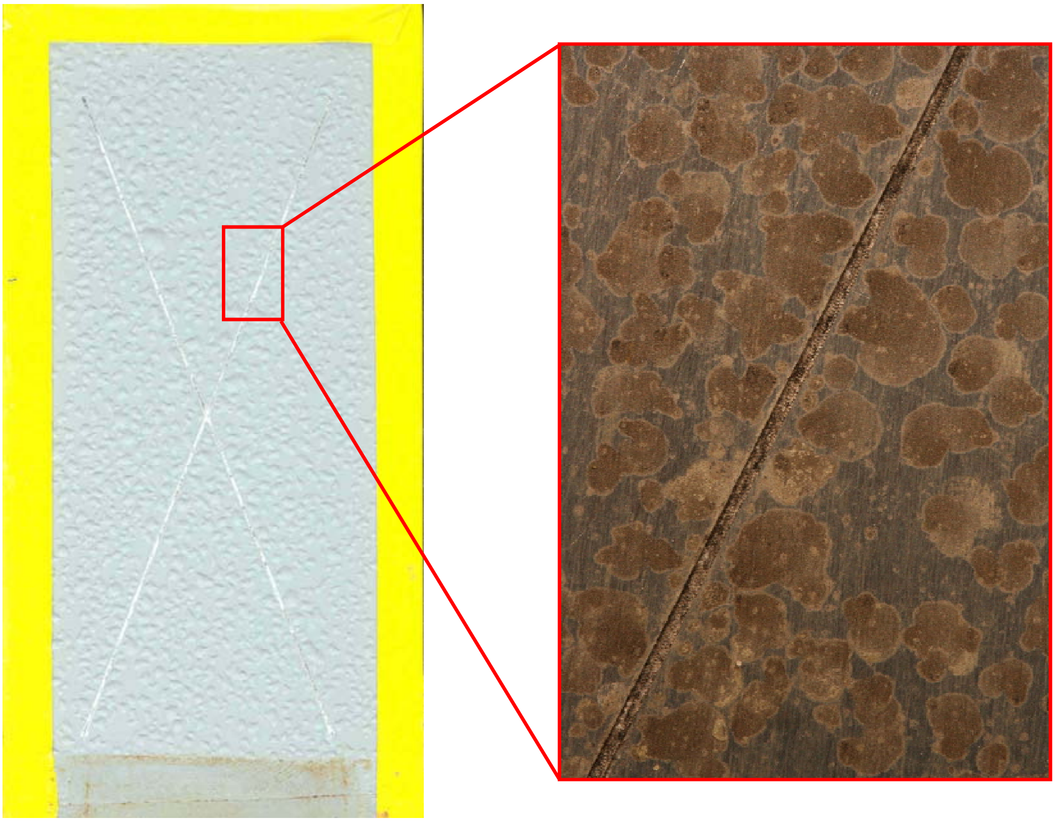


Figure 13: A close up view of the AA 7075 panel in Figure 12 after coating removal.

The XP-417 was also subjected to wet tape adhesion tests. The coatings were immersed in deionized (DI) water at room temperature for 1 day, 120 °F for four days or 150 °F for seven days. As observed with the XP-406, all XP-417 panels passed the tests, although the panels darkened with longer exposures to water. Figure 14 shows the results for primer only panels.

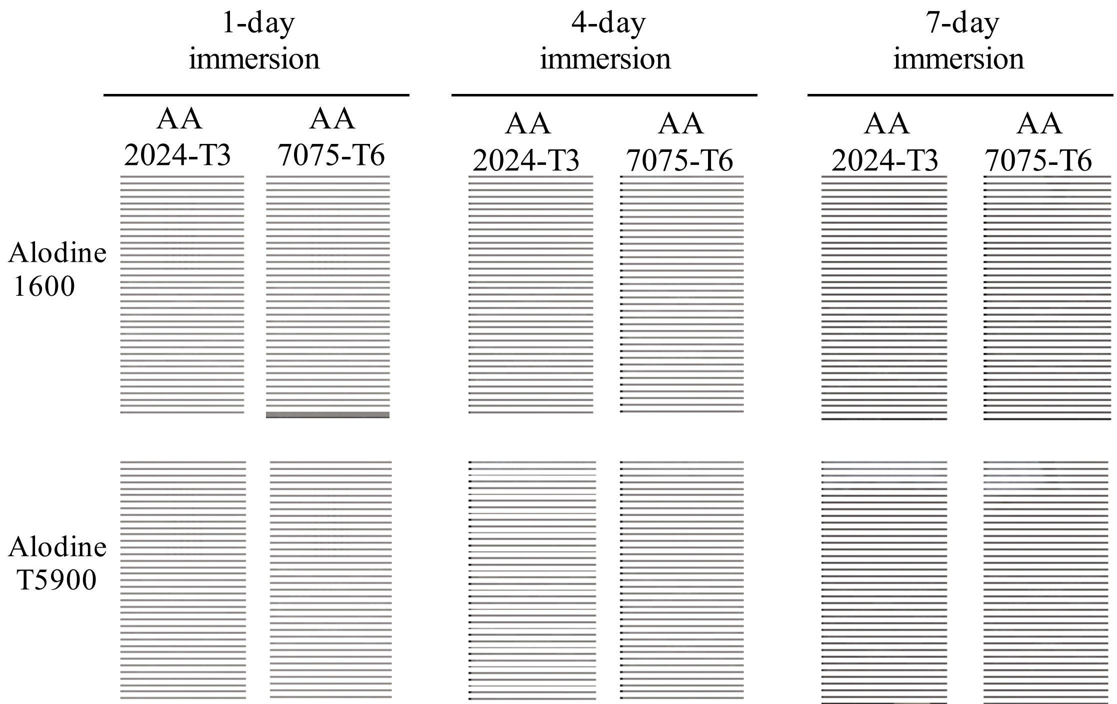


Figure 14: XP-417 wet tape adhesion tests panels.

In addition, galvanic test panels were used to assess the XP-417. These panels are AA 2024 with three sets of bolts through the panel – titanium (alloy TiAl6V4), 316 corrosion resistant stainless steel (CRES), and aluminum from left to right – designed to more accurately simulate galvanic interfaces found in actual aircraft structures. The panels were tested at the KSC outdoor exposure site for 4 months. After that exposure, the XP-417 was showing early signs of self-corrosion (Figure 15) similar to what was observed on the XP-406 flat panels. The non-chromate control primer shows some minor undercutting at the CRES bolts, but the coating was otherwise intact.

Figure 15: XP-417 and non-chromate control galvanic test panels without a topcoat after 4 months outdoor exposure at KSC.

In addition, the first commercial version of the Mg-rich primer was tested – the Aerodur 2100 MgRP. This formulation is essentially the same as the XP-417, with a yellow pigment added to aid in contrast with the grey substrate and any eventual grey topcoat. This pigment was subsequently suspected of decreasing the performance of the primer. Initial testing of the Aerodur 2100 MgRP both with and without a topcoat are shown in Figure 16 and Figure 17 respectively. When the coating was removed after testing, pits were observed near the scribe line for both test configurations.

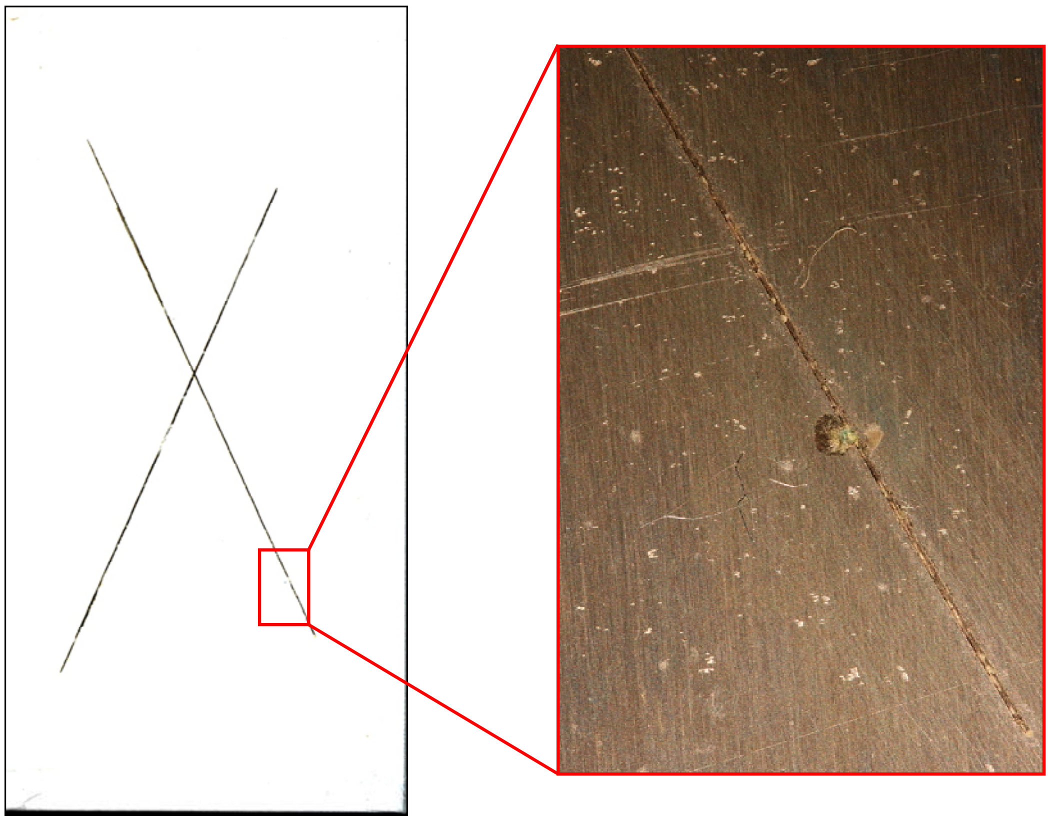


Figure 16: Aerodur 2100 MgRP with a topcoat on AA 2024 after 2000 hrs. ASTM B 117 neutral salt fog, along with a close-up view of panel after coating removal.

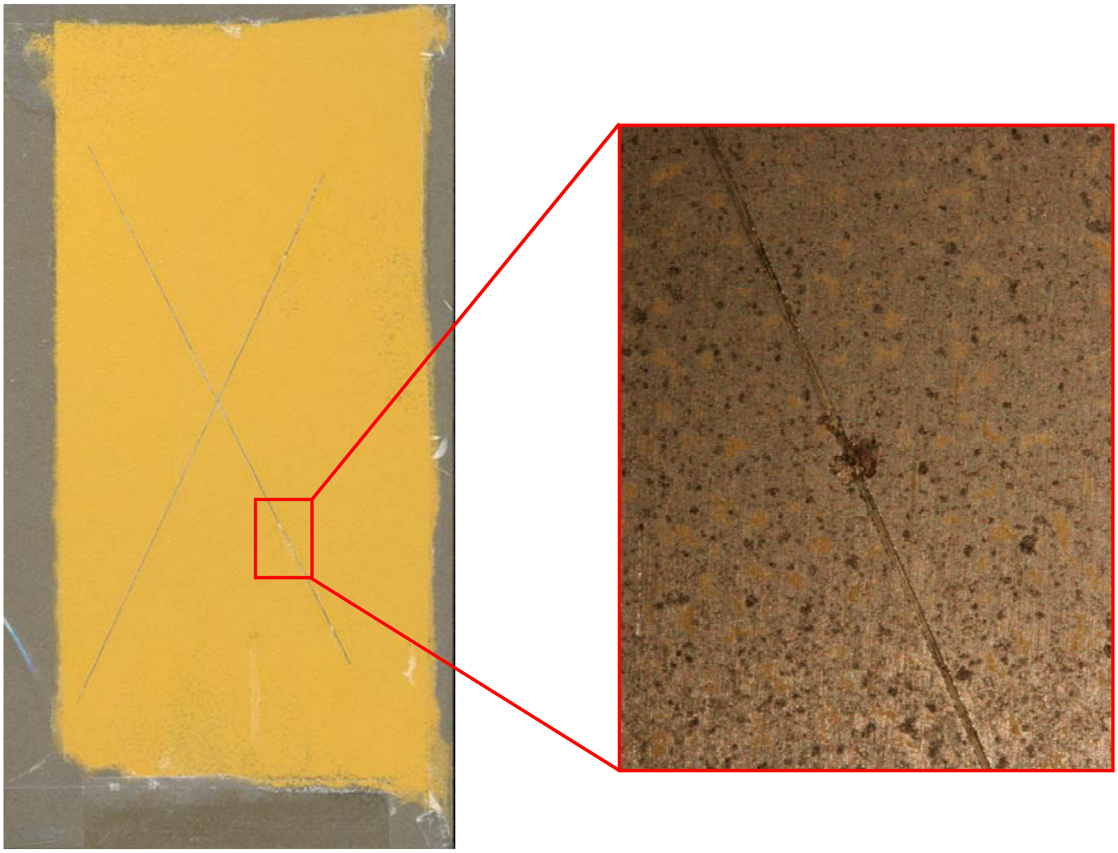


Figure 17: Aerodur 2100 MgRP primer only on AA 2024 after 2000 hrs. ASTM B 117 neutral salt fog, along with a close-up view of panel after coating removal.

2.3 Advantages and Limitation of the Technology

Magnesium rich primers have the potential to be used at any DoD facility that paints aircraft or aircraft components. Benefits of a hexavalent chromium free paint system would include the elimination of workplace hexavalent chromium exposure and the elimination of all hexavalent chromium based waste that has to be handled in a standard liquid-spray process (overspray, filters, contaminated spray equipment, etc). This has become increasingly important, as OSHA's new PEL values [2] serve to further increase the cost associated with hexavalent chromium (required PPE, waste disposal, etc.). In addition, all subsequent paint operations, such as stripping and sanding, could be performed quicker and cost much less because the coating being removed does not contain hexavalent chromium.

A key challenge of any hexavalent chromium alternative will be matching the technical performance, cost, and ease of application of conventional hexavalent chromium primers. Although there are other non-chromate primers currently qualified to MIL-PRF-23377, Class N and MIL-PRF-85582, Class N, their performance is good, but not equivalent to chromate primers. Therefore, any implementation of these Class N primers may cause a reduction in corrosion protection, depending on the aluminum alloys used, other materials in contact with the substrate (galvanic couples) and the severity of the operating environment. For the Mg-rich primer (or any new non-chromate primer) to be widely adopted, it must perform better than currently-qualified products – not simply meet the minimum requirements of the specification.

Even if the performance of the Mg-rich primer can be increased such that it is better than other qualified non-chromate primers, one key disadvantage is that it must be applied thicker than traditional primers. The thicker dry film thickness (DFT) decreases the flexibility of the coating system (possibly leading to cracks in the coating system and exposing the underlying substrate to the environment), causes an increase in coating weight and makes the coating harder to remove during de-paint operations. A detailed discussion and calculation is provided in Sections 3.2 and 6.3.1.

3.0 PERFORMANCE OBJECTIVES

3.1 Overview

Performance objectives for this demonstration are summarized in Table 3 below. Multiple products are currently qualified to Class N of the two military performance primer specifications (MIL-PRF-23377 and MIL-PRF-85582) and they have been used on DoD assets for more than five years. To be competitive and attractive from a business-case point of view, the Mg-rich primer needs to perform better than these current non-chromate coating systems with regard to all coating-related tests. In addition, the coating should reduce worker exposure to HazMat and reduce HazMat waste. Finally, the Mg-rich primer must be available in commercial quantities and it must not require any specialized equipment or skills for application.

Table 3: Performance Objectives

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives			
Product Testing -Corrosion Resistance -Paint Adhesion -Coating Weights	-MIL-PRF-23377 -ASTM B 117 -ASTM G 85 -ASTM D 2803 -ASTM D 4541	-Lab Performance: better than other non-chromate primers -Field performance: demonstration of paint primer alternative for flight testing and support vehicles	Objective Not Met
Hazardous Material -Reduction/elimination of hazardous waste -Reduce worker exposure to HazMat	-OSHA Method 215 -EPA Methods 3060A and 7199	>75% reduction from current process	N/A
COTS Procurement	Feedback from manufacturer on production capabilities	Available in production-scale quantities	Objective Met
Qualitative Performance Objectives			
Ease of Use	Feedback from field technicians on usability	-Minimal or no extra training required -No specialized equipment required	Objective Met

3.2 Product Testing

Both laboratory and field testing of the Mg-rich primer will be performed prior to any aircraft flight testing. Corrosion protection is crucial for any primer. Non-chromate primers offer lower corrosion protection than chromates, and understanding this difference is critically important. In addition, the primer should be tested in configurations that mimic how it will be used in the field. This includes both with and without a topcoat (most internal surfaces of aircraft are not topcoated), on multiple substrates, and in galvanic interfaces with dissimilar metals. Performance will be assessed after exposure to standard accelerated corrosion tests, and after outdoor exposures. Panels were rated quantitatively according to Table 4 for accelerated corrosion tests and according to Table 5 for outdoor exposures. In addition, panels coated with chromate primers and other non-chromate primers were tested beside the Mg-rich primer so that qualitative performance can be assessed.

Table 4: Three Digit Rating Scheme for Accelerated Corrosion Testing.

1st Digit Scribe Appearance		**2nd Digit Undercutting**		**3rd Digit Blistering**	
				Size	Frequency
0:	Bright and clean	0:	No lifting of coating	0: None	F: Few
1:	Staining, minor corrosion but no build up	1:	Lifting or loss of adhesion up to 1/16" (2 mm)	1: Very Small	M: Medium
2:	Minor/moderate corrosion product build up	2:	Lifting or loss of adhesion up to 1/8" (3 mm)	2: Small	MD: Med. Dense
3:	Moderate corrosion product build up	3:	Lifting or loss of adhesion up to 1/4" (7 mm)	3: Small to Medium	D: Dense
4:	Major corrosion product build up	4:	Lifting or loss of adhesion up to 1/2" (13 mm)	4: Medium to Large	
5:	Severe corrosion product build up	5:	Lifting or loss of adhesion >1/2" (>13 mm)	5: Large	

Table 5: Panel Rating Scheme for Outdoor Exposure Testing.

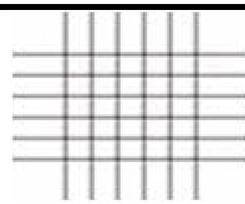
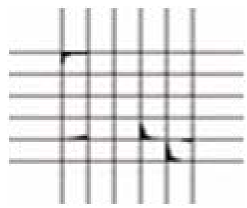
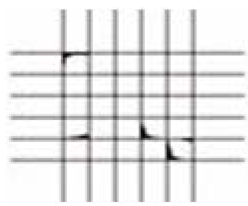
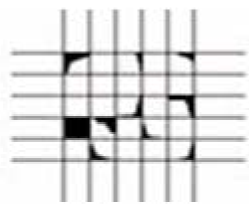
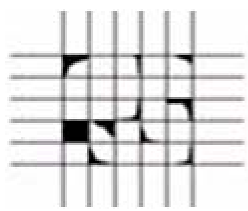
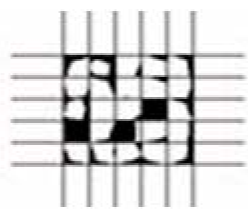
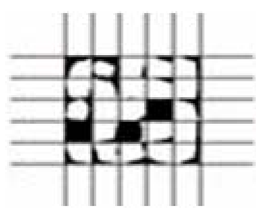
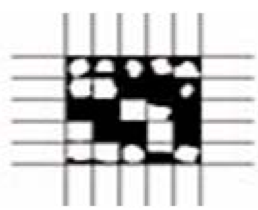
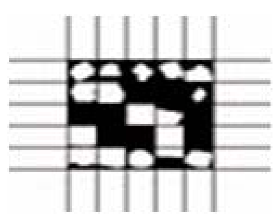
Rating	Creepage from Scribe (mm)
10:	0.0
9:	0.0 to 0.5
8:	0.5 to 1.0
7:	1.0 to 2.0
6:	2.0 to 3.0
5:	3.0 to 5.0
4:	5.0 to 7.0
3:	7.0 to 10.0
2:	10.0 to 13.0
1:	13.0 to 16.0
0:	16.0 and up

Another important function of primers is coating adhesion. Polyurethane topcoats typically do not have high adhesion to aluminum substrates, and the epoxy-based primer layer provides the adhesion for the coating system. Adhesion of the Mg-rich primer layer to the substrate and adhesion of the entire coating system was tested using a modified ASTM D 3359 wet tape adhesion procedure that provides five scribe intersection points (see MIL-PRF-23377 §4.5.4 for description, and Figure 14 above for a picture of the scribe pattern). The adhesion will be rated from 5A (best) to 0A (worst) according to Table 6. In addition, cross-hatched tape adhesion tests were performed in accordance with ASTM D 3359 and rated from 5B (best) to 0B (worst) according to Table 7. A rating of 4 or 5 is considered passing for both tests.

Table 6: Rating Scale for the Modified Wet Tape Adhesion Test

Rating	Description
5A	No peeling or removal
4A	Trace peeling or removal along scribe or at intersections
3A	Jagged removal along scribe up to 1/16" on either side
2A	Jagged removal along most of the scribe up to 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

Table 7: Rating Scale for the Cross Hatched Tape Adhesion Test

Rating	Area Removed	Visual Representation
5B	0%	
4B	<5%	
3B	5-15%	 
2B	15-35%	 
1B	35-65%	 
0B	>65%	

Finally, coating weights for typical aircraft were calculated based on the manufacturer's coating weight data. Total aircraft weight is very important – especially for rotary wing aircraft which are typically weight limited – as it affects aircraft range and impacts the weight of weapons and fuel the aircraft can carry. The coating density (in pounds per square foot per mil thickness of coating) was converted to estimated coating weights for the aircraft. The weight of the Mg-rich primer must not negatively affect the range or performance of the aircraft.

3.3 Hazardous Materials

The overarching purpose of this project is to reduce or eliminate the use of hexavalent chromium primers. Although the material data safety sheet (MSDS) for the Mg-rich primer does not list chromate, testing would have been performed during field applications to determine the levels (if any) of chromate present. OSHA Method 215 would have been used to test for airborne chromates, and EPA Methods 3060A and 7199 would have been used to test the waste stream. Chromate concentrations, in parts per million (ppm), would have been recorded before, during and after primer application. Success in this objective would have been at least a 75% reduction in the concentration of chromate when the Mg-rich primer was being used, compared to the chromate control.

3.4 Off-The-Shelf Procurement

The goal is to have a commercial off-the-shelf (COTS) product available through normal procurement procedures. This is important if the Mg-rich primer is to be widely used. Success criteria for this objective are that the product is available in large lots to support painting larger aircraft (C-130, etc.), and that it is available through normal COTS procurement procedures.

3.5 Ease of Use

To simplify implementation of the Mg-rich primer, it should be easy to use and essentially a "drop-in" replacement for current primers. It should be sprayable with currently-used high volume low pressure (HVLP) spray equipment and require no extra equipment for application. In addition, the Mg-rich primer should require only minimal personnel training for successful implementation. This performance objective will be verified by interviewing representatives from ANAC and government/contractor painters who use the product to ensure that it can be applied using current equipment and processes.

4.0 SITE AND PLATFORM DESCRIPTION

This section of the report was to provide a description of the platforms selected for demonstration of the Mg-rich primer, the current paint procedures for those aircraft and any permits that were required to demonstrate the technology. Since the Mg-rich primer is not being demonstrated through this ESCTP project, this information is not available.

5.0 TEST DESIGN

5.1 Laboratory Testing

Prior to flight testing any new coating, extensive laboratory testing is done. While a Joint Test Protocol (JTP) was not developed for this project, extensive laboratory testing was done.

Table 8 provides a summary of the laboratory test performed on the Mg-rich primer along with the applicable American Society for Testing and Materials (ASTM) test method or military performance (MIL-PRF) specification and the substrates tested.

Table 8: Laboratory Tests Performed

Test	Reference	Test Substrates
Accelerated Corrosion		
Neutral Salt Fog	ASTM B 117	flat and galvanic panels
Acidic Salt Fog	ASTM G 84, Annex 4	flat and galvanic panels
Filiform Corrosion	ASTM D 2803	flat panels
Working Properties		
Viscosity and Pot Life	ASTM D 1200	admixed liquid coating
Application	MIL-PRF-23377, §4.5.11.2	admixed liquid coating
Stripability	MIL-PRF-23377, §4.5.13	Flat panels
Operational Properties		
Solvent Resistance (Cure)	MIL-PRF-23377, §4.5.9	flat panels
Fluid Resistance	MIL-PRF-23377, §4.5.10	flat panels
Water Resistance	MIL-PRF-23377, §4.5.7	flat panels
Flexibility	MIL-PRF-23377, §4.5.5	zero temper flat panels
Adhesion	ASTM D 3359	flat panels

The applicable ASTM methods and sections in the MIL-PRF specifications provide sufficient details on experimental procedure that these tests can be easily replicated. However, panel preparation procedures are important for these tests, especially for the accelerated corrosion tests. Please see Section 5.3 for panel preparation procedures.

5.2 Field Testing

Although no aircraft testing was performed as a part of this project, panels were subjected to outdoor field exposure. Panels were placed at the Kennedy Space Center (KSC) Beach Corrosion Test Site and at Battelle Florida Materials Research Facility near Daytona Beach. Panels exposed at the KSC site are racked 30° from horizontal and positioned 100 ft. from the mean high-tide. Figure 18 and Figure 19 show close up and an area views the exposure site, respectively.

Figure 18: A close up view of the KSC exposure site.

Figure 19: An area view of the KSC exposure site showing the proximity to the Atlantic Ocean and the two Space Shuttle launch pads.

5.3 Panel Preparation

Panel preparation procedures are as follows. When applicable, details are provided for both the Air Force Research Lab's (AFRL) Coatings Technology Integration Office (CTIO) procedure and procedures from the Naval Air Warfare Center-Aircraft Division (NAWC-AD). All CTIO panels were wiped with methyl ethyl ketone (MEK) prior to the procedures below. Panels prepared by NAWC-AD were wiped with acetone prior to the procedures below

5.3.1 *No Pretreatment Preparation*

NAWC-AD Procedure: Panels were scrubbed with a green Scotch-Brite pad and Alconox cleaner in warm water until a water-break free surface was achieved. Panels were rinsed with deionized (DI) water and allowed to dry at ambient laboratory conditions overnight.

5.3.2 *Anodized Preparation (per MIL-A-8625, Type IC)*

NAWC-AD Procedure: Panels were placed in titanium racks and immersed in Turco 4215 NCLT cleaner at 120 °F for 5 minutes. They were rinsed twice with hot tap water and then immersed in Turco SmutGo NC deoxidizer at ambient temperature for 60 seconds. The panels were rinsed twice in cold tap water and immersed in an anodizing solution of 3-5 wt% sulfuric acid and 0.5-1.0 wt% boric acid at ambient temperature. A DC current of 5 volts was passed through the bath for 60 seconds. Then, the current was ramped up to 15 volts at 2 volts/minute and the bath was held at 15 volts for 20 minutes. The panels were removed and rinsed once in cold tap water, then sealed in 190 °F water for two minutes. Panels were rinsed in cold tap water, then DI water and allowed to dry overnight at ambient laboratory conditions.

5.3.3 *PreKote Pretreatment Preparation*

NAWC-AD Procedure: Panels were flooded with the PreKote solution and the surface was abraded with a green Scotch-Brite pad. Without allowing the solution to dry on the surface of the panel, a second layer of solution was applied immediately. The panel was rinsed with DI water and allowed to dry overnight at ambient laboratory conditions.
CTIO Procedure: The PreKote product was applied in a three-step process that models the actual process used at Hill Air Force Base (AFB)

5.3.4 *BoeGel Pretreatment Preparation*

NAWC-AD Procedure: Panels were manually deoxidized with a green Scotch-Brite pad. They were then sprayed with the ACT Tech AC-130 BoeGel solution, and allowed to sit for 60 seconds. Fresh BoeGel solution was applied once during the 60 second period. Panels were allowed to dry overnight at ambient laboratory conditions.

5.3.5 *Chromate Conversion Coating (CCC) Preparation (per MIL-PRF-81706, Type I)*

NAWC-AD Procedure: Panels were placed in titanium racks and immersed in Turco 4215 NCLT cleaner at 120 °F for 5 minutes. They were rinsed twice with hot tap water and then immersed in Turco SmutGo NC deoxidizer at ambient temperature for 60 seconds. The panels were rinsed twice in cold tap water and then immersed in the Alodine 1200s or Alodine 1600 solution for three minutes at ambient conditions. They were rinsed twice with cold tap water, then rinsed with DI water and allowed to dry at ambient laboratory conditions overnight.
CTIO Procedure: Panels were scrubbed using a maroon Scotch-Brite pad and a 10:1 mix of tap water/Brulin. The test panels then received a tap water rinse, were verified to be water break free, and immersed in deionized water. Each rack of panels received a 5-minute immersion in the tap water/Brulin (10:1) circulating bath heated to 140ºF. Panels then received a two-stage rinse: 1) tap water immersion (10 dunks without aeration) followed by 2) deionized water low pressure spray. Panels were then immersed in a circulating deoxidizing bath for two minutes. The panels then received a second two-stage rinse: 1) tap water immersion (10 dunks with

aeration) followed by 2) deionized water low pressure spray. The panels were then immersed in a circulating bath of Alodine 1600 (pH 1.76). The test panels then received a final two-stage rinse: 1) deionized water immersion (10 dunks with aeration) followed by 2) deionized water low pressure rinse. The panels were then allowed to dry overnight at ambient conditions.

5.3.6 Trivalent Chromium Pretreatment (TCP) Procedures (per MIL-PRF-81706, Type II)

NAWC-AD Procedure: Panels were placed in titanium racks and immersed in Turco 4215 NCLT cleaner at 120 °F for 5 minutes. They were rinsed twice with hot tap water and then immersed in Turco SmutGo NC deoxidizer at ambient temperature for 60 seconds. The panels were rinsed twice in cold tap water and then immersed in the Surtec 650 solution for five minutes at ambient conditions. They were rinsed twice with cold tap water, then rinsed with DI water and allowed to dry at ambient laboratory conditions overnight.

5.3.7 Primer Application Procedures

Control primers were sprayed using HVLP equipment to a DFT of 0.6-0.9 mil. Control primers are qualified to MIL-PRF-23377 and MIL-PRF-85582. The Mg-rich primer was sprayed at both the specification-required DFT of 0.6-0.9 mil and the manufacturer's recommended thickness of 1.0-1.4 mil.

5.3.8 Topcoat Application Procedures

Topcoats qualified to MIL-PRF-85285 were sprayed using HVLP equipment to a DFT of 1.7-2.3 mil.

6.0 PERFORMANCE ASSESSMENT

6.1 Laboratory Evaluation Results

6.1.1 Round Robin Testing

As a part of the ESTCP project, round robin testing was performed on the Aerodur 2100 MgRP in 2008. Panels were prepared by AFRL and by ANAC and they were exposed to ASTM B 117 at AFRL, ANAC, NAWC-AD, Hill AFB, Boeing Long Beach, and Battelle. In addition, panels were exposed outdoors at Daytona Beach and KSC. The test matrix is provided in Appendix B. Figure 20 and Figure 21 show the fully hexavalent chromium control panels and Mg-rich test panels after 1000 hour of ASTM B 117 exposure, respectively.

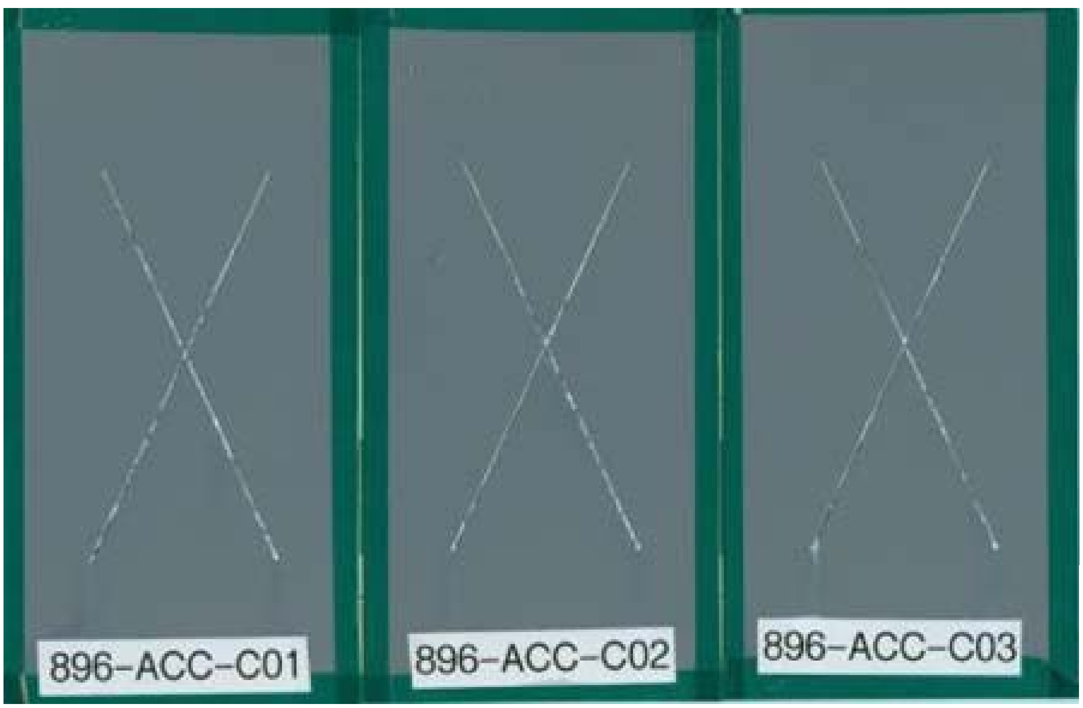


Figure 20: Three replicate AA 2024 panels with hexavalent chromium pretreatment and primer, with a topcoat, after 1000 hrs. ASTM B 117.

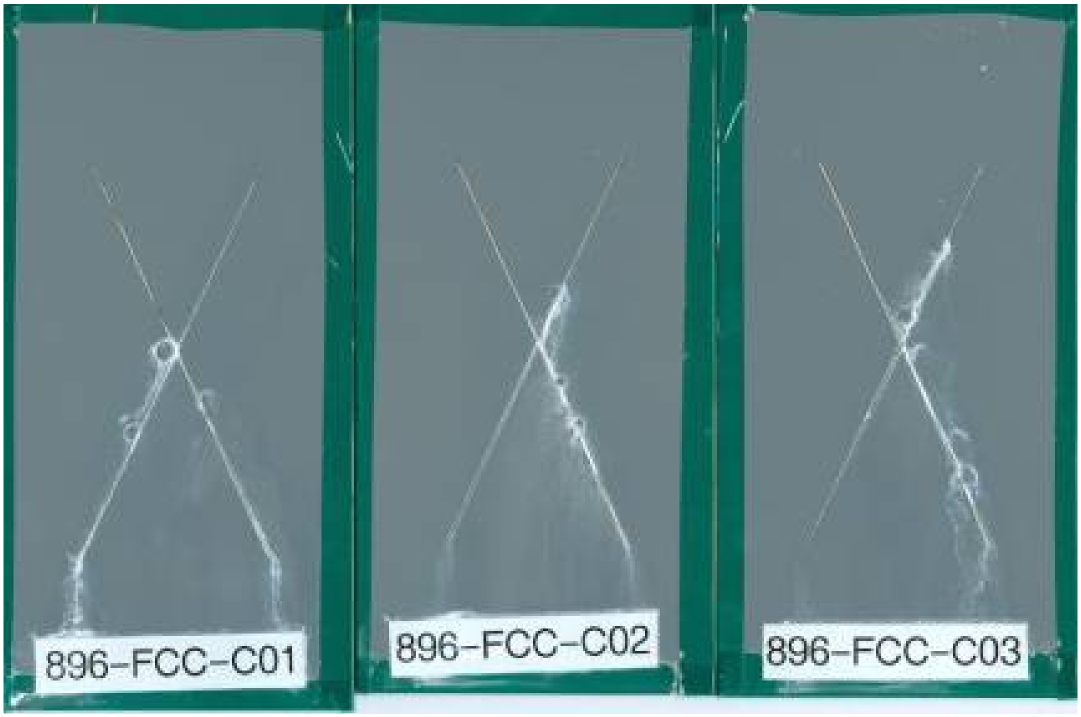


Figure 21: Three replicate AA 2024 panels with PreKote pretreatment and Mg-rich primer, with a topcoat, after 1000 hrs. ASTM B 117.

The panels were rated according to the scheme presented in Table 4, above. The test panels show premature failure, with the Mg-rich panels receiving undercutting ratings of 2 after exposure to ASTM B 117 for 1000 hours (Figure 22). The test was ended early, and Mg-rich panels were removed after 1000 hours. The results from this test led ANAC to reformulate the Aerodur 2100 MgRP product, producing the MgRP002 and MgRP003 versions in 2009 and 2010.

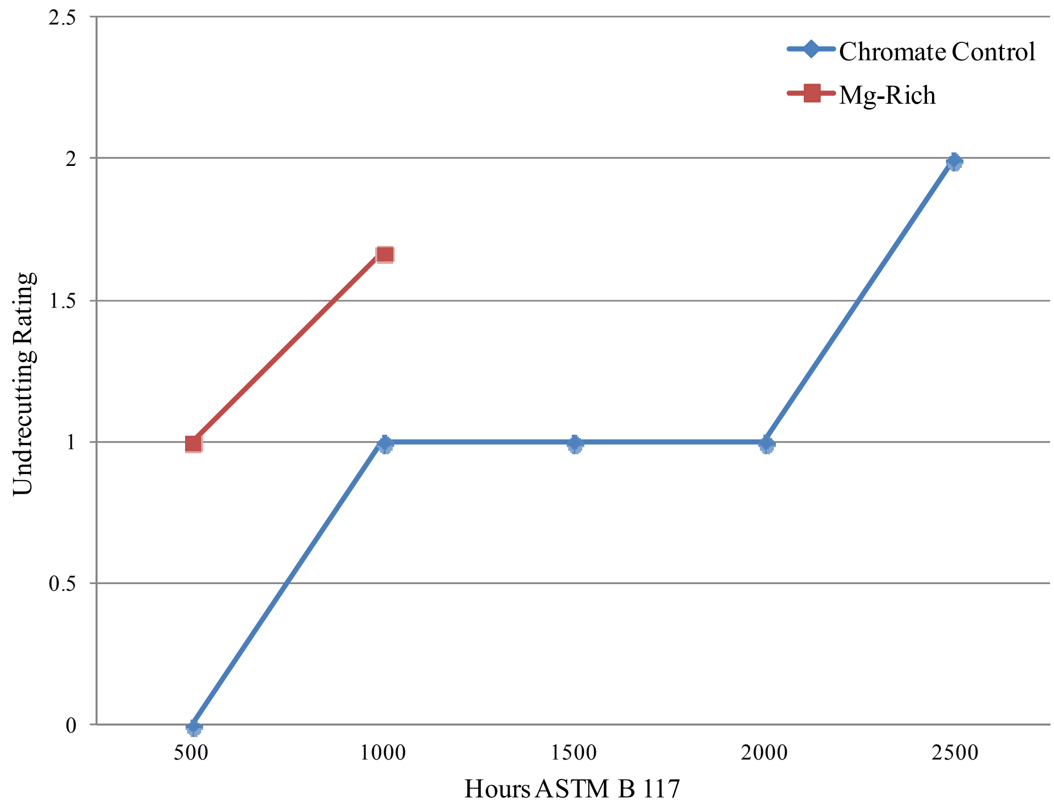


Figure 22: Undercutting ratings for round robin panels exposed at NAWC-AD.

6.1.2 Qualification Results

The current Aerodur MgRP003 product from ANAC was subjected to qualification testing to two military performance specifications. Qualification testing to the MIL-PRF-23377 primer specification was performed by NAWC-AD; however, the Mg-rich primer did not meet the requirements for qualification to this specification. In addition, partial testing to the MIL-PRF-32239 coating system specification was performed by AFRL. Again, the Mg-rich did not meet the requirements of the specification. The Mg-rich did perform better than chromate controls during AFRL testing, but those chromate controls performed similarly to negative blank controls (those without any corrosion inhibitors) indicating the possibility of improper panel preparation with the chromate control panels (Appendix C).

6.2 Performance Objectives

6.2.1 Product Testing

In Round Robin testing, the Mg-Rich primer failed to achieve corrosion performance equal to that of other qualified non-chromate primers. In addition, it failed to qualify to the two performance specifications that it was tested to: MIL-PRF-23377 and MIL-PRF-32239. The Mg-rich primer fails to meet this portion of the performance objective.

The Mg-rich primer performed well in all adhesion testing, scoring 5A on all wet tape adhesion tests and 5B on all dry cross-hatch adhesion tests. A cross-hatch rating of 4B was assigned for samples immersed in water or JP-8 jet fuel. The Mg-rich primer meets this portion of the performance objective.

ANAC recommends that the Mg-rich primer be applied at a dry film thickness (DFT) of 1.0-1.4 mil, compared to the 0.6-0.9 mil called out in the primer specifications. While the Mg-rich primer is less dense than typical primers, the extra thickness makes up for this difference causing the overall weight of the coating on the aircraft to increase slightly (Table 9). It is important to note that the areas used in Table 9 only consider the exterior painted surface which would be painted during a depot-level rework cycle. It does not include the interior surface area which is usually only primed (no topcoat) and is often at least equal to the exterior surface area. An increase of ~9 lbs. on a C-130 cargo aircraft during depot-level repaint is not considered a significant increase and the Mg-rich primer meets this portion of the performance objective. It is important to note that the Mg-rich primer generally performs better at ANAC's recommended DFT. It was initially believed that this was due to more magnesium particles being available for sacrificial protection. However, recent work [10] has shown it is likely due to increased resistivity (lower electrical connectivity) with thinner coatings.

Table 9: Comparison of Coating Weights.

Primer	Density (lbs. / ft^2•mil)	Coating Thickness (mil)	Weight[a] (lbs. / ft^2)	C-130 Primer Weight[b] (lbs.)	H-60 Primer Weight[c] (lbs.)
Mg-rich	0.00766	1.0-1.4	0.00766-0.01072	34.47-48.26	8.43-11.79
Typical Primer	0.00967	0.6-0.9	0.00580-0.00870	26.11-39.16	6.38-9.57
			Difference	8.36-9.10	2.05-2.22

a. At recommended thickness. *b*. 4500 ft^2 exterior painted surface. *c*. 1100 ft^2 exterior painted surface.

6.2.2 Hazardous Materials

Since no field demonstrations were performed, this performance objective was not evaluated.

6.2.3 COTS Procurement

Discussions with ANAC make it clear that the Mg-rich primer is able to be produced in large-scale batches to support painting larger aircraft like the C-130. The magnesium powder and other raw materials are readily available. The Mg-rich primer meets this performance objective.

6.2.4 Ease of Use

While painting test panels for the laboratory and field exposures, it was verified that the Mg-rich primer can be successfully applied using HVLP paint equipment. Discussions with the painters revealed that the Mg-rich primer sprays similarly to qualified primers. However, there was a slight learning curve, as they adjusted to applying the target thickness. This is largely due to the grey color and metallic nature of the Mg-rich primer which had little contrast with the aluminum test panels.

6.3 Formulation Improvements

NAWC-AD performed testing on another commercial formulation from ANAC – the Aerodur MgRP002. Testing showed an improvement in performance compared to the original commercial version. In addition, NAWC-AC worked to modify the P002 version of ANAC's primer, developing the P002+. At the same time, ANAC was also working on further improvements to the Mg-rich primer, and produced the Aerodur MgRP003. In addition, two MIL-PRF-23377 Class N primers were tested, along with chromate controls. The ratings, based on Table 4, are shown in Figure 23 and Figure 24 and are an average of both AA 2024 and AA 7075 panels. The chromate control outperforms the non-chromate primers in these tests (lower ratings), and the two different Mg-rich formulations out-performed the non-chromate controls.

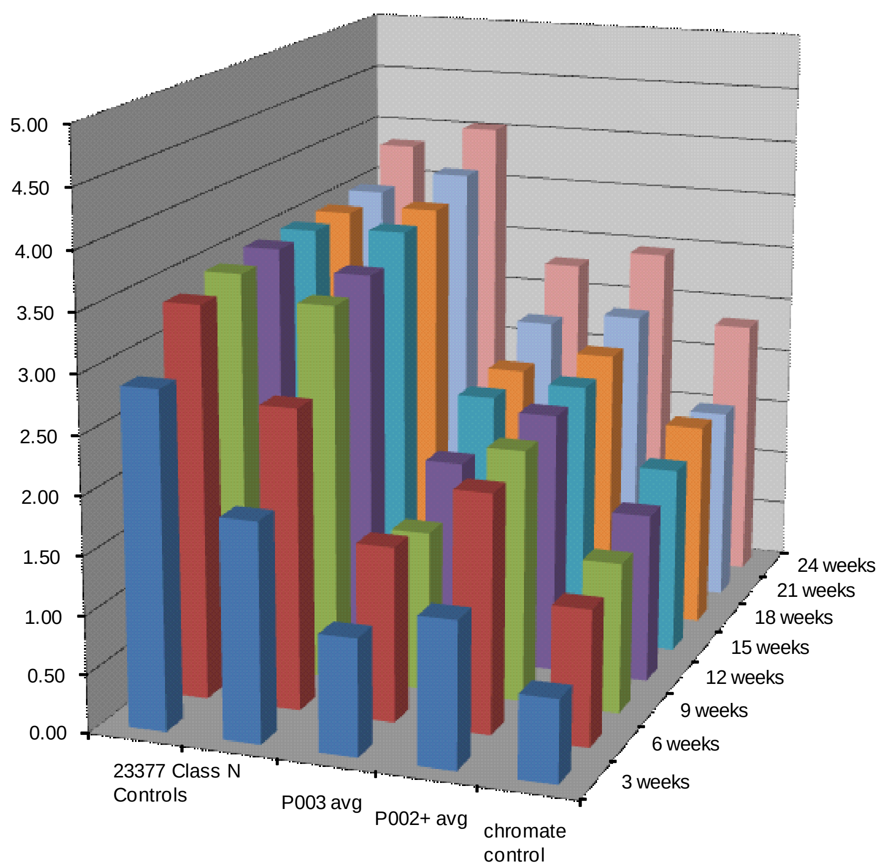


Figure 23: Scribe ratings for two Class N control primers, two Mg-rich versions and a chromate control after exposure to ASTM B 117 neutral salt fog.

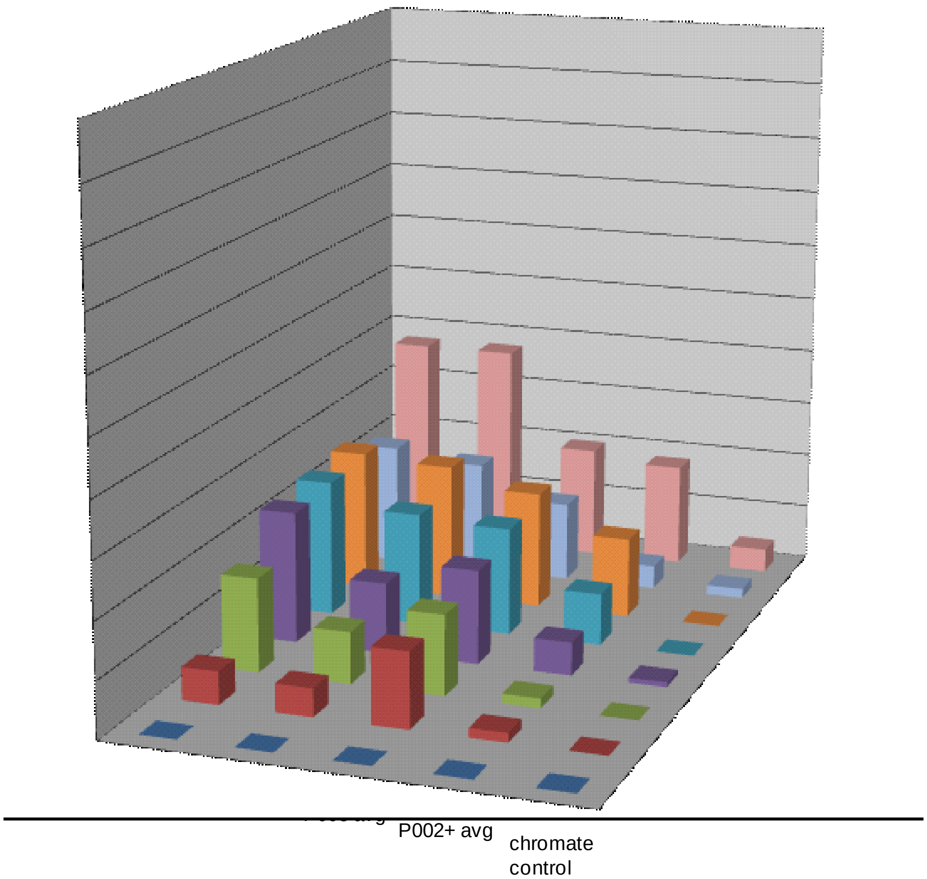


Figure 24: Undercutting ratings for two Class N control primers, two Mg-rich versions and a chromate control after exposure to ASTM B 117 neutral salt fog.

However, in ASTM G 85 acidic salt fog, the Mg-rich primer performs worse (higher ratings) than the other non-chromate controls. Again, the chromate control coating outperforms all non-chromate primers (Figure 25 and Figure 26). Scribe corrosion appeared in the first three weeks of the test for all primers, and did not worsen significantly through the rest of the test. The P003 shows the worst rating for undercutting, driven mainly by the poor performance on AA 7075.

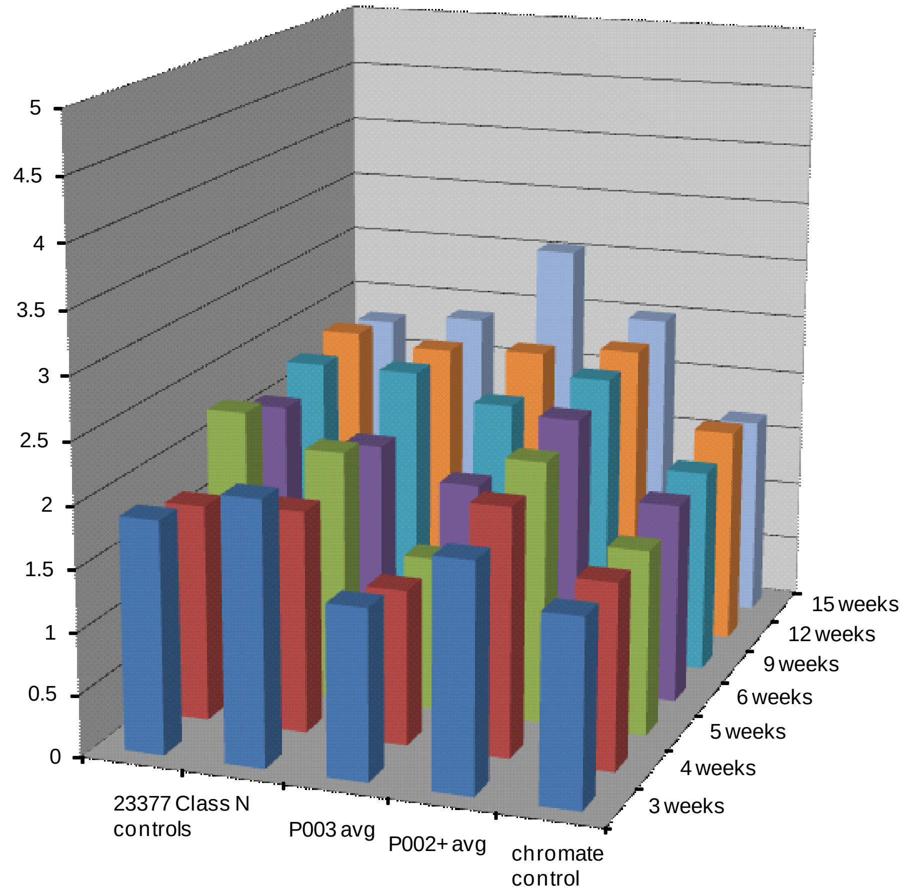


Figure 25: Scribe ratings for two Class N control primers, two Mg-rich versions and a chromate control after exposure to ASTM G 85 acidic salt fog.

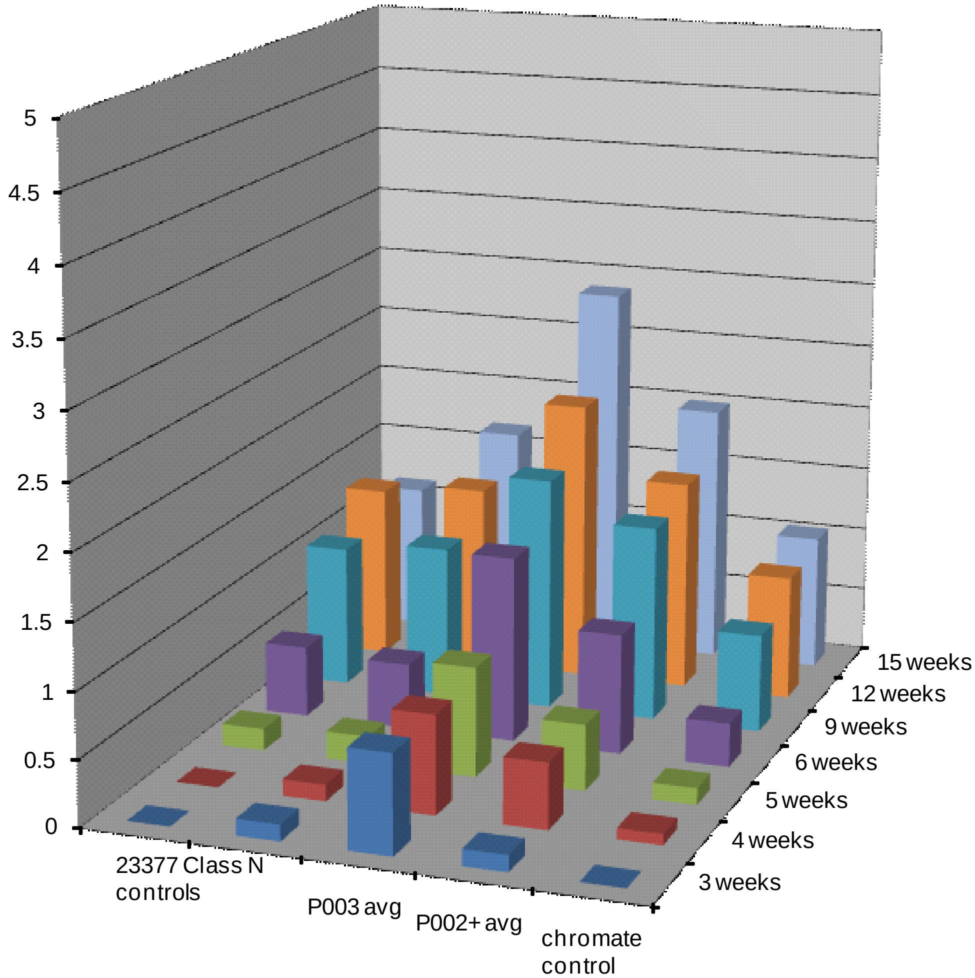
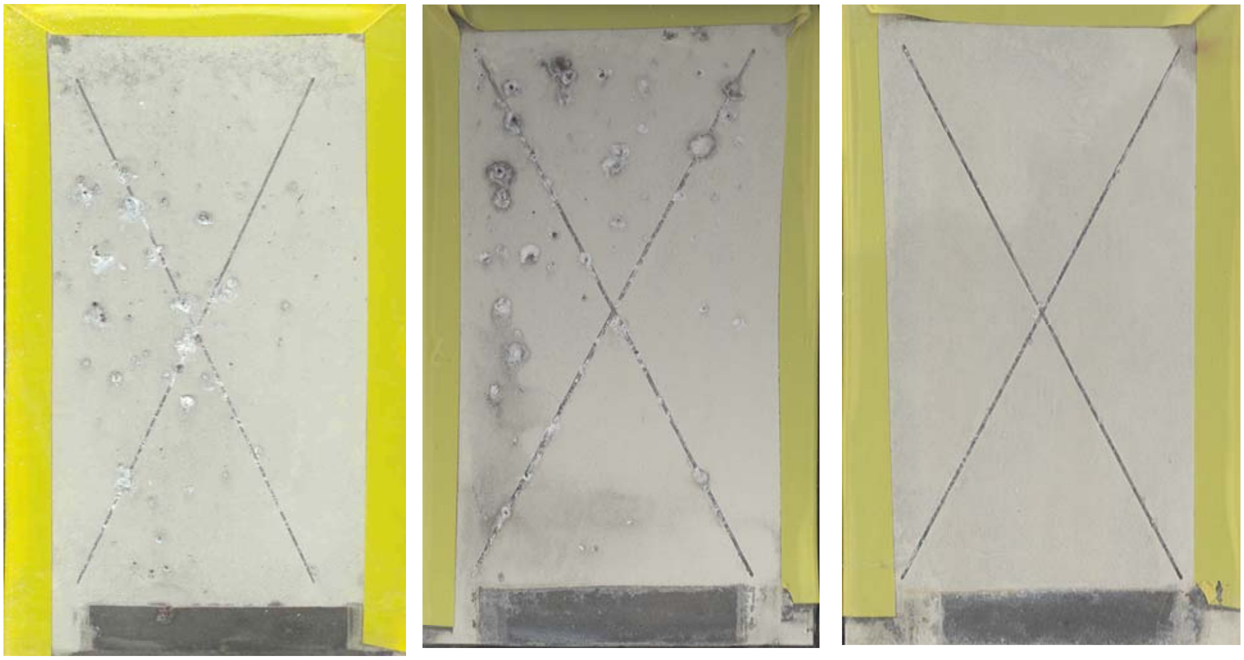


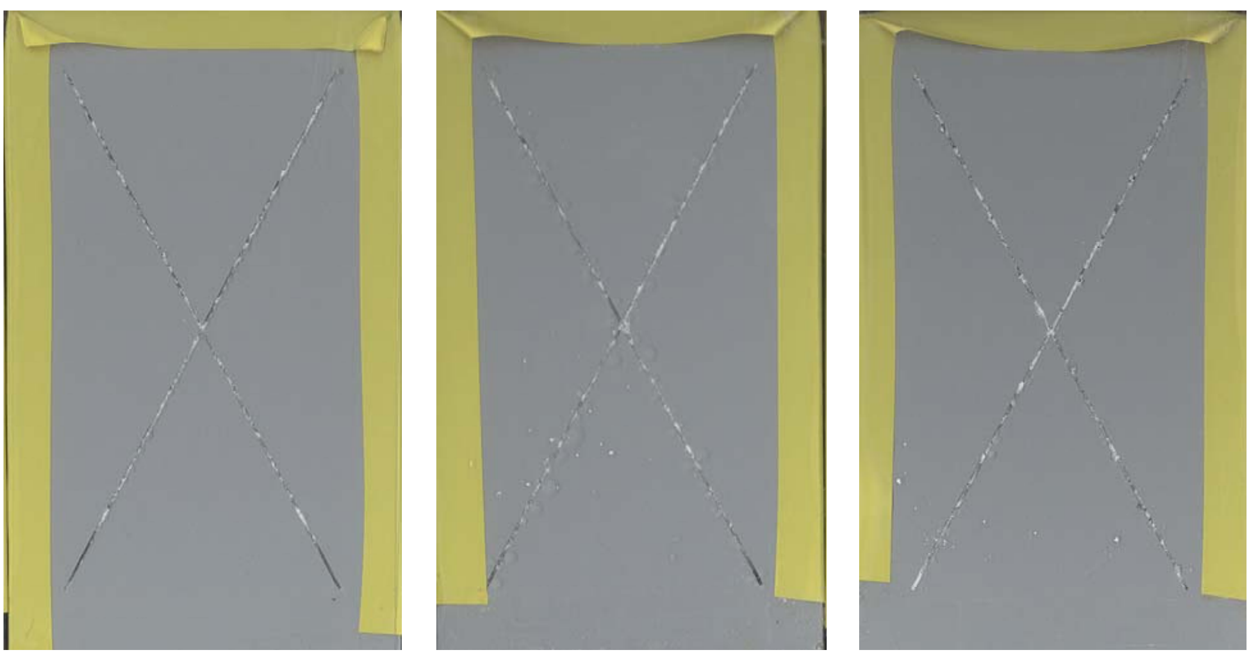
Figure 26: Undercutting ratings for two Class N control primers, two Mg-rich versions and a chromate control after exposure to ASTM G 85 acidic salt fog.

An important improvement with regards to coating rupturing in ASTM G 85 acidic salt fog was realized with the P002+ and P003 formulations. The XP-406 and XP-417 exhibited ruptures through the coating beginning around 44 days of exposure to ASTM G 85 acidic salt fog. When the coating was removed, large pits were observed in the substrate directly below the ruptures (see Figure 10). While the improved formulations do not eliminate the rupturing phenomenon, they do delay the onset significantly. While the early versions of the Mg-rich exhibited rupturing fairly quickly, the P003 showed similar degree of rupturing after 84 days. The P002+ was tested out to 126 days with no evidence of rupturing (Figure 27). In addition, the improvements have greatly reduced the instances of blisters on topcoated panels (Figure 28), although the performance is still worse than the non-chromate control coating.



XP-417 | P003 | P002+
44 days exposure | 84 days exposure | 126 days exposure

Figure 27: Three versions of the Mg-rich primer showing a delay in the onset of rupturing through the coating in ASTM G 85 acidic salt fog.



23377 Class N Control | P003 | P002+

Figure 28: Non-chromate control panel and two Mg-rich formulations after 105 days exposure to ASTM G 85 acidic salt fog.

The Mg-rich P002+ and P003 versions were also subjected to outdoor exposure. These panels, along with non-chromate and chromate controls, were installed at the beach-front test site at KSC (Figure 29). No substrate corrosion was observed on topcoated panels after 7 months exposure. However, after 6 months, both Mg-rich formulations began to show signs of self corrosion as seen with earlier versions of the primer (see Figure 6). This is approximately the same time frame that earlier versions started to exhibit signs of self corrosion. So, while the improvements have pushed out the onset of rupturing through the coating that plagued earlier versions of the Mg-rich in accelerated corrosion testing, these same improvements do not seem to improve the performance on the beach.

However, the improved Mg-rich primer formulations do not perform as well as non-chromate control coatings in galvanic test assemblies. As explained above, these assemblies are tested because they more accurately simulate galvanic interfaces found in actual aircraft structures. Over the course of using this test assembly for the past several years, NAWC-AD noticed very little substrate corrosion around the aluminum bolts. As a result, unlike the panels in Figure 15, the test panels shown below only have two sets of bolts – titanium on the left and CRES on the right. After only 2 months exposure at KSC, the P003 showed signs of crevice corrosion around the CRES bolts. This was not observed on the non-chromate control or the P002+ panels (Figure 30).

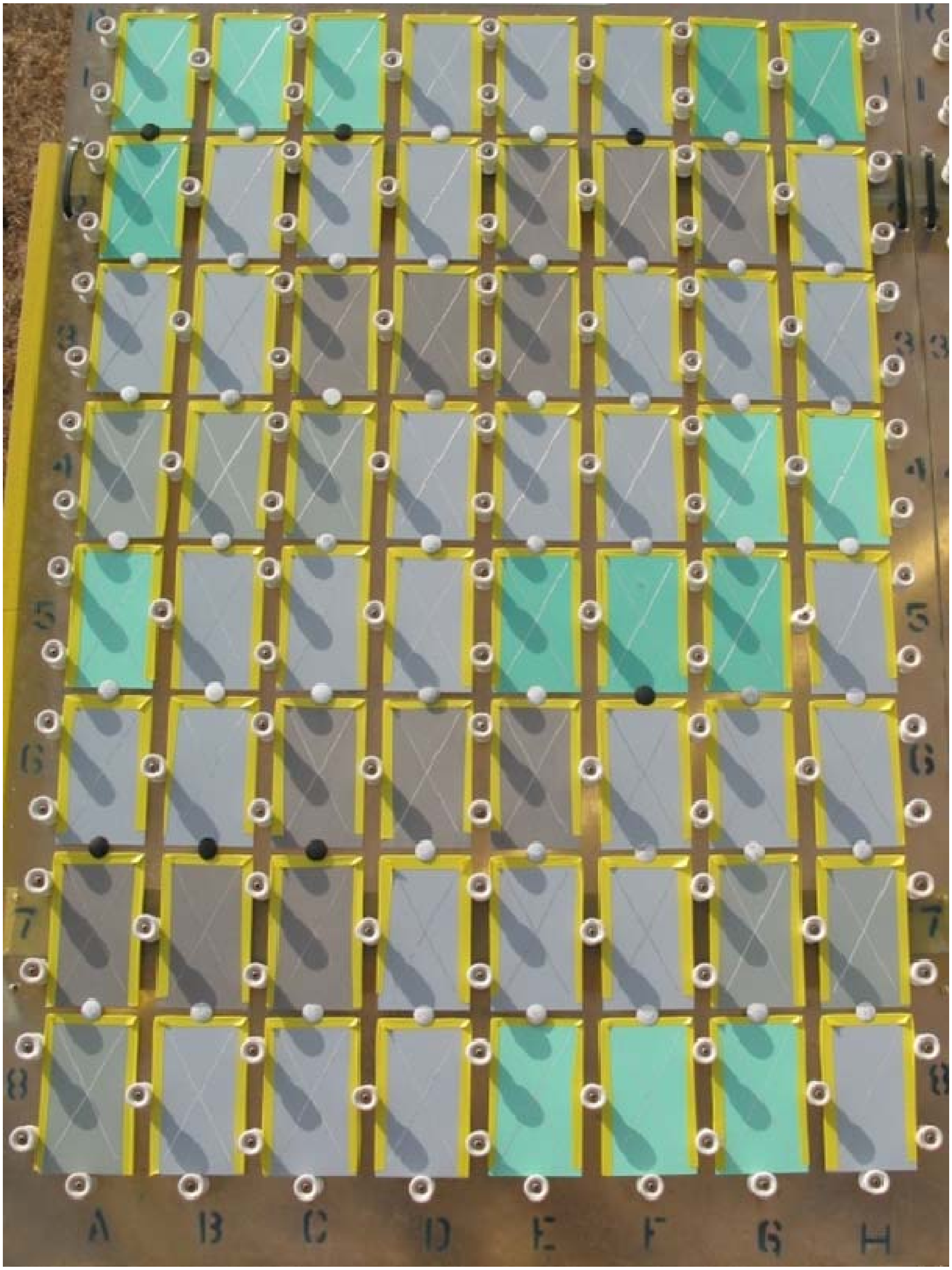
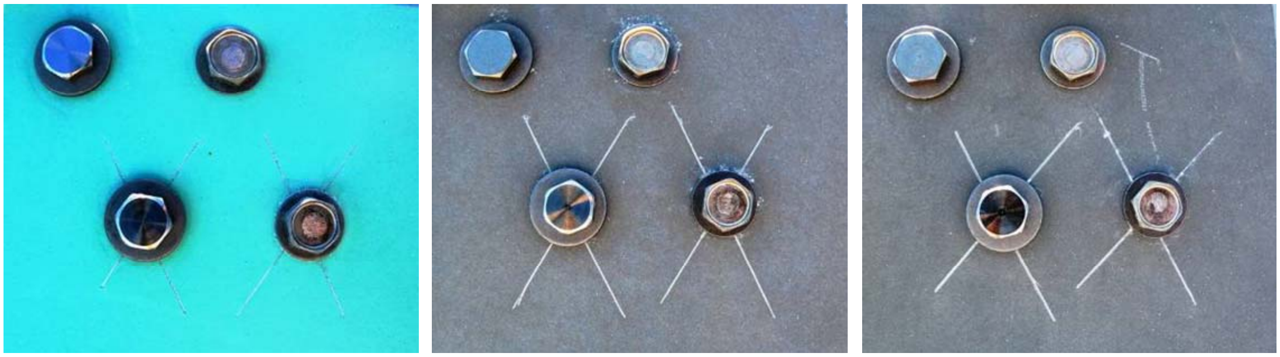


Figure 29: Test panels, as installed, at KSC.



23377 Class N control P003 P002+

Figure 30: Galvanic test panels with TCP pretreatment after 2 months exposure at KSC.

6.4 Comprehensive Primer Evaluation

6.4.1 Overview

With the preliminary data for the two improved formulations – the P003 from ANAC and the NAWC-AD modified version of the P002 (called P002+) – a comprehensive test matrix, which included nearly 950 test panels, was started to look at many different variables. The test looked at different substrates, surface treatments, topcoat/primer only combinations and test conditions. Table 10 lists the variable tested and Appendix D shows the full test matrix. The purpose of this test was to evaluate the leading non-chromate primers – including the P003 and P002+, as well as traditional non-chromate primers – over many different substrates and different pretreatments. In all cases, chromate primers were tested along with the non-chromate primers in order to serve as controls. While time consuming, exhaustive testing such as this has been shown to greatly reduce the instances of false positive and false negative results, compared to testing a primer in only one or two conditions (i.e. only testing topcoated over one pretreatment and one substrate) [11]. Testing included two adhesion promoters in the surface preparation test matrix (PreKote and BoeGel) because early testing by ANAC and AFRL indicated that the Mg-rich primers perform well over these surfaces. In addition, three qualified surface preparations were tested – chromate conversion coating, TCP and anodized. Primers were tested both with and without a topcoat. As mentioned before, a large percentage (50-75%) of the painted surface of any aircraft is the un-topcoated interior surfaces. Therefore, for any primer to be widely implemented, it must have good corrosion performance both with and without a topcoat.

Table 10: Variable Matrix for Comprehensive Non-Chromate Primer Test.

Variable	Permutations
Substrate	AA 2024 AA 7075 Galvanic test assembly
Surface Preparation	MIL-A-8625 Type IC (CCC) MIL-PRF-81706 Type II (TCP) MIL-PRF-8623 Type IC (anodized, hot water seal) PreKote BoeGel
Primer	MIL-PRF-23377 Type I, Class C (solvent borne chromate control) MIL-PRF-23377 Type II, Class C (solvent borne chromate control) MIL-PRF-85582 Type I, Class C1 (water borne chromate control) MIL-PRF-23377 Type I, Class N (solvent borne non-chromate control) MIL-PRF-85582 Type I, Class N (water borne non-chromate control) ANAC Aerodur MgRP003 (commercial Mg-rich) P002+(NAWC-AD modified Mg-rich)
Topcoat	Primer only With MIL-PRF-85285 Type IV topcoat
Test	ASTM B 117 neutral salt fog ASTM G 85 acidic salt fog Outdoor exposure at KSC (galvanic assemblies only)

6.4.2 ASTM B 117 Neutral Salt Fog

Flat AA 2024 and 7075 panels were exposed to ASTM B 117 neutral salt fog for 3500 hours, and they were rated according to Table 4 (0 (best) to 5 (worst)). CCC, TCP and anodized pretreatments performed about the same, with the adhesion promoters (PreKote and BoeGel) performing worse (higher ratings) when averaged over all primers. In addition, as previous test have shown, 7075 is harder to protect than 2024, resulting in higher (worse) ratings for 7075 panels (Figure 31 and Figure 32). The solvent-borne chromate control coatings (23377, Type I and Type II, Class C) performed well when tested on both alloys. The Mg-rich primers also performed well when averaged over all pretreatments and topcoat conditions. However, this average performance of the Mg-rich is bolstered by its performance on PreKote and BoeGel. The Mg-rich out-performs the other primers over these adhesion promoters, with the other primers – including the chromate controls – typically receiving much higher (worse) undercutting ratings on those products (Figure 33). This trend hold for AA 7075 as well, with the P003 performing better over PreKote than any other pretreatment (Figure 34).

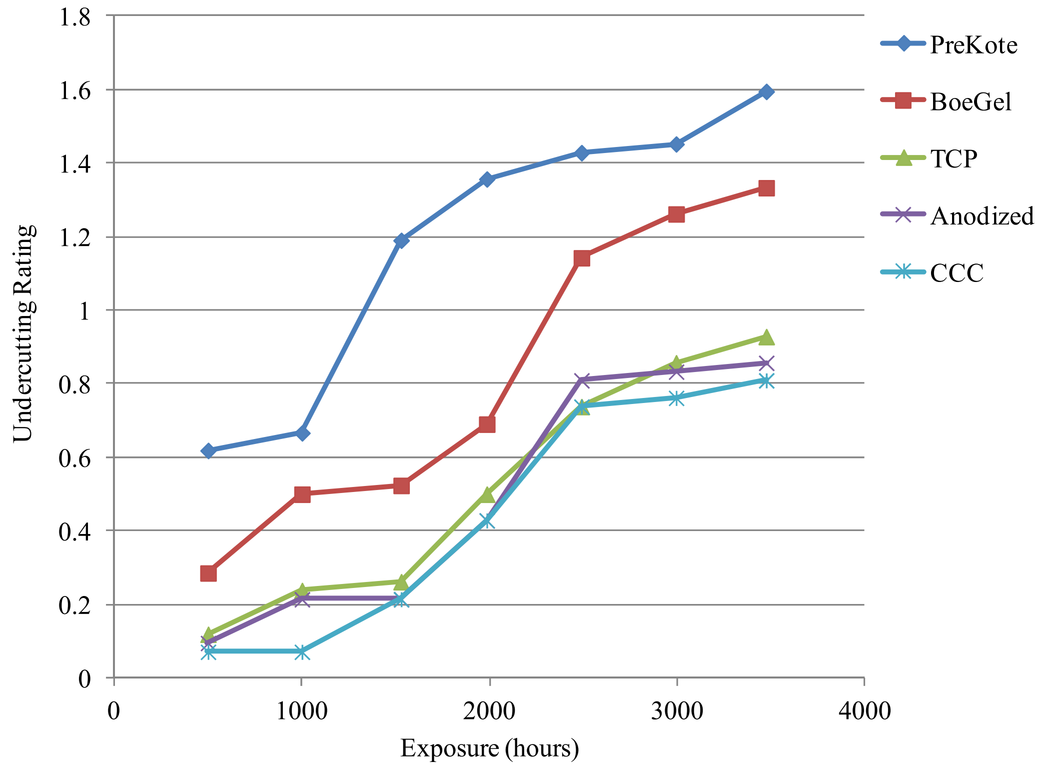


Figure 31: Average undercutting ratings for each pretreatment, averaged for all primers and topcoat conditions for AA 2024 panels after exposure to ASTM B 117 neutral salt fog

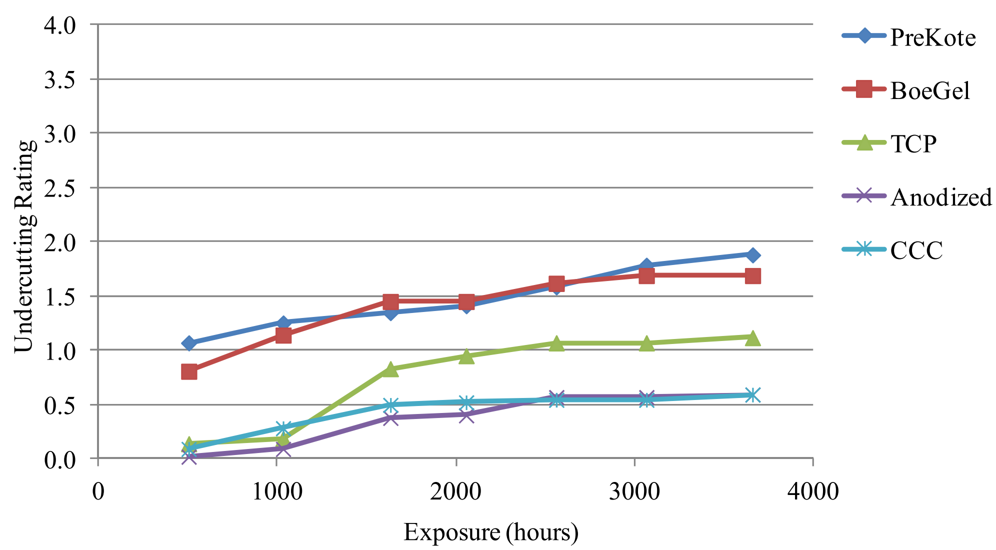


Figure 32: Average undercutting ratings for each pretreatment, averaged for all primers and topcoat conditions for AA 7075 panels after exposure to ASTM B 117 neutral salt fog.

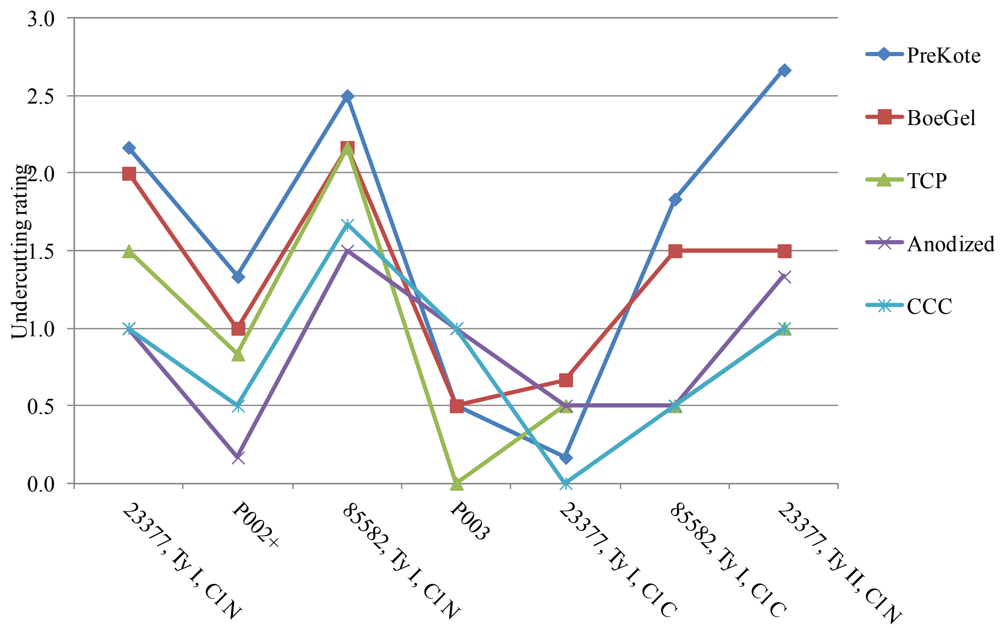


Figure 33: Average undercutting ratings on 2024 panels for each primer/pretreatment combination after 3500 hours of ASTM B 117 exposure.

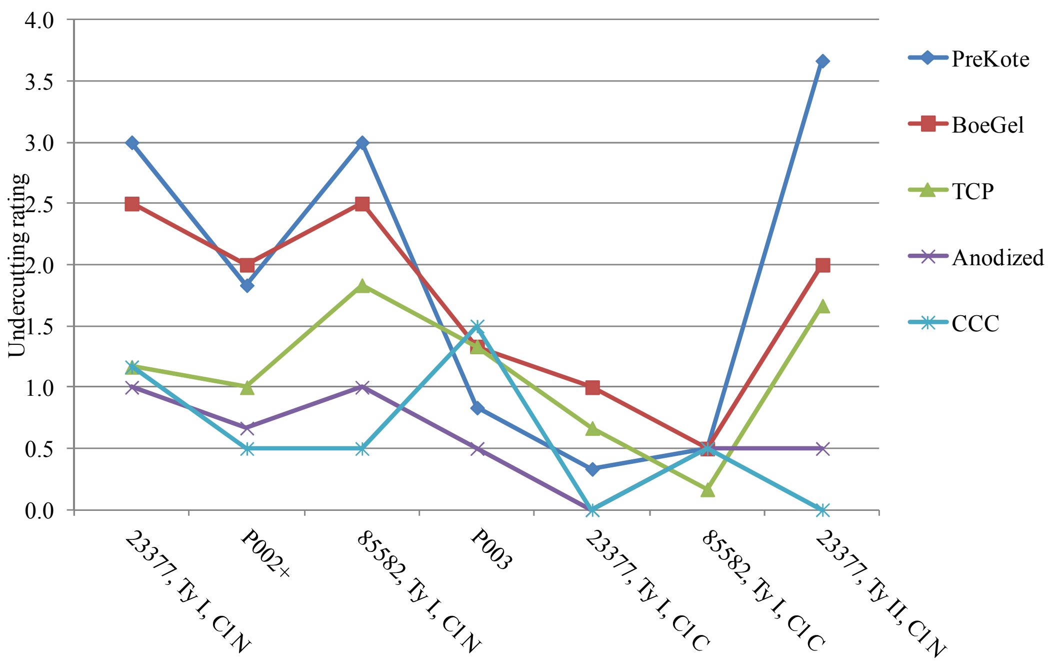


Figure 34: Average undercutting ratings on 7075 panels for each primer/pretreatment combination after 3500 hours of ASTM B 117 exposure.

Galvanic panels were exposed to ASTM B 117 neutral salt fog for 504 hours. This is much shorter test than the 2000 hours called for in military performance specifications or the 3500 hours exposure for the non-galvanic panels in this evaluation. When compared to flat panels, the galvanic panels present a more difficult corrosion protection challenge to the primers; however, these panels are more representative of how the primers will be used on actual aircraft structures. Because the galvanic interfaces are much harder to protect, differentiation between coatings are seen much sooner. Figure 35 shows the average undercutting rating (see Table 4, 0 (best) to 5 (worst)) for each primer, as an average of all pretreatment and topcoat conditions (with and without a topcoat). Undercutting was evaluated for the scribes only. The commercial P003 version of the Mg-rich primer is performing the best of all primers, although all the primers are performing very well in undercutting (all averages are less than 1). Again, as with the flat panels above, the average performance of the P003 Mg-Rich is bolstered by its good performance on PreKote and BoeGel relative to the other primers (Figure 36). However, the Mg-rich primers are consistently performing poorer (higher ratings) that the other primers with regard to scribe protection (Figure 37). Figure 38 shows an average of the undercutting rating for all primers, broken out by pretreatment. After only 120 hours exposure to ASTM B 117 neutral salt fog, the three qualified conversion coatings are clearly performing better than the two adhesion promoters with the performance gap widening with increased exposure time.

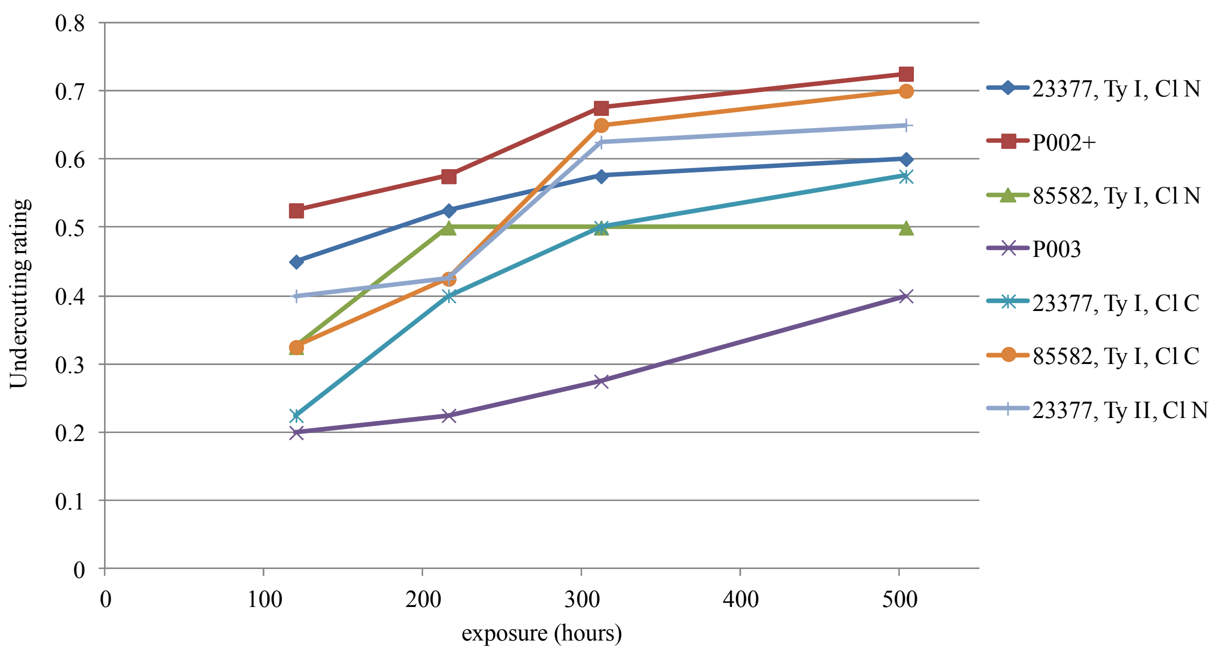


Figure 35: Undercutting rating for each primer, as an average of all pretreatments and topcoat conditions, after exposure to ASTM B 117 neutral salt fog.

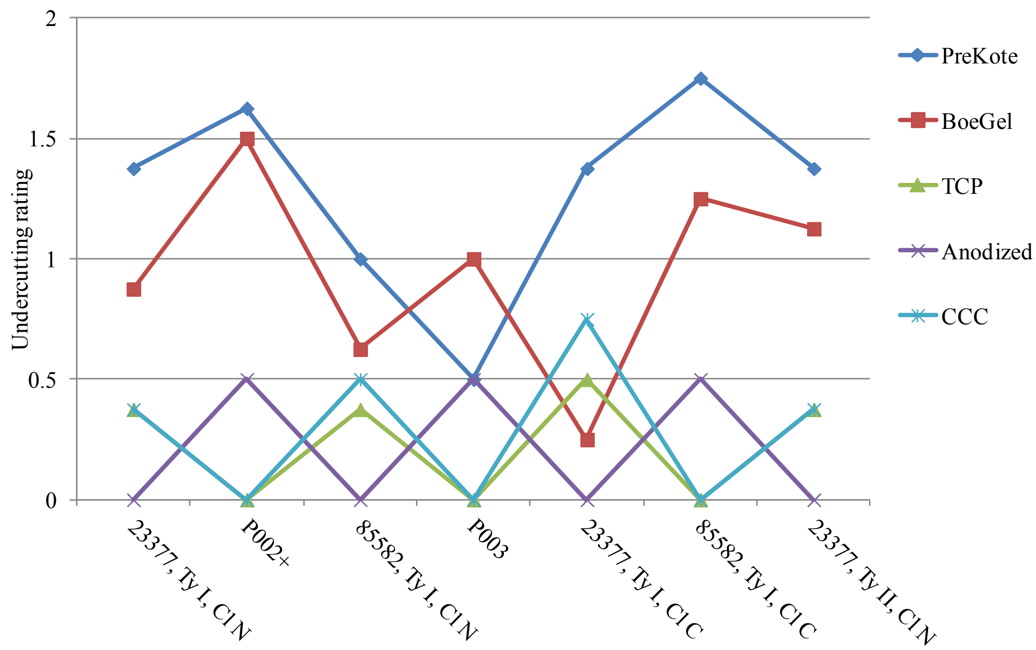


Figure 36: Average undercutting ratings on galvanic panels for each primer/pretreatment combination after 504 hours of ASTM B 117 exposure.

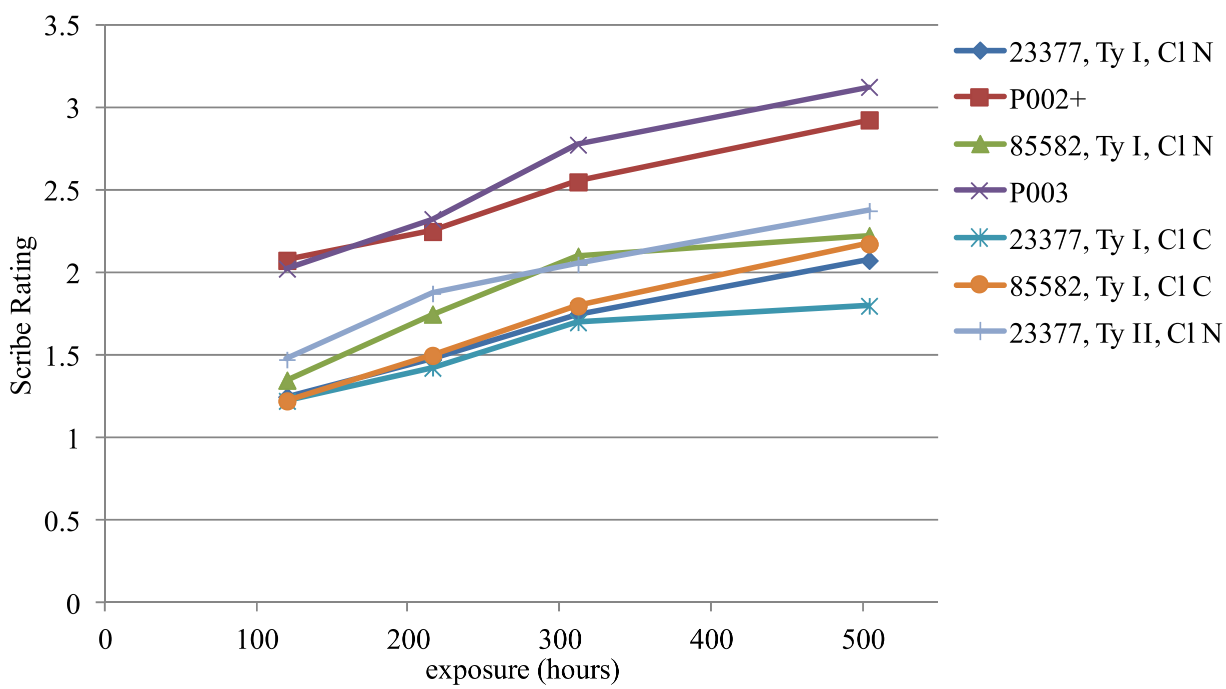


Figure 37: Scribe rating for each primer, as an average of all pretreatments and topcoat conditions, after exposure to ASTM B 117 neutral salt fog.

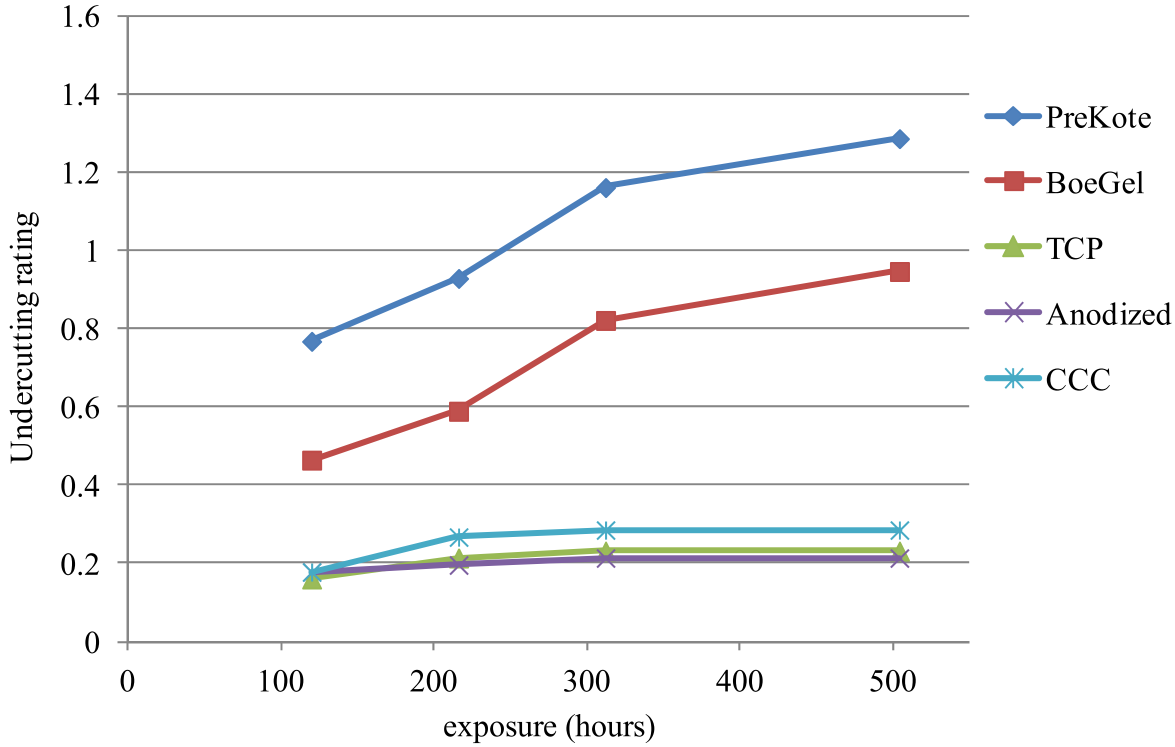


Figure 38: Plot of the average undercutting rating for all primers, separated by pretreatment after exposure to ASTM B 117 neutral salt fog.

6.4.3 ASTM G 85 Acidic Salt Fog

AA 2024 and 7075 panels were exposed to ASTM G 85 acidic salt fog for 2000 hours and 1680 hours, respectively. Again, when averaged over all primers, the PreKote and BoeGel are the worst performing pretreatments (highest ratings for undercutting) regardless of alloy (Figure 39). Again, the AA 7075 received higher (worse) undercutting ratings than the AA 2024. On AA 2024, the P003 performed better over PreKote than any other pretreatment (Figure 41), with all other primers performing significantly worse. A similar trend is noticed for AA 7075 panels (Figure 42). However, the best performing coating in these tests was, not surprisingly, the chromate control primers over CCC. While the Mg-rich formulations did outperform the non-chromate control primers over PreKote, the controls received lower (better) ratings than Mg-rich over approved pretreatments.

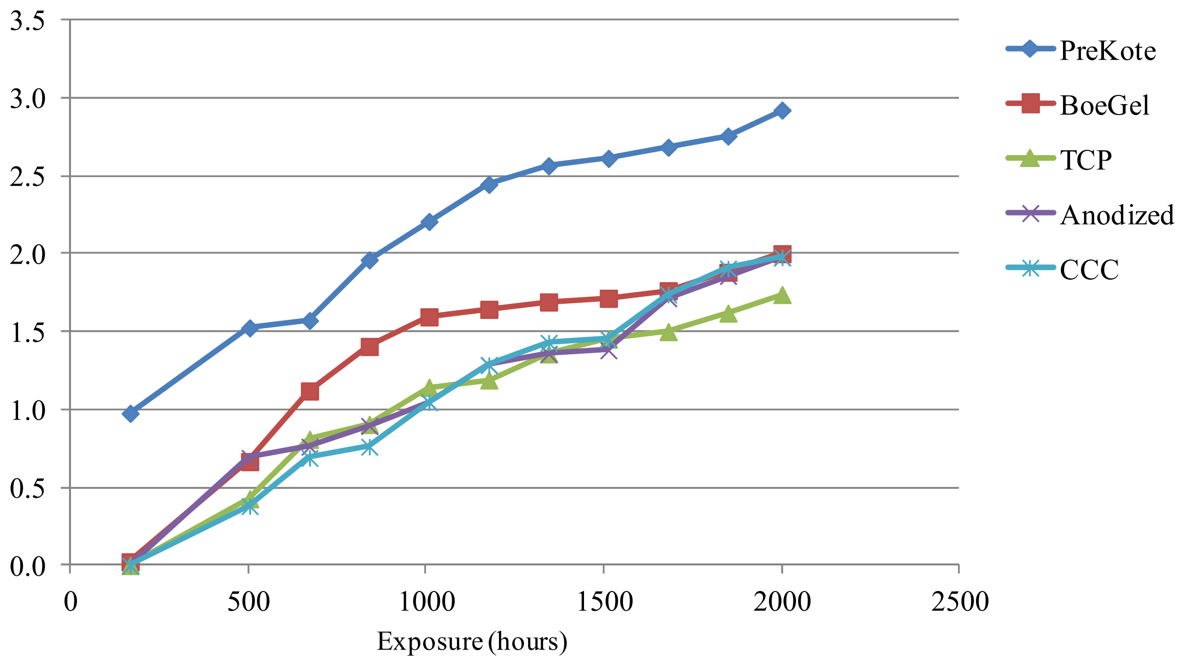


Figure 39: Average undercutting ratings for each pretreatment, averaged for all primers and topcoat conditions for AA 2024 panels after exposure to ASTM G 85 salt fog

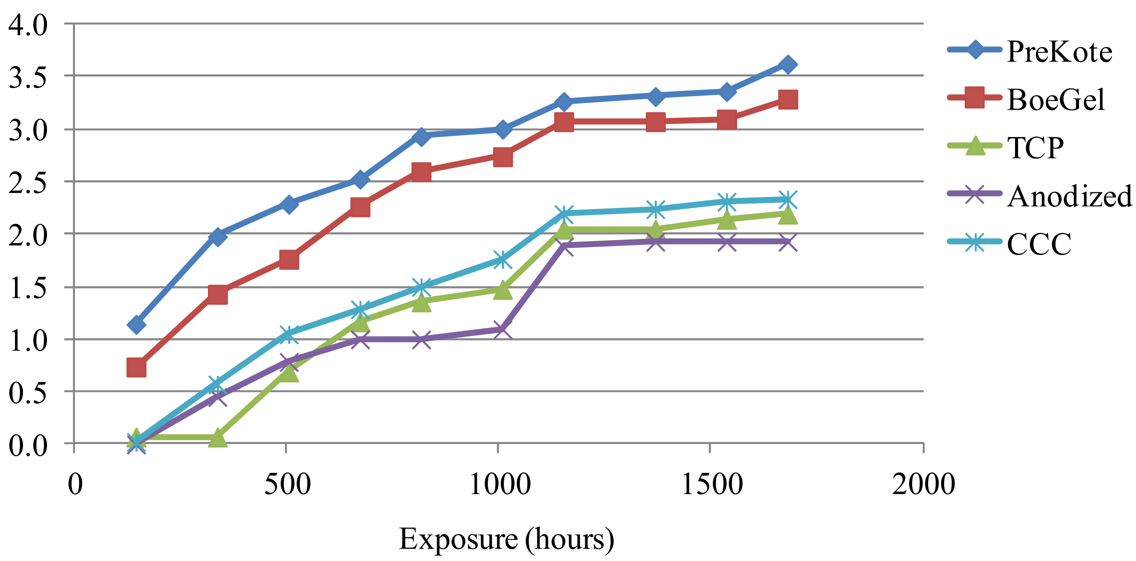


Figure 40: Average undercutting ratings for each pretreatment, averaged for all primers and topcoat conditions for AA 7075 panels after exposure to ASTM G 85 salt fog

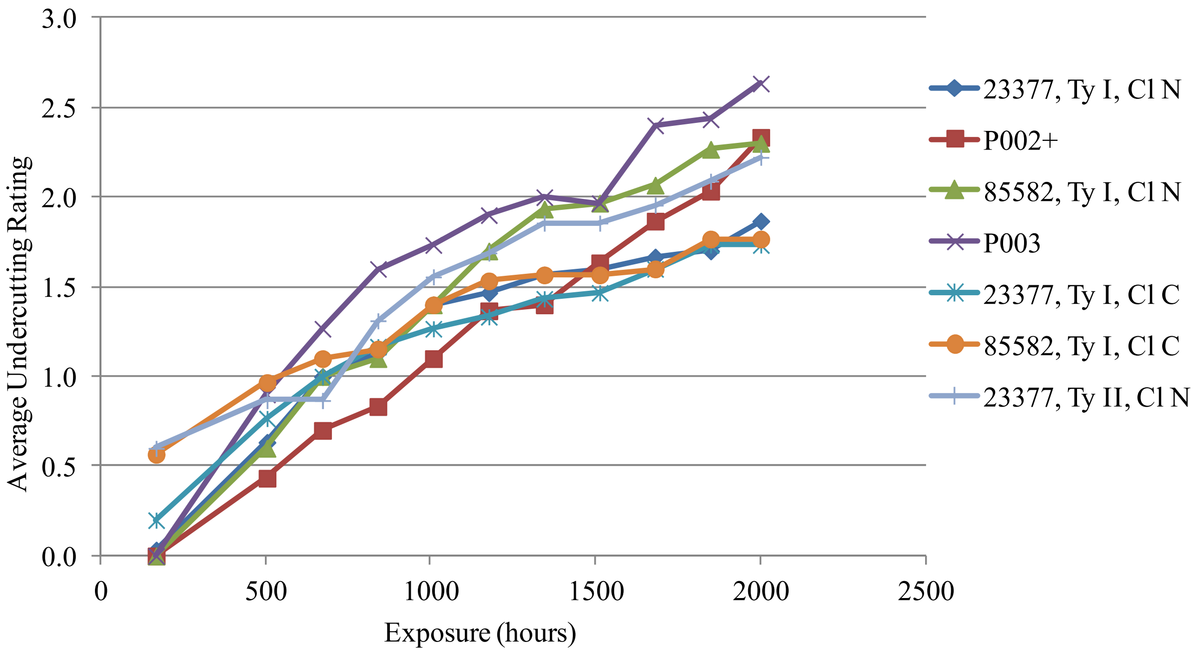


Figure 41: Average undercutting ratings on AA 2024 panels for each primer, averaged for all pretreatments, after ASTM G 85 exposure.

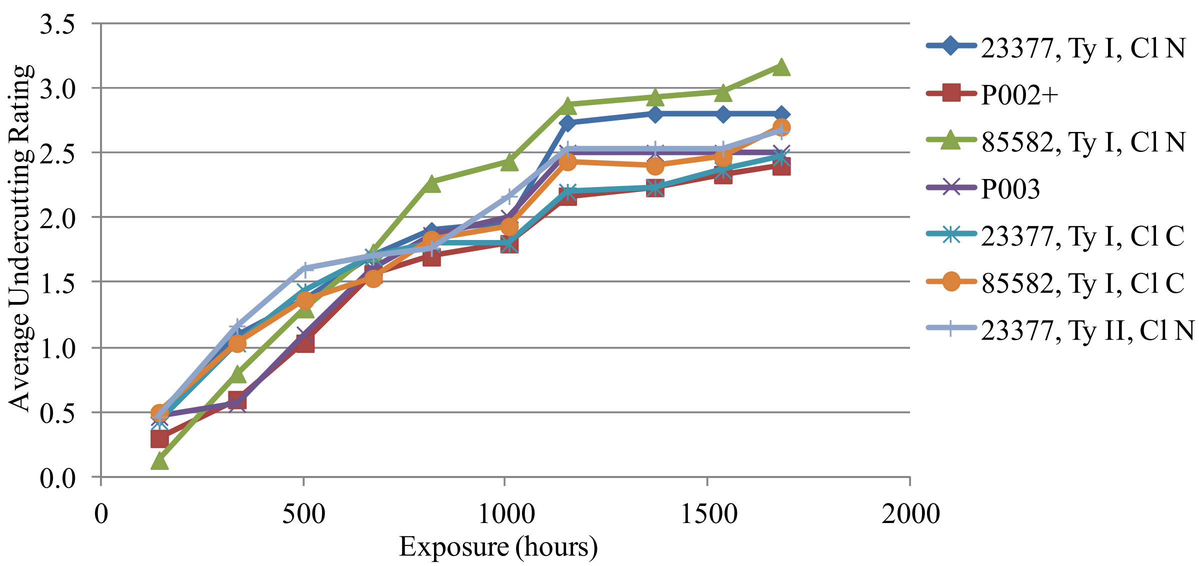


Figure 42: Average undercutting ratings on AA 7075 panels for each primer, averaged for all pretreatments, after ASTM G 85 exposure.

Galvanic panels were exposed to ASTM G 85 acidic salt fog for 360 hours. Again, this is much shorter exposure compared to the non-galvanic panels in this evaluation. Unlike with neutral salt fog above, the Mg-rich primers are some of the worst performers in acidic salt fog. Figure 43 shows the average undercutting rating (see Table 4, 0 (best) to 5 (worst)) for each primer, as an average of all pretreatment and topcoat conditions (with and without a topcoat). The commercial P003 version of the Mg-rich primer and the modified P002+ version consistently receive higher (worse) ratings. However, the scribe protection for all primers is largely identical (Figure 44). While the Mg-rich products generally perform well on the adhesion promoters, as compared to other primers, the performance of any primer over an adhesion promoter is worse than the same primer over one of the qualified pretreatments (Figure 45). Figure 46 shows an average of the undercutting rating for all primers, broken out by pretreatment. As in neutral salt fog, the three qualified conversion coatings are clearly performing better than the two adhesion promoters in acidic salt fog, with the performance gap widening with increased exposure time.

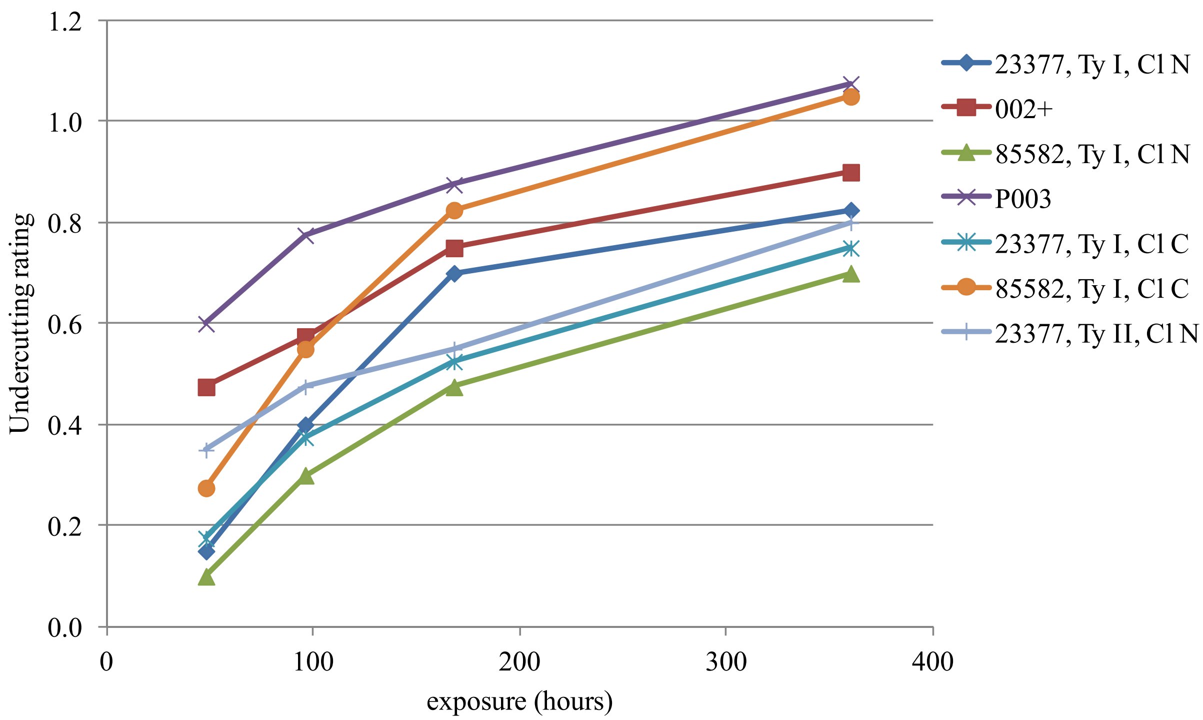


Figure 43: Undercutting rating for each primer, as an average of all pretreatments and topcoat conditions, after exposure to ASTM G 85 acidic salt fog.

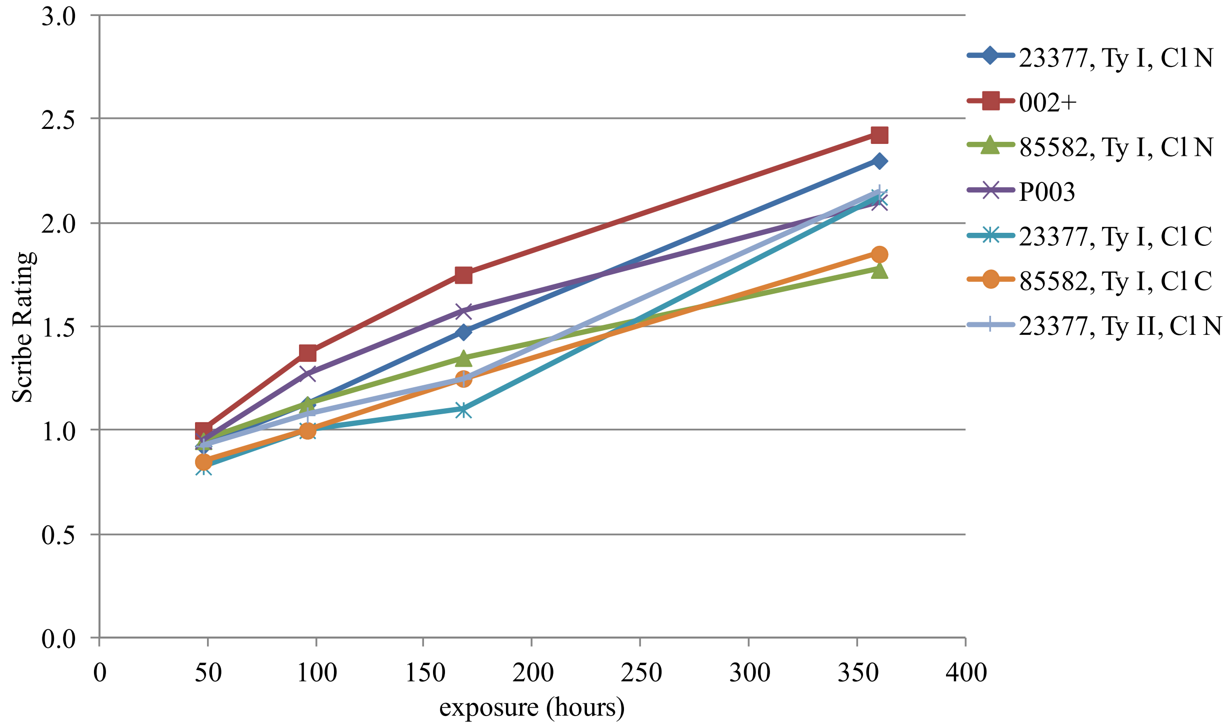


Figure 44: Scribe rating for each primer, as an average of all pretreatments and topcoat conditions, after exposure to ASTM G 85 acidic salt fog.

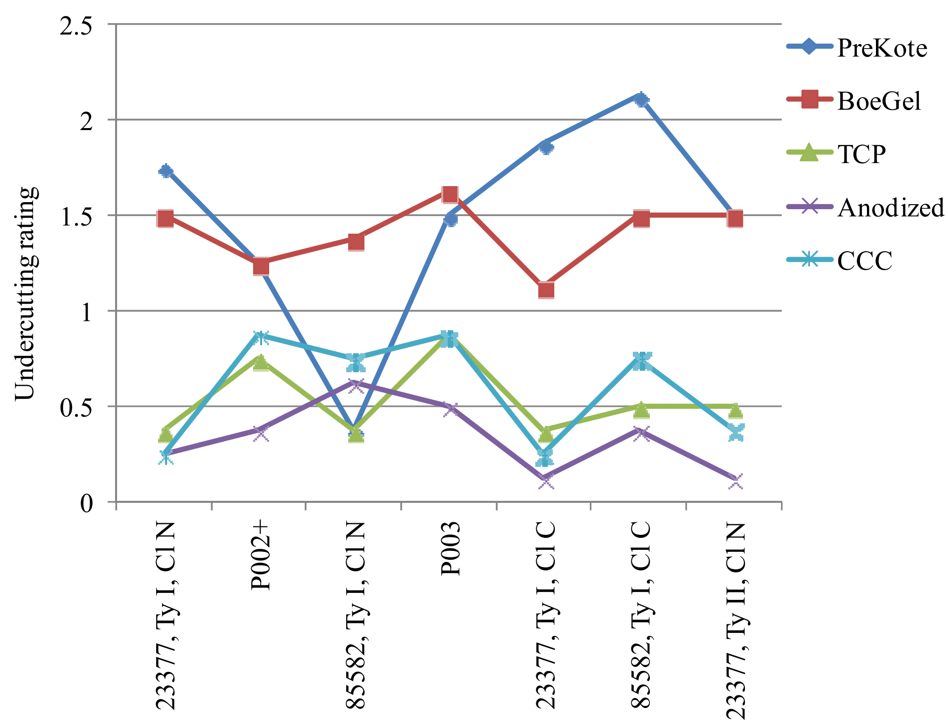


Figure 45: Average undercutting ratings for each primer/pretreatment combination after 360 hours of ASTM G 85 exposure

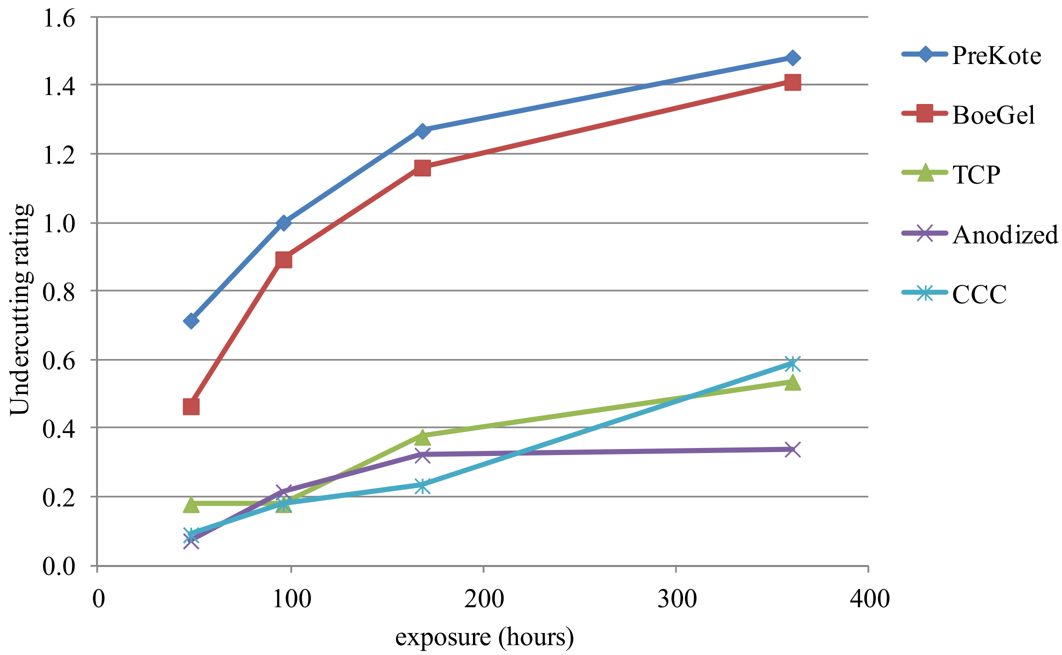


Figure 46: Undercutting rating for each primer, as an average of all pretreatments and topcoat conditions, after exposure to ASTM G 85 acidic salt fog.

6.4.4 Outdoor Exposure

Only galvanic test assemblies were subjected to outdoor exposures at KSC. This is because previous experience has shown that it typically takes several years to obtain useful data from high-performance coating systems on non-galvanic substrates during outdoor exposure. Outdoor samples were rated from 0 (worst) to 10 (best) using the outdoor undercutting rating system in Table 5. Undercutting was evaluated from both the bolts and the scribes. Early results are shown in Figure 47. After only 4 months, differences between the surface treatments are evident, with the conversion coating and anodizing pretreatments performing better than the adhesion promoters (PreKote and BoeGel). In addition, the performance of the waterborne (MIL-PRF-85582) non-chromate primer is noticeably worse than other primers over the non-chromate pretreatments. These performance gaps widened with longer outdoor exposures (Figure 48). It is important to note that of all primers tested over the PreKote and BoeGel adhesion promoters, the P003 Mg-rich primer was consistently the best performer – even better than the chromate control primers. However, their performance with the adhesion promoters are significantly worse than any primer over a qualified surface preparation (i.e. chromate conversion coating, TCP or anodized). It is also important to note that the rating scales used only accounts for undercutting from the scribe. It does not take into account the self-corrosion of the Mg-rich primers typically seen in beach-front testing. In fact, the self corrosion is typically worse around the fasteners and coating edges when compared to the rest of the coating field (Figure 49).

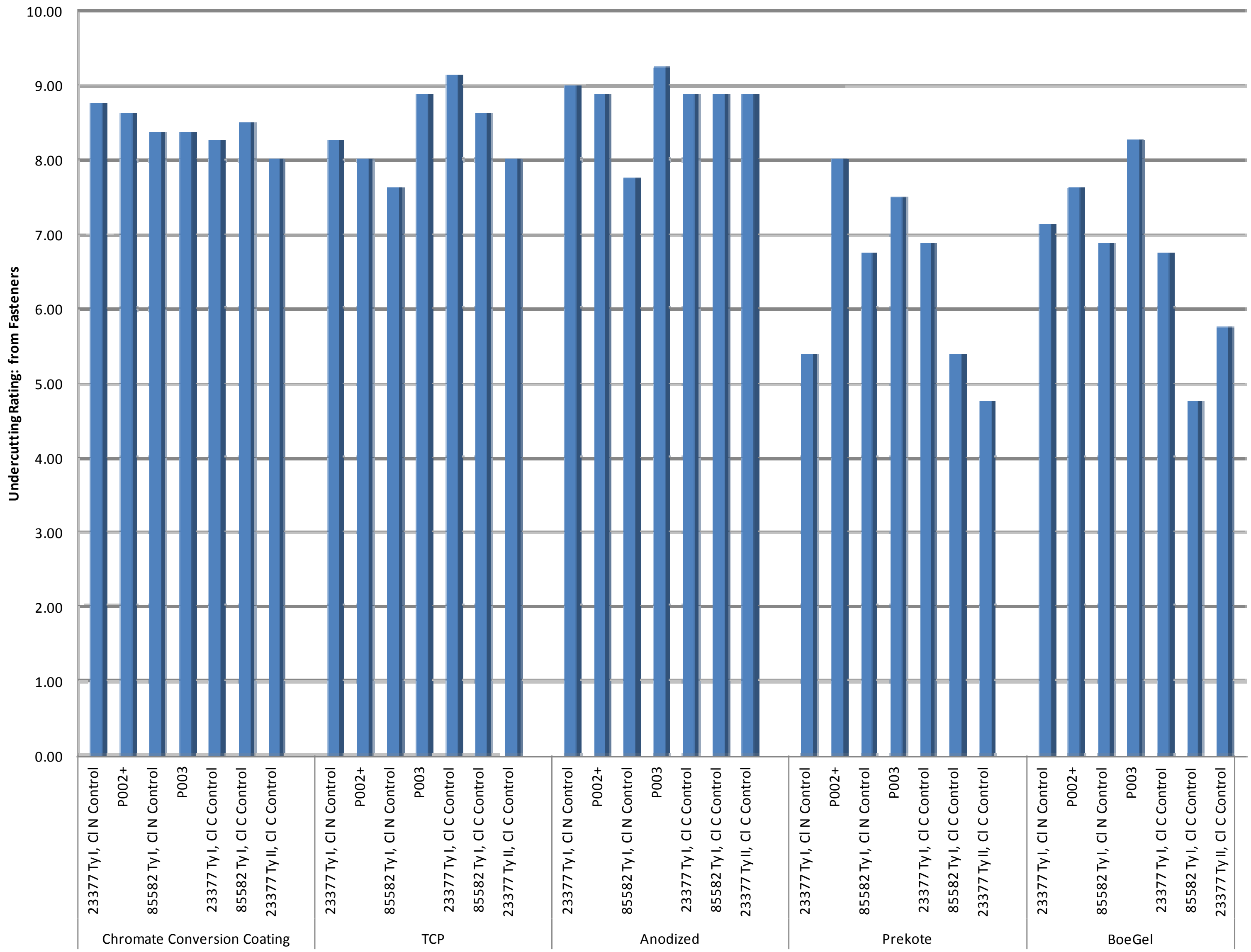


Figure 47: Galvanic fastener panel ratings after 4 months of outdoor exposure at KSC.

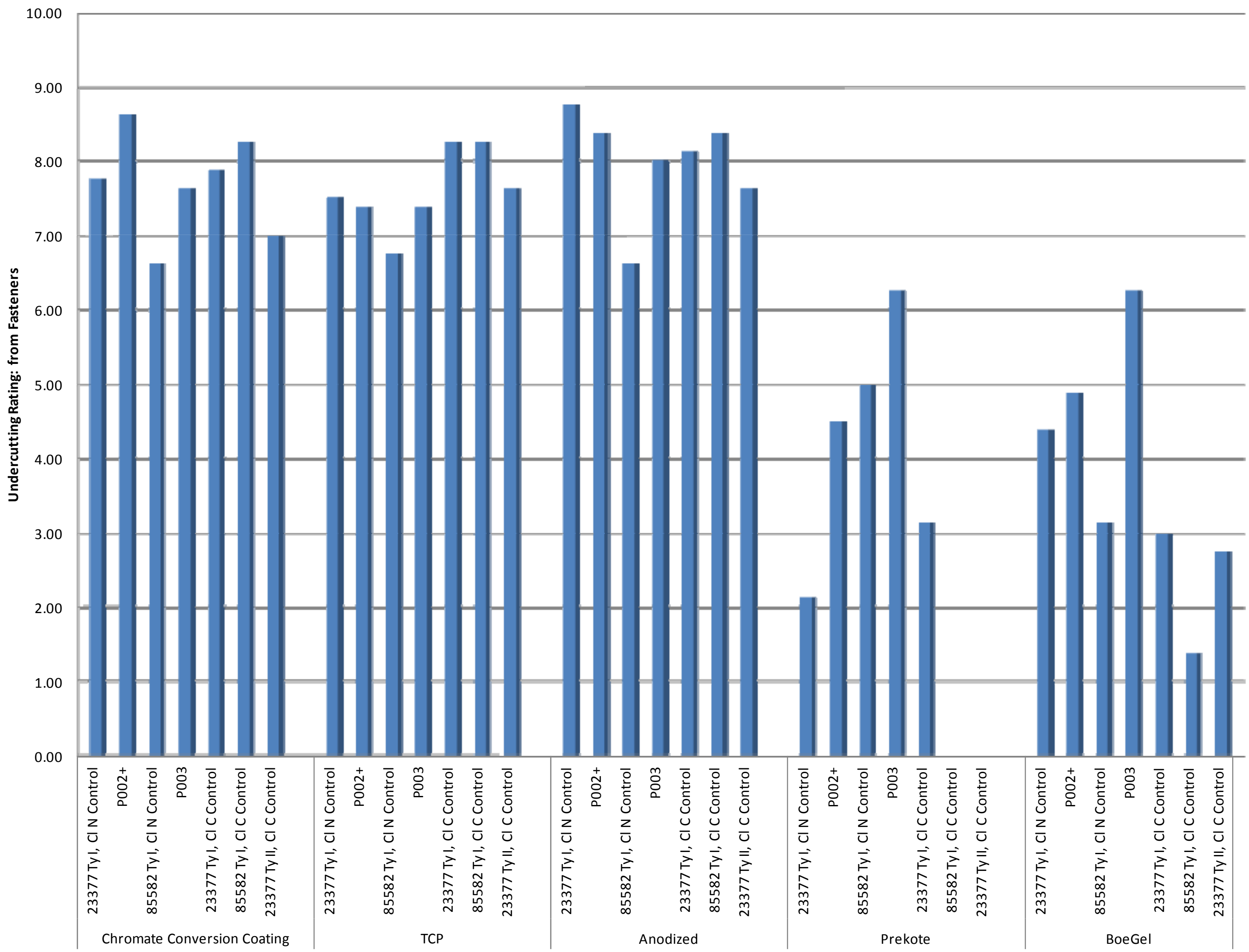
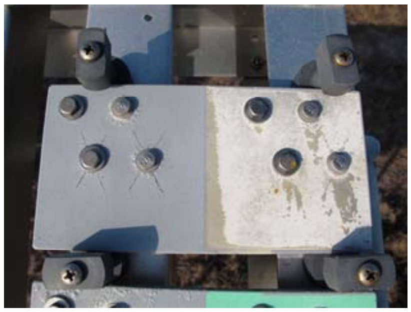


Figure 48: Galvanic fastener panel ratings after 11 months of outdoor exposure at KSC.

CCC

Anodized

TCP



PreKote

BoeGel

Figure 49: P003 Mg-Rich galvanic panels after 36 weeks of outdoor exposure at KSC.

6.4 Testing Summary

The relative performance of the Mg-rich primer, as compared to control coatings, is highly variable depending on the pretreatment. In some instances, such as with PreKote and BoeGel, the Mg-rich primer out-performs both the non-chromate and the chromate controls. However, over pretreatments such as CCC, TCP and anodized, the Mg-rich is not as good as the control coatings. In addition, poor performance was observed when the Mg-rich was tested without a topcoat. This is especially concerning since large portions of the interior of military aircraft do not receive a topcoat, and much of this surface area is in locations that are difficult or impossible to inspect. In addition, relatively poor performance was observed in acidic salt fog, similar to that seen in early Mg-rich primer testing in the early 1970's [8].

Overall, the best performing non-chromate coating system is the qualified Class N primers over TCP. However, if a user was only authorized to use PreKote, the Mg-rich primers may be a viable alternative to chromate primers. The ultimate goal is to produce a commercial non-chromate product that exceeds the performance of the currently qualified non-chromate primers regardless of surface preparation. While improvements to the Mg-rich primer over the past several years have led to increased performance, the Mg-rich primers still fall short of this goal.

7.0 COST ASSESSMENT

The Cost Assessment section is intended to discuss the costs associated with implementing the Mg-rich primer and the life-cycle cost savings it would afford. Since the Mg-rich primer is not being demonstrated through this ESCTP project, this information is not available.

8.0 IMPLEMENTATION ISSUES

One key step in the broad implementation of alternatives to hexavalent chromium is the development of specifications to govern the new coatings. As many companies and government agencies are bound by military and/or commercial specifications, a coordinated approach to updating the related specifications is essential. Individual organizations or programs may implement alternatives based on mechanisms such as approval letters, local process specification changes, or contract modifications. These methods will need to be considered by the user on a case-by-case basis depending on the success of future field-testing.

An additional consideration may be which pretreatment(s) are available to the user. The relative performance of the Mg-rich primer, as compared to control coatings, is highly variable as the pretreatment changes. In some instances, such as with PreKote and BoeGel, the Mg-rich primer out-performs both the non-chromate and the chromate controls. However, over pretreatments such as CCC, TCP and anodized, the Mg-rich is not as good as the control coatings. So, while the best non-chromate alternative is the qualified Class N primers over TCP, if a user was only authorized to use PreKote, the Mg-rich primers are a viable alternative.

NAWC-AD feels that, while the Mg-rich primer has promise as a potential chromate primer alternative, additional work needs to be done to improve the performance over qualified pretreatments and to address the self-corrosion issue seen in primer-only test panels. To this end NAWC-AD and ANAC are pursuing a limited purpose research and development agreement (LP-CRADA). The proposed LP-CRADA would facilitate joint research on the Mg-rich formulation, with an ultimate goal of producing a commercial product that exceeds the performance of the currently qualified non-chromate primers regardless of surface preparation.

Ultimately, each user has unique platforms and operating environments and it will be up to each user to determine acceptable level of performance for their assets.

9.0 REFERENCES

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APPENDICES

Appendix A:
Points of Contact

Name	Organization	Phone Fax E-Mail	Role in Project
Craig Price	Naval Air Systems Command 48066 Shaw Road, Unit 5 Building 2188 Patuxent River, MD 20670-1908	(301) 342-8050 (301) 757-1213 craig.price@navy.mil	PI
Craig Matzdorf	Naval Air Systems Command 48066 Shaw Road, Unit 5 Building 2188 Patuxent River, MD 20670-1908	(301) 342-9372 (301) 757-1213 craig.matzdorf@navy.mil	Co-PI
Michael Spicer	Coatings Technology Integration Office AFRL/RXSSO 2700 D Street, Building 1661 Wright-Patterson AFB, OH 45433	(937) 255-0942 (937) 255-0954 mike.spicer@wpafb.af.mil	AFRL Lead
Joel Johnson	Office of Chief Scientist AFRL/RX 2941 Hobson Way, Bldg. 654 Wright-Patterson AFB, OH 45433	(937) 904-4322 (937) 656-4706 joel.johnson@wpafb.af.mil	Former PI
Patrick Adams	AkzoNobel Aerospace Coatings 5630 New Amsterdam Rd. SW Central, IN 47110	(812) 732-5071 (812) 732-5071 pat.adams@akzonobel.com	ANAC Rep
Elizabeth Shell	Naval Air Systems Command 48066 Shaw Road, Unit 5 Building 2188 Patuxent River, MD 20670-1908	(301) 342-8108 (301) 757-1213 elizabeth.a.shell@navy.mil	Testing Co-ordinator
Rachel Naumann	Naval Air Systems Command 48066 Shaw Road, Unit 5 Building 2188 Patuxent River, MD 20670-1908	(301) 342-8052 (301) 757-1213 rachel.naumann@navy.mil	Testing Co-ordinator

Appendix B:
Round Robin Test Matrix

Project # 896			MAG RICH Round Robin Testing			Account # : 3700 01 0104		
MRRR						Mgr : Chris Joseph		
1st Letter = Coating System .. 2nd = Prep Location .. 3rd = Uncovered / Covered Back .. RED Background = Retain C = CTIO .. A = ANAC .. N = NAVAIR .. B = Boeing .. H = Hill AFB .. K = Kennedy SC .. D = Daytona Beach .. X =Battelle Columbus .. [BLUE Background Application @ CTIO Only P = KSC Pad]								
System	Substrate / Code	Pre Clean	Clean/Wash	De-Ox	Conversion Coat	Primer 0.6 - 0.9 Mils	Topcoat 1.7 - 2.3 Mils	Panel ID #s (12"x12" 8UP)
A	2024-T3 Bare .032"	MEK Wipe	Brulin GD815	Butyl Alcohol 35% IPA 25% Phosphoric Acid 18% DI Water 22%	Alodine 1200S	Deft 02-Y-40	ANAC Aerodur 5000	896-ACU-C01 .. C03
								896-ACU-A04 .. A06
								896-ACU-N07 .. N09
								896-ACU-B10 .. B12
								896-ACU-H13 .. H15
								896-ACU-K16 .. K18
								896-ACU-D19 .. D21
								896-ACU-X22 .. X24
								896-ACU-P25 .. P27
								896-ACC-C01 .. C03
								896-ACC-A04 .. A06
								896-ACC-N07 .. N09
								896-ACC-B10 .. B12
								896-ACC-H13 .. H15
								896-ACC-K16 .. K18
								896-ACC-D19 .. D21
								896-ACC-X22 .. X24
								896-ACC-P25 .. P27
		ANAC Standard			Alodine 1200S	Deft 02-Y-40	ANAC Aerodur 5000	896-AAU-C01 .. C03
								896-AAU-A04 .. A06
								896-AAU-N07 .. N09
								896-AAU-B10 .. B12
								896-AAU-H13 .. H15
								896-AAU-K16 .. K18
								896-AAU-D19 .. D21
								896-AAU-X22 .. X24
								896-AAC-C01 .. C03
								896-AAC-A04 .. A06
								896-AAC-N07 .. N09
								896-AAC-B10 .. B12
								896-AAC-H13 .. H15
								896-AAC-K16 .. K18
								896-AAC-D19 .. D21
								896-AAC-X22 .. X24

Project # 896	MAG RICH Round Robin Testing			Account # : 3700 01 0104	
MRRR				Mgr : Chris Joseph	
Cure Time	Test	# of Panels	Panel #s	Notes	
2024-T3 Bare 0.032"					
14 Day Minimum	Salt Spray	3	C01 - C03	Exposure for 3024 Hrs .. 504 Hr Intermediate Evaluation 896-xxC-xxx = Edge Mask - Back side mask. 896-xxU-xxx = Edge Mask - Back side not masked.	
		3	A04 - A06		
		3	N07 - N09		
		3	B10 - B12		
		3	H13 - H15		
	Outdoor Exposure	3	K16 - K18	Kennedy Space Center	MASKING PER SALT SPRAY REQUIREMENT
		3	D19 - D21	Daytona Beach	
	Salt Spray	3	X22 - X24	Battelle Columbus	
	Outdoor Exposure	3	P25 - P27	KSC Launch Pad	MASKING PER SALT SPRAY REQUIREMENT
	N/A	1	P28	Retain Panels From Each System	

B	2024-T3 Bare .032"	PreKote 3 Step Process per TO 1-1-8 Sections 3.1.20 - 3.1.21	PRC CA 7233	PRC 9311	896-BCU-C01 .. C03
					896-BCU-A04 .. A06
					896-BCU-N07 .. N09
					896-BCU-B10 .. B12
					896-BCU-H13 .. H15
					896-BCU-K16 .. K18
					896-BCU-D19 .. D21
					896-BCU-X22 .. X24
					896-BCU-P25 .. P27
					896-BCC-C01 .. C03
					896-BCC-A04 .. A06
					896-BCC-N07 .. N09
					896-BCC-B10 .. B12
					896-BCC-H13 .. H15
					896-BCC-K16 .. K18
					896-BCC-D19 .. D21
					896-BCC-X22 .. X24
					896-BCC-P25 .. P27
		PreKote 3 Step Process per TO 1-1-8 Sections 3.1.20 - 3.1.21	PRC CA 7233	PRC 9311	896-BAU-C01 .. C03
					896-BAU-A04 .. A06
					896-BAU-N07 .. N09
					896-BAU-B10 .. B12
					896-BAU-H13 .. H15
					896-BAU-K16 .. K18
					896-BAU-D19 .. D21
					896-BAU-X22 .. X24
					896-BAC-C01 .. C03
					896-BAC-A04 .. A06
					896-BAC-N07 .. N09
					896-BAC-B10 .. B12
					896-BAC-H13 .. H15
					896-BAC-K16 .. K18
					896-BAC-D19 .. D21
					896-BAC-X22 .. X24

Project # 896		MAG RICH Round Robin Testing		Account # : 3700 01 0104	
MRRR				Mgr : Chris Joseph	
Cure Time	Test	# of Panels	Panel #s	Notes	
2024-T3 Bare 0.032"					
14 Day Minimum	Salt Spray	3	C01 - C03	Exposure for 3024 Hrs .. 504 Hr Intermediate Evaluation 896-xxC-xxx = Edge Mask - Back side mask. 896-xxU-xxx = Edge Mask - Back side not masked.	
		3	A04 - A06		
		3	N07 - N09		
		3	B10 - B12		
		3	H13 - H15		
	Outdoor Exposure	3	K16 - K18	Kennedy Space Center	MASKING PER SALT SPRAY REQUIREMENT
		3	D19 - D21	Daytona Beach	
	Salt Spray	3	X22 - X24	Battelle Columbus	
	Outdoor Exposure	3	P25 - P27	KSC Launch Pad	MASKING PER SALT SPRAY REQUIREMENT
	N/A	1	P28	Retain Panels From Each System	

C	2024-T3 Bare .032"	PreKote 3 Step Process per TO 1-1-8 Sections 3.1.20 - 3.1.21	ANAC NEG Blank	ANAC Aerodur 5000	896-CCU-C01 .. C03
					896-CCU-A04 .. A06
					896-CCU-N07 .. N09
					896-CCU-B10 .. B12
					896-CCU-H13 .. H15
					896-CCU-K16 .. K18
					896-CCU-D19 .. D21
					896-CCU-X22 .. X24
					896-CCU-P25 .. P27
					896-CCC-C01 .. C03
					896-CCC-A04 .. A06
					896-CCC-N07 .. N09
					896-CCC-B10 .. B12
					896-CCC-H13 .. H15
					896-CCC-K16 .. K18
					896-CCC-D19 .. D21
					896-CCC-X22 .. X24
					896-CCC-P25 .. P27
		PreKote 3 Step Process per TO 1-1-8 Sections 3.1.20 - 3.1.21	ANAC NEG Blank	ANAC Aerodur 5000	896-CAU-C01 .. C03
					896-CAU-A04 .. A06
					896-CAU-N07 .. N09
					896-CAU-B10 .. B12
					896-CAU-H13 .. H15
					896-CAU-K16 .. K18
					896-CAU-D19 .. D21
					896-CAU-X22 .. X24
					896-CAC-C01 .. C03
					896-CAC-A04 .. A06
					896-CAC-N07 .. N09
					896-CAC-B10 .. B12
					896-CAC-H13 .. H15
					896-CAC-K16 .. K18
					896-CAC-D19 .. D21
					896-CAC-X22 .. X24

Appendix B

Project # 896		MAG RICH Round Robin Testing		Account # : 3700 01 0104	
MRRR				Mgr : Chris Joseph	
Cure Time	Test	# of Panels	Panel #s	Notes	
2024-T3 Bare 0.032"					
14 Day Minimum	Salt Spray	3	C01 - C03	Exposure for 3024 Hrs .. 504 Hr Intermediate Evaluation 896-xxC-xxx = Edge Mask - Back side mask. 896-xxU-xxx = Edge Mask - Back side not masked.	
		3	A04 - A06		
		3	N07 - N09		
		3	B10 - B12		
		3	H13 - H15		
	Outdoor Exposure	3	K16 - K18	Kennedy Space Center	MASKING PER SALT SPRAY REQUIREMENT
		3	D19 - D21	Daytona Beach	
	Salt Spray	3	X22 - X24	Battelle Columbus	
	Outdoor Exposure	3	P25 - P27	KSC Launch Pad	MASKING PER SALT SPRAY REQUIREMENT
	N/A	1	P28	Retain Panels From Each System	

D	2024-T3 Bare .032"	PreKote 3 Step Process per TO 1-1-8 Sections 3.1.20 - 3.1.21	ANAC MAG Rich Alt 1	ANAC Aerodur 5000	896-DCU-C01 .. C03
					896-DCU-A04 .. A06
					896-DCU-N07 .. N09
					896-DCU-B10 .. B12
					896-DCU-H13 .. H15
					896-DCU-K16 .. K18
					896-DCU-D19 .. D21
					896-DCU-X22 .. X24
					896-DCU-P25 .. P27
					896-DCC-C01 .. C03
					896-DCC-A04 .. A06
					896-DCC-N07 .. N09
					896-DCC-B10 .. B12
					896-DCC-H13 .. H15
					896-DCC-K16 .. K18
					896-DCC-D19 .. D21
					896-DCC-X22 .. X24
					896-DCC-P25 .. P27
		PreKote 3 Step Process per TO 1-1-8 Sections 3.1.20 - 3.1.21	ANAC MAG Rich Alt 1	ANAC Aerodur 5000	896-DAU-C01 .. C03
					896-DAU-A04 .. A06
					896-DAU-N07 .. N09
					896-DAU-B10 .. B12
					896-DAU-H13 .. H15
					896-DAU-K16 .. K18
					896-DAU-D19 .. D21
					896-DAU-X22 .. X24
					896-DAC-C01 .. C03
					896-DAC-A04 .. A06
					896-DAC-N07 .. N09
					896-DAC-B10 .. B12
					896-DAC-H13 .. H15
					896-DAC-K16 .. K18
					896-DAC-D19 .. D21
					896-DAC-X22 .. X24

Project # 896	MAG RICH Round Robin Testing			Account # : 3700 01 0104	
MRRR				Mgr : Chris Joseph	

Cure Time	Test	# of Panels	Panel #s	Notes	
2024-T3 Bare 0.032"					
14 Day Minimum	Salt Spray	3	C01 - C03	Exposure for 3024 Hrs .. 504 Hr Intermediate Evaluation 896-xxC-xxx = Edge Mask - Back side mask. 896-xxU-xxx = Edge Mask - Back side not masked.	
		3	A04 - A06		
		3	N07 - N09		
		3	B10 - B12		
		3	H13 - H15		
	Outdoor Exposure	3	K16 - K18	Kennedy Space Center	MASKING PER SALT SPRAY REQUIREMENT
		3	D19 - D21	Daytona Beach	
	Salt Spray	3	X22 - X24	Battelle Columbus	
	Outdoor Exposure	3	P25 - P27	KSC Launch Pad	MASKING PER SALT SPRAY REQUIREMENT
	N/A	1	P28	Retain Panels From Each System	

E	2024-T3 Bare .032"	PreKote 3 Step Process per TO 1-1-8 Sections 3.1.20 - 3.1.21	ANAC MAG Rich Alt 2	ANAC Aerodur 5000	896-ECU-C01 .. C03
					896-ECU-A04 .. A06
					896-ECU-N07 .. N09
					896-ECU-B10 .. B12
					896-ECU-H13 .. H15
					896-ECU-K16 .. K18
					896-ECU-D19 .. D21
					896-ECU-X22 .. X24
					896-ECU-P25 .. P27
					896-ECC-C01 .. C03
					896-ECC-A04 .. A06
					896-ECC-N07 .. N09
					896-ECC-B10 .. B12
					896-ECC-H13 .. H15
					896-ECC-K16 .. K18
					896-ECC-D19 .. D21
					896-ECC-X22 .. X24
					896-DCC-P25 .. P27
		PreKote 3 Step Process per TO 1-1-8 Sections 3.1.20 - 3.1.21	ANAC MAG Rich Alt 2	ANAC Aerodur 5000	896-EAU-C01 .. C03
					896-EAU-A04 .. A06
					896-EAU-N07 .. N09
					896-EAU-B10 .. B12
					896-EAU-H13 .. H15
					896-EAU-K16 .. K18
					896-EAU-D19 .. D21
					896-EAU-X22 .. X24
					896-EAC-C01 .. C03
					896-EAC-A04 .. A06
					896-EAC-N07 .. N09
					896-EAC-B10 .. B12
					896-EAC-H13 .. H15
					896-EAC-K16 .. K18
					896-EAC-D19 .. D21
					896-EAC-X22 .. X24

Project # 896 MRRR		MAG RICH Round Robin Testing		Account # : 3700 01 0104 Mgr : Chris Joseph	
Cure Time	Test	# of Panels	Panel #s	Notes	
2024-T3 Bare 0.032"					
14 Day Minimum	Salt Spray	3	C01 - C03	Exposure for 3024 Hrs .. 504 Hr Intermediate Evaluation 896-xxC-xxx = Edge Mask - Back side mask. 896-xxU-xxx = Edge Mask - Back side not masked.	
		3	A04 - A06		
		3	N07 - N09		
		3	B10 - B12		
		3	H13 - H15		
	Outdoor Exposure	3	K16 - K18	Kennedy Space Center	MASKING PER SALT SPRAY REQUIREMENT
		3	D19 - D21	Daytona Beach	
	Salt Spray	3	X22 - X24	Battelle Columbus	
	Outdoor Exposure	3	P25 - P27	KSC Launch Pad	MASKING PER SALT SPRAY REQUIREMENT
	N/A	1	P28	Retain Panels From Each System	

F	2024-T3 Bare .032"	PreKote 3 Step Process per TO 1-1-8 Sections 3.1.20 - 3.1.21	ANAC MAG Rich Aerodur 2100	ANAC Aerodur 5000	896-FCU-C01 .. C03
					896-FCU-A04 .. A06
					896-FCU-N07 .. N09
					896-FCU-B10 .. B12
					896-FCU-H13 .. H15
					896-FCU-K16 .. K18
					896-FCU-D19 .. D21
					896-FCU-X22 .. X24
					896-FCU-P25 .. P27
					896-FCC-C01 .. C03
					896-FCC-A04 .. A06
					896-FCC-N07 .. N09
					896-FCC-B10 .. B12
					896-FCC-H13 .. H15
					896-FCC-K16 .. K18
					896-FCC-D19 .. D21
					896-FCC-X22 .. X24
					896-FCC-P25 .. P27
		PreKote 3 Step Process per TO 1-1-8 Sections 3.1.20 - 3.1.21	ANAC MAG Rich Aerodur 2100	ANAC Aerodur 5000	896-FAU-C01 .. C03
					896-FAU-A04 .. A06
					896-FAU-N07 .. N09
					896-FAU-B10 .. B12
					896-FAU-H13 .. H15
					896-FAU-K16 .. K18
					896-FAU-D19 .. D21
					896-FAU-X22 .. X24
					896-FAC-C01 .. C03
					896-FAC-A04 .. A06
					896-FAC-N07 .. N09
					896-FAC-B10 .. B12
					896-FAC-H13 .. H15
					896-FAC-K16 .. K18
					896-FAC-D19 .. D21
					896-FAC-X22 .. X24

Appendix B

Appendix C:
AFRL Coating System Testing Final Report

MAGNESIUM-RICH (Mg-Rich) PRIMER COATING SYSTEM

FINAL REPORT

Contract No. FA8601-06-D-0013, Delivery Order 5307
CTIO Tracking No: UDRI-3703070104-02
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Prepared by:

Christopher A. Joseph
University of Dayton Research Institute (UDRI)
300 College Park
Dayton, OH 45469-0054

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Accredited Coatings Laboratory
Certificate # L1189-1 Testing

Prepared for:

Coating Technology Integration Office
AFRL/RXSSO
2700 D Street, Building 1661
Wright-Patterson AFB, OH 45433

22 March 2010

Accepted: Approved:

Mike Spicer Date	William Culhane Date
Project Leader, CTIO, RXSSO	Coatings Group Leader, UDRI

ABSTRACT
Chrome containing conversion coatings and primers used on various weapons systems are carcinogens due to the inclusion of hexavalent chrome in the chemical make-up of the products. The United States Air Force (USAF) is committed to reducing and/or eliminating the use of hexavalent chrome and is funding testing of new technologies of materials that can provide corrosion protection of the weapon systems without the use of chrome-containing materials. Magnesium-Rich (Mg-Rich) Primers is one such effort. The magnesium in the primer is a sacrificial anode preferentially corroding instead of the aluminum substrate thus providing protect to the aircraft. This project tested an updated version of Mg-Rich primer supplied by Akzo Nobel Aerospace Coatings (ANAC).

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SUMMARY:

The Mg-Rich primer from ANAC was the best performing coating system out of the four coating systems tested. The negative blank coating system was included and was expected to fail the corrosion tests so in actuality only three coating systems were tested for this project. The three coating systems (Systems A, B, and D) are summarized in **Table C1**. The corrosion testing performed during this effort is being re-tested. The chrome containing coating systems (System A and System B) performed much worse than expected and would not be classified as a pass to any of the current military specifications. Based on these results, the CTIO salt fog cabinets were evaluated and determined to be providing a more corrosive environment. However, the corrosion test data and analysis is very interesting and is being presented. The Mg-Rich primer coating system was the best performing coating system tested when looking at the ASTM B-117 Salt Spray results with protection lasting up to 2000 hours of exposure. The other two systems provided Salt Spray corrosion protection of less than 1000 hours of exposure. The Mg-Rich primer coating system was deficient in Filiform testing and Pencil Hardness. All other tests the Mg-Rich primer coating system was exposed to performed well.

None of the three coating systems tested met all the requirements stated in the MIL-PRF-32239 Coating System Specification.

It is the belief of the Coatings Technology Integration Office (CTIO) that the Mg-Rich primer coating system, when compared to the other coating systems tested, is ready for a field trial and should be moved along to the next phase of testing. As soon as a weapon system is identified for field testing then a decision should be made in favor of the Mg-Rich coating system.

Further work is needed to improve some of the deficiencies that have been found. The test results and discussion of the deficiencies will be made with ANAC.

C1.0 Introduction

Phase 1 testing of a magnesium-rich (Mg-Rich) primer developed by the Akzo Nobel Aerospace Coatings (ANAC) group began at the Coatings Technology Integration Office (CTIO) in August 2007. Mg-Rich primers are environmentally-friendly because they provide corrosion protection for aluminum without carcinogen hexavalent chrome (chrome-6). Great effort is being made on all fronts to eliminate chrome from the conversion coat and primers used on Air Force weapons systems.

Results from the Phase 1 ASTM B 117 *(Standard Test Method of Salt Spray [Fog] Testing)* salt spray exposure indicated a problem with the Mg-Rich coating systems, as the corrosion results were unacceptable after just 500 hours of exposure. These results were not consistent with previous tests performed by ANAC. One theory was that the backs of these panels were not coated, which could have allowed an electrolyte bridge to form from the back of the panel to the front of the panel. A second theory suggested there was a problem with the batch of magnesium pigment used to make the coating. As a result, a series of round robin tests were conducted at various test facilities to determine if the poor salt spray results were isolated to the CTIO test facility or not. The round robin tests confirmed that the formulation of Mg-Rich primer tested was deficient, because multiple testing locations achieved similar results.

This project, funded by the Environmental Security Technology Certification Program (ESTCP), tested the latest version of Mg-Rich primer that was developed and tested by ANAC. Additionally, this project tested the coating systems to a limited number of critical coating tests as specified in MIL-PRF-32239, *Performance Specification: Coating System, Advanced Performance for Aerospace Applications.*

C2.0 Methods, assumptions, and procedures

The test matrix in **Table C1** shows the test panel preparation. The test panels were 3 x 6 x 0.032 inch aluminum alloy (AA) 2024-T3 bare aluminum and AA 7075-T6 bare, except as noted. The test panels were cured for 14 days from the date of topcoat application. The test panels identified for corrosion testing received an X-scribe as described in UDRI/CTIO Laboratory Procedure CLG-LP-019 Salt Spray Corrosion, in accordance with ASTM B 117.

Table C1: Test Matrix.

Mg-Rich System Summary					
System	**Test Panel Preparation**			**Primer**	**Topcoat**
A Control	MEK Wipe	CTIO Standard Prep	Alodine 1600	Deft 02-Y-40	ANAC Aerodur 5000
B HAFB* F16	MEK Wipe	PreKote 3 step process per T.O. 1-1-8**		PRC CA 7233	PRC 9311
C Negative Control	MEK Wipe	PreKote 3 step process per T.O. 1.1.8		ANAC Negative Blank XP-467-053	ANAC Aerodur 5000
D Mg-Rich	MEK Wipe	PreKote 3 step process per T.O. 1.1.8		ANAC 2100P003	ANAC Aerodur 5000

** HAFB (Hill Air Force Base)*
*** T.O. 1-1-8 Application and Removal of Organic Coatings, Aerospace and Non-Aerospace Equipment*

NOTE: SYSTEM C WAS ADDED AS THE NEGATIVE CONTROL. THIS SYSTEM IS THE SAME AS SYSTEM D EXCEPT THAT THE MG-RICH CORROSION INHIBITORS HAVE BEEN REMOVED FROM THE AERODUR 2100 FORMULATION. THIS SYSTEM WAS EXPECTED TO CORRODE TO SHOW THE BENEFIT OF THE MG-RICH TECHNOLOGY.

C2.1 ISO Certification

All tests are covered under the scope of UDRI's ISO 17025 certification.

C2.2 Application

All materials were applied as close to manufacturer's recommendation as possible.

C2.3 Conversion Coat and Pretreatments

C2.3.1 CTIO Standard Prep

Panels were scrubbed using a maroon Scotch-Brite pad and a 10:1 mix of tap water/Brulin. The test panels then received a tap water rinse, were verified to be water break free, and immersed in deionized water. Each rack of panels received a 5-minute immersion in the tap water/Brulin (10:1) circulating bath heated to 140ºF. Panels then received a two-stage rinse: 1) tap water immersion (Tank #2; 10 dunks; without aeration) followed by 2) deionized water low pressure spray (Tank #7). Panels were then immersed in a circulating deoxidizing bath for two minutes. The panels then received a second two-stage rinse: 1) tap water immersion (Tank #4; 10 dunks; with aeration) followed by 2) deionized water low pressure spray (Tank #7). The panels were then immersed in a circulating bath of Alodine 1600 (pH 1.76)

The test panels then received a final two-stage rinse: 1) deionized water immersion (Tank #6; 10 dunks; with aeration) followed by 2) deionized water low pressure rinse. The panels were then allowed to dry overnight at ambient conditions.

C2.3.2 Alodine 1600

Test panels were alkaline-cleaned, deoxidized, and then immersed in Alodine 1600 until a proper coating weight was achieved. Witness panels were used to verify when the proper coating weight was reached. Initial Alodine 1600 application of the AA 2024-T3 clad and bare were below the recommended coating weight (approximately 25 g/ft^2) with an immersion time of 45 seconds. These panels were redone with a longer immersion time (90 seconds) and achieved a proper coating weight with an average of 41 g/ft$^{2.}$ The recommended coating weight is between 40 and 60 g/ft^2.

C2.3.3 PreKote

After the panels were wiped with MEK, a PreKote pretreatment was applied with the three-step process that was modeled after the process used at Hill AFB (HAFB), Ogden, UT.

C2.4 Primers

The target filmbuild for the standard primers was 0.6 mils to 0.9 mils; a cross-coat application method was used to achieve this filmbuild. The target filmbuild for the Mg-Rich primer was 1.0 mil to 1.4 mils. The average filmbuilds are in **Table C2**. Witness panels were sprayed first to verify the number of passes needed to achieve proper filmbuild.

Table C2: Filmbuild Averages.

Average of 16 panels; each panel is 12 x 12 inch			
System	**Primer**	**Topcoat**	**Total**
A	1.00	2.16	3.16
B	0.83	2.14	2.97
C	0.84	2.05	2.89
D	2.00	1.86	3.86

C2.5 Topcoat

Two topcoats were used: 1) PRC-DeSoto 9311, and 2) ANAC Aerodur 5000. The topcoats were cured for a minimum of 14 days at ambient conditions before testing began.

PRC-DeSoto 9311 was part of a control system to simulate the coating system applied on the F-16 at HAFB. The other control, and the two test coating systems, used ANAC Aerodur 5000. The target filmbuild for the topcoats were 1.7 mils to 2.3 mils; a cross-coat application method was used to achieve this filmbuild. The average filmbuilds are in **Table C2**.

C2.6 Filmbuilds

The average filmbuilds were all within the manufacturer's recommendation, except for the Mg-Rich primer (System D).

C2.7 Spray Properties and Appearance

The sprayed materials were visually evaluated for standard spray properties including ease of application, wet appearance, hiding, and other application and appearance properties. There were no application or appearance issues with any of the spray-applied materials.

C2.8 Viscosity

Prior to application, the coatings were tested for viscosity. The viscosities were measured after the material has been mixed per manufacturer's recommendation and a dwell time of 15-30 minutes. Approximately 30 minutes after the viscosity was checked, the materials were sprayed. Viscosity was measured using UDRI/CTIO Laboratory Procedure CLG-LP-012 Ford Cup Viscosity, a procedure based pm ASTM D 1200 *Standard Test Method for Viscosity by Ford Viscosity Cup.*

C2.9 Color and Gloss

Three test panels of each coating system were subjected to 4000 hours of xenon arc exposure. The panels were evaluated approximately every 504 hours until 4000 hours had been reached. Color data were obtained using UDRI/CTIO Laboratory Procedure CLG-LP-036 Xenon-Arc Accelerated Weathering Test, in accordance with MIL-PRF-32239 and ASTM G 155, *Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials.* Color change (Delta E) was measured using CLG-LP-006 Color Measurement of Dry Coatings in accordance with ASTM E 1164 Standard Practice for Obtaining Spectrometric Data for Object – Color Evaluation.

Gloss was measured on the four coating systems. 60° gloss was used and tested per UDRI/CTIO Laboratory Procedure CLG-LP-013 Specular Gloss, according to ASTM D 523 *Standard Test Method for Specular Gloss*.

C2.10 ASTM B117 Salt Spray Exposure

The test panels were evaluated according to UDRI/CTIO Laboratory Procedure CLG-LP-019 Salt Spray Corrosion, in accordance with ASTM B 117 *Standard Practice for Operating Salt Spray (Fog) Apparatus*. Test panels were exposed for approximately 3000 hours. The panels were evaluated and scanned at approximately 504 hours intervals (21 days). The scans include: (1) all three samples for the coating system, (2) panel identification number, and (3) exposure hours.

C2.11 Filiform Corrosion

Filiform corrosion testing was evaluated using UDRI/CTIO Laboratory Procedure CLG-LP-018 Filiform Corrosion, in accordance with procedures described in MIL-PRF-32239.

C2.12 Adhesion and Pencil Hardness

The procedure described by ASTM D 3359-02 *Standard Test Methods for Measuring Adhesion by Tape Test* was followed to determine crosshatch adhesion. Fluid exposure protocols were consistent with those called for by MIL-PRF-32239 and detailed in UDRI/CTIO Laboratory Procedures CLG-LP-023 Fluid Immersion-Hydraulic Fluid; CLG-LP-024 Fluid Immersion-Jet Fuel (JP8+100); and CLG-LP-025 Fluid Immersion-Lubricating Oil. Modified X adhesion tests were determined using CLG-LP-033 Wet Tape Adhesion. Pencil Hardness, before and after fluid exposure, were obtained in accordance with ASTM D 3363-05 *Standard Test Method for Film Hardness by Pencil Test*.

C2.13 Flexibility and Elongation

AA 2024-O 0.020 inch was used as the substrate for these tests. Cold temperature flexibility and ambient temperature flexibility were determined using UDRI/CTIO Laboratory Procedure CLG-LP-020 Low Temperature Flexibility, in accordance with ASTM D 522, *Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings*. Reverse GE Impact was evaluated using UDRI/CTIO Laboratory Procedure CLG-LP-016 GE Impact Flexibility Test, in accordance with ASTM D 6905, *Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings*.

C3.0 Results and Discussion

C3.1 Spray Properties and Appearance

All materials were applied per manufacturer's recommendations. The primers and topcoats were all sprayed with a Devilbiss HVLP Spray Gun. No problems were encountered while applying them. Substrates were painted as 12"x12" panels and then sheared into 3"x6" test panels. Appearance of the painted panels was smooth and defect-free. The painters commented that the Mg-Rich primer sprayed especially well.

C3.2 Viscosity

The viscosities of the coatings were obtained 30 minutes prior to application, and these are reported in **Table C3**. The viscosities are close enough to the manufacturer's recommended range that no problems were experienced during application of the coating systems. The primers had excellent spray qualities.

Table C3: Spray Viscosity (seconds).

Primers		Recommended Viscosity
Deft 02-Y-40	25.1	40 max
PRC CA 7233	19.2	30 max
ANAC Negative Blank	14.6	N/A
ANAC 2100P003 Mg-Rich	17.0	18 - 22
Topcoats		**Recommended Viscosity**
PRC CA 9311	21.7	30 max
ANAC Aerodur 5000	21.4	22 - 32

C3.3 Color and Gloss

C3.3.1 Color (Delta E)

The test data are in **Table C4** and **Figure C1**. The acceptable color change (Delta E) after exposure to 3000 hours of xenon arc is a less than 1.0. The substrate used had no effect on color change. The AA 2024-T3 data and AA 7075-T6 data are very similar. The differences are presented in Table C4a.

Table C4: Delta E after Xenon Arc

Coating System Substrate	Delta E					
	504 Hrs	1008 Hrs	1512 Hrs	2016 Hrs	2520 Hrs	3024 Hrs
(A) Control AA 2024 T3	0.120	0.190	0.179	0.306	0.352	0.467
(B) HAFB AA 2024 T3	0.672	0.791	0.837	0.936	0.959	0.985
(C) Negative Control AA 2024 T3	0.145	0.213	0.200	0.331	0.406	0.535
(D) Mg-Rich AA 2024 T3	0.165	0.207	0.218	0.381	0.505	0.696
(A) Control AA 7075 T6	0.131	0.215	0.199	0.327	0.367	0.404
(B) HAFB AA 7075 T6	0.680	0.760	0.812	0.895	0.916	0.929
(C) Negative Control AA 7075 T6	0.143	0.209	0.215	0.328	0.397	0.541
(D) Mg-Rich AA 7075 T6	0.156	0.222	0.235	0.376	0.474	0.671

Table C4a: Delta E Comparison over Different Substrates after Xenon Arc.

	System A Control	System B HAFB	System C Negative Control	System D Mg-Rich Primer
AA 2024 T3	0.467	0.985	0.535	0.696
AA 7075 T6	0.404	0.929	0.541	0.671

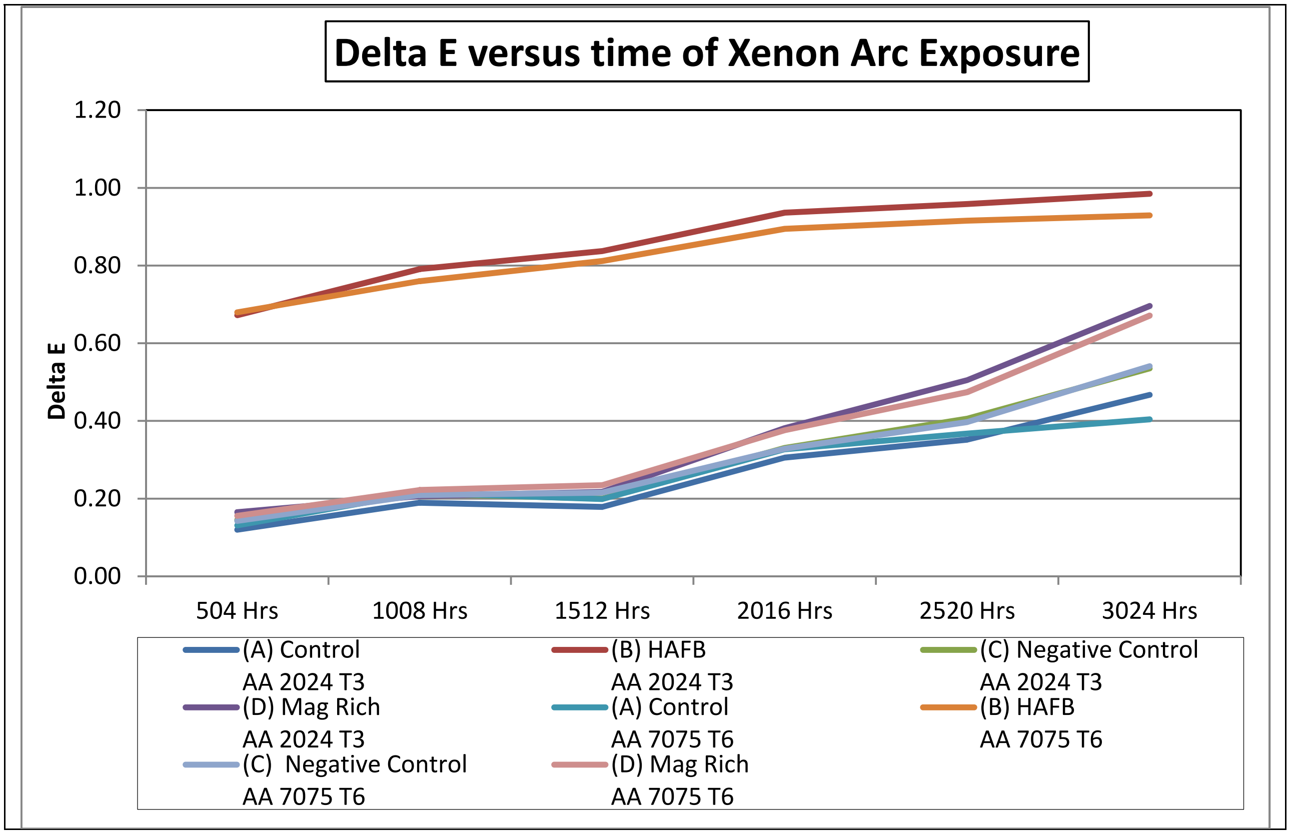


Figure C1: Delta E Plotted Against Xenon Arc Exposure.

The color changes were also calculated after immersion in hydraulic fluid, JP8+100, lube oil and water. The results are in **Table C4b**. The results indicate that the systems including Aerodur 5000 topcoat (Systems A, C, and D) did not have good color retention when exposed to Hydraulic Fluid and to Lubricating Oil. Even the values that were less than Delta E of 1 were very close to failing as the values were all above 0.90.

Table C4b: Delta E after Fluid Immersions.

Coating System Substrate	**Hydraulic Fluid**	**JP8 + 100**	**Lube Oil**	**Water**
(A) Control AA 2024 T3	1.05	0.47	1.10	0.31
(B) HAFB AA 2024 T3	0.51	0.15	0.42	0.20
(C) Negative Control AA 2024 T3	0.97	0.63	1.07	0.28
(D) Mg-Rich AA 2024 T3	0.93	0.74	1.26	0.30
(A) Control AA 7075 T6	0.98	0.61	1.12	0.26
(B) HAFB AA 7075 T6	0.55	0.25	0.33	0.18
(C) Negative Control AA 7075 T6	0.91	0.60	1.10	0.28
(D) Mg-Rich AA 7075 T6	0.99	0.09	1.24	0.31
	Average of AA 2024 T3 and AA 7075 T6			
(A) Control AA 2024 T3	1.02	0.52	0.99	0.27
(B) HAFB AA 2024 T3	0.53	0.20	0.37	0.19
(C) Negative Control AA 2024 T3	0.94	0.61	1.09	0.28
(D) Mg-Rich AA 2024 T3	0.96	0.41	1.25	0.31

C3.3.2 Gloss

The required gloss levels for camouflage topcoats must be below the levels for the different angles of incidence found in **Table C5.** Surprisingly, the only deviance from this was the 85° requirement coating system currently used at Hill AFB. The results are in **Table C6**.

Table C5: Gloss Requirements.

85º angle of incidence	9 max.
60º angle of incidence	5 max.

Table C6: Gloss Results.

Coating System Substrate	**504 Hours**		**1008 Hours**		**1512 Hours**		**2016 Hours**		**2520 Hours**		**3024 Hours**	
	60°	**85°**	**60°**	**85°**	**60°**	**85°**	**60°**	**85°**	**60°**	**85°**	**60°**	**85°**
(A) Control AA 2024 T3	2.3	5.8	2.3	5.9	2.3	6.0	2.2	6.1	2.2	6.3	2.1	6.4
(B) HAFB AA 2024 T3	3.2	10.4	3.2	10.4	3.0	10.2	2.8	10.4	2.6	10.3	2.3	10.2
(C) Negative Control AA 2024 T3	2.0	5.2	2.0	5.3	1.9	5.4	1.9	5.5	1.9	5.8	1.7	5.8
(D) Mg-Rich AA 2024 T3	1.7	4.4	1.7	4.5	1.7	4.7	1.7	4.7	1.6	5.1	1.6	5.1
(A) Control AA 7075 T6	2.3	5.5	2.3	5.6	2.3	5.7	2.3	5.8	2.2	6.0	2.1	6.1
(B) HAFB AA 7075 T6	3.5	10.3	3.4	10.4	3.1	10.3	2.9	10.2	2.7	10.2	2.4	10.5
(C) Negative Control AA 7075 T6	2.1	5.0	2.1	5.2	2.1	5.3	2.0	5.4	2.0	5.5	1.8	5.4
(D) Mg-Rich AA 7075 T6	1.7	4.2	1.8	4.4	1.7	4.5	1.7	4.5	1.7	4.6	1.5	4.6

C3.4 ASTM B117 Salt Spray Exposure
The coating systems were exposed to over 3000 hours of ASTM B117 salt spray exposure. Panels were evaluated and photographs taken at approximately 500 hour intervals. The photos are in the **Appendix.** The rating scale used to evaluate panels is in **Table C7**. The corrosion testing performed during this effort is being re-tested. The chrome containing coating systems (System A and System B) performed much worse than expected and would not be classified as a pass to any of the current military specifications. Based on these results, the CTIO salt fog cabinets were evaluated and determined to be out of specification and was providing a more corrosive environment. However, the corrosion test data and analysis is very interesting and is being presented.
System A: This control system did not perform as well as expected. The primer and topcoat were from different suppliers. The primer was chromated Deft 02-Y-40 and the topcoat applied over the primer was the ANAC Aerodur 5000.
System B: This coating system, used on the F-16 at HAFB, had very poor performance, especially the results over AA 7075 T6. This system was considered a failure after just 504 hours of exposure.
System C: The negative control (primer had no corrosion inhibitors) performed poorly, as expected.
System D: The Mg-Rich primer system with ANAC Aerodur 5000 topcoat had the best performance. Over the AA 2024 T3, there was some scribe staining, but no undercutting. Undercutting can be defined as blistering that initiates at the scribe. Over AA 7075 T6, the Mg-Rich primer had some scribe staining and very little undercutting.
None of the coating systems experienced any field blistering.

Table C7: Rating scale for ASTM B117 Salt Spray.

1st Digit - Scribe Appearance	
0	Bright and clean (**acceptable**)
1	Staining, minor corrosion but no build up (**acceptable**)
2	Minor/moderate corrosion product build up (**unacceptable**)
3	Moderate corrosion product build up (**unacceptable**)
4	Major corrosion product build up (**unacceptable**)
5	Severe corrosion product build up (**unacceptable**)
2nd Digit - Undercutting	
0	No lifting of coating (**acceptable**)
1	Lifting or loss of adhesion up to 1/16" (2 mm) (**unacceptable**)
2	Lifting or loss of adhesion up to 1/8" (3 mm) (**unacceptable**)
3	Lifting or loss of adhesion up to 1/4" (7 mm) (**unacceptable**)
4	Lifting or loss of adhesion up to 1/2" (13 mm) (**unacceptable**)
5	Lifting or loss of adhesion beyond 1/2" (>13 mm) (**unacceptable**)

Size - 3rd Digit - Blistering	
Size	**Frequency**
0 = None (acceptable)	F = Few (**unacceptable**)
1 = Very Small (**unacceptable**)	M = Medium (**unacceptable**)
2 = Small (**unacceptable**)	MD = Medium Dense (**unacceptable**)
3 = Small to Medium (**unacceptable**)	D = Dense (**unacceptable**)
4 = Medium to Large (**unacceptable**)	
5 = Large (**unacceptable**)	

Salt spray exposure results are in **Table C8**. No coating system passed the 3000 hour test requirement called for in MIL-PRF-32239. The Mg-Rich coating system was by far the best performing system, with minimal scribe staining and very little undercutting. This includes System A which contained chrome in the conversion coat and in the primer and System B which contained chrome in just the primer. When comparing the different systems to each other, the best performing system was the Mg-Rich primer system (System D), followed by control System A. The coating system used at HAFB, (System B) performed poorly.

Table C8: ASTM B117 Salt Spray Exposure.

ASTM B 117 Salt Spray	**504 Hours**			**1013 Hours**			**1496 Hours**			**2017 Hours**			**2516 Hours**			**3024 Hours**		
System	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Control 2024	1	0	No	1	0	No	2	1	No	2	0	No	2	1	0	3	1	No
	1	0	No	1	0	No	2	1	No	2	0	No	2	1	0	3	1	No
	1	0	No	2	1	No	2	0	No	2	0	No	2	0	0	3	0	No
HAFB 2024	2	0	No	1	0	No	2	2	No	2	1	No	2	1	0	3	1	No
	2	0	No	2	1	No	2	2	No	2	3	No	2	3	0	3	3	No
	1	0	No	1	0	No	2	1	No	2	1	No	2	2	0	3	2	No
Negative Control 2024	2	2	No	2	4	No	2	5	No	2	5	No	2	5	0	3	5	No
	2	3	No	2	3	No	2	4	No	2	4	No	2	4	0	3	5	No
	2	2	No	2	3	No	2	4	No	2	4	No	2	4	0	3	4	No
Mg-Rich 2024	0	0	No	0	0	No	1	0	No	1	0	No	1	0	0	1	0	No
	0	0	No	0	0	No	1	0	No	2	0	No	2	0	0	2	0	No
	0	0	No	1	0	No	1	0	No	2	0	No	2	0	0	2	1	No
Control 7075	2	1	No	1	1	No	2	1	No	2	2	No	2	1	0	2	1	No
	2	1	No	2	1	No	2	1	No	2	1	No	2	1	0	2	1	No
	2	1	No	2	1	No	2	1	No	2	1	No	2	1	0	2	1	No
HAFB 7075	1	1	No	1	3	No	2	3	No	2	4	No	2	4	0	2	4	No
	0	0	No	2	3	No	2	3	No	2	3	No	2	3	0	2	3	No
	0	0	No	2	3	No	2	3	No	2	3	No	2	3	0	2	3	No
Negative Control 7075	2	4	No	2	5	No	2	5	No	2	5	No	2	5	0	2	5	No
	2	3	No	2	5	No	2	5	No	2	5	No	2	5	0	2	5	No
	2	3	No	2	4	No	2	5	No	2	4	No	2	5	0	2	5	No
Mg-Rich 7075	0	0	No	0	0	No	1	0	No	1	0	No	1	0	0	1	0	No
	1	0	No	1	1	No	1	1	No	1	1	No	2	1	0	1	1	No
	0	0	No	0	0	No	1	0	No	1	0	No	1	0	0	1	0	No
For each exposure time: 1st column Scribe Brightness	For each exposure time: 2nd column Undercutting									For each exposure time: 3rd column Field Blistering								

C3.5 Filiform Corrosion

Filiform corrosion panels were evaluated using a template similar to the one shown in **Figure C2**. Each square of the template is 1/8 x 1/8 inch. The template is initially place on one leg of the X scribe such that the center line covers the scribe mark. The evaluator begins by counting the number of inner squares into which corrosion filiments intrude. This number is recorded and the evaluator then counts the number of outer squares into which filiments intrude. The process is then repeated for the other leg of the X. This is a quantitative system developed by UDRI to help determine a coating system’s ability to protect against filiform corrosion.

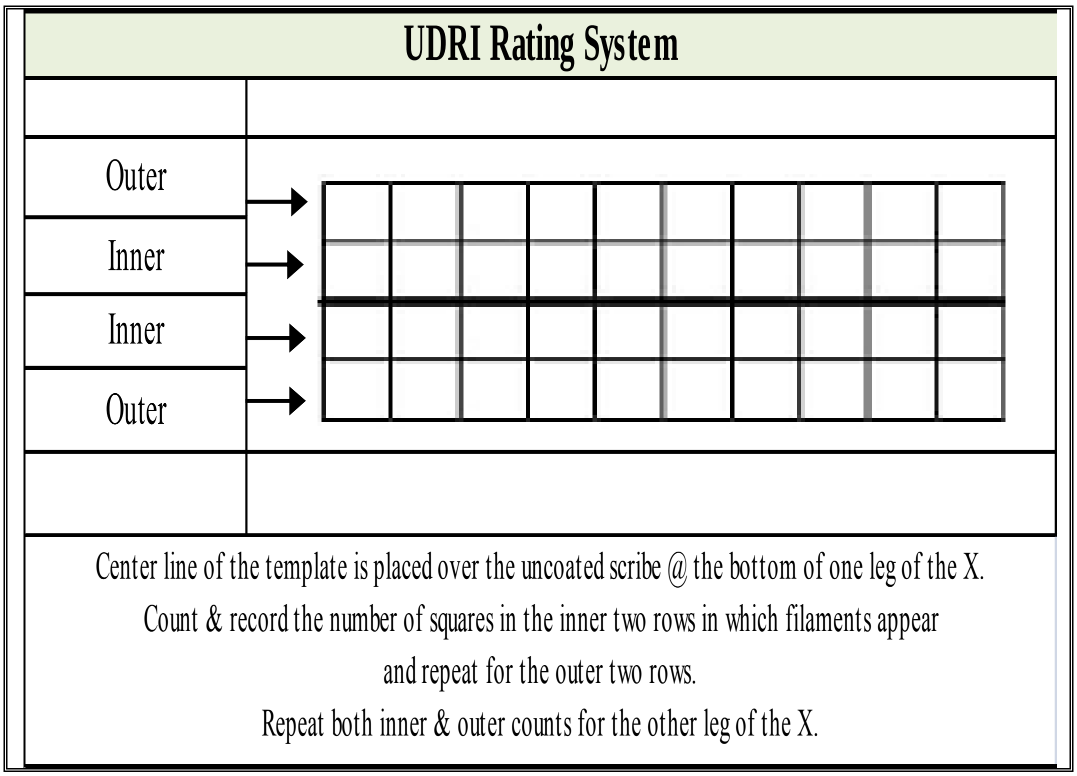


Figure C2: Filiform Corrosion Rating Template (not to scale).

Results of the filiform corrosion test are in **Table C9**. Performance ranking of the systems was different than that observed with ASTM B 117 salt spray exposure. Whereas the Mg-Rich primer performed better than the other systems in salt spray corrosion resistance, it performed worse than the chrome systems in filiform corrosion. The reason for this discrepancy is unclear. One theory is that at the end of a filiform filament is a chloride ion. A chrome conversion coat does a very good job of preventing the chloride ion from penetrating further under a coating. The Mg-Rich primers do not perform as well over a chrome conversion coat, as they act as an insulator and prevent magnesium from acting as a sacrificial metal.

The filiform controls did not achieve filament growth that would normally be expected. Filiform was present on the controls, indicating that there was a proper environment to facilitate filiform growth, but no growth was observed beyond 1/8 inch on the controls.

Table C9: Filiform Corrosion Results.

Panel Rating (1008 hours)									
System	**Inner Legs**		**Inner Count**	**Outer Legs**		**Outer Count**	**Total Count**	**> 1/4"**	
	Right	**Left**		**Right**	**Left**			**Right**	**Left**
Control System A	20	19	39	1	2	3	42	0	0
	20	19	39	4	3	7	46	1	0
	20	19	39	4	2	6	45	0	0
HAFB System B	18	19	37	1	0	1	38	0	0
	20	20	40	0	0	0	40	0	0
	20	20	40	0	0	0	40	0	0
Negative Control System C	20	20	40	20	20	40	80	10	11
	20	20	40	20	20	40	80	6	13
	20	20	40	20	20	40	80	19	17
Mag-Rich Primer System D	20	20	40	18	14	32	72	3	0
	20	20	40	17	15	32	72	2	2
	20	20	40	15	20	35	75	6	4
Filiform Controls	**20**	**20**	**40**	**0**	**0**	**0**	**40**	**0**	**0**
	20	**20**	**40**	**0**	**0**	**0**	**40**	**0**	**0**
	20	**20**	**40**	**0**	**0**	**0**	**40**	**0**	**0**

C3.6 Adhesion and Pencil Hardness

C3.6.1 Adhesion

The Mg-Rich primer coating (System D) passed all adhesion tests. Ratings of 4B or 5B were given for all crosshatch tests and 5A ratings for the Modified X test. The results were similar for both AA 2024-T3 and AA 7075-T6.

The control coating (System A) had very poor adhesion between the topcoat and the primer. It is possible that a light scuff sand of the primer would facilitate better adhesion, but scuff sanding the entire outer mold line of an aircraft may not be feasible. The rating scales used to rate crosshatch adhesion and modified X adhesion are in **Figures C3-C4**. The adhesion data are in **Table C10**.

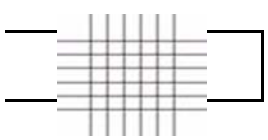
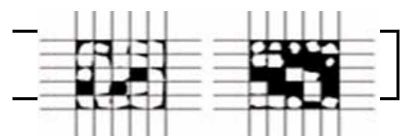
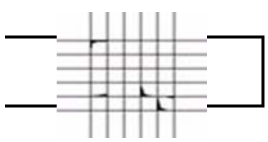
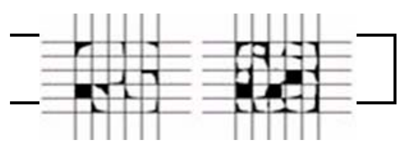
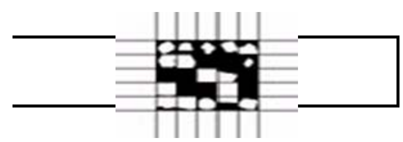
Classification - Percent Area Removed					
5B 0%		3B 5 - 15%		1B 35 - 65%	
4B < 5%		2B 15 - 35%		0B > 65%	

Figure C3: Crosshatch Adhesion Rating Scale.

5A	No peeling or removal.	2A	Jagged removal along most of incision up to 1/8" on either side.
4A	Trace peeling of removal along incisions or at intersections.	1A	Removal from most of the area of the X under the tape.
3A	Jagged removal along incisions up to 1/16" on either side.	0A	Removal beyond the area of the X.

Figure C4: Modified X Rating Scale.

Table C10: Adhesion Results (Crosshatch and Modified X).

System	**Before Immersion**	**After JP8 + 100**	**After Water**	**After Hydraulic Fluid**	**After Lubricating Oil**	**Wet Tape Modified X**
Control AA 2024 T3	**2B**	**3B**	4B	**1B**	**0B**	**0A**
	2B	**1B**	4B	**1B**	**1B**	**0A**
	3B	**3B**	4B	**1B**	**1B**	**1A**
HAFB AA 2024 T3	5B	4B	4B	5B	5B	5A
	5B	4B	4B	5B	5B	**2A**
	5B	4B	4B	5B	5B	5A
Negative Control AA 2024 T3	5B	4B	4B	5B	5B	**3A**
	5B	4B	4B	5B	5B	5A
	5B	4B	4B	5B	5B	4A
Mg-Rich AA 2024 T3	**5B**	**4B**	**4B**	**5B**	**5B**	**5A**
	5B	**4B**	**4B**	**5B**	**5B**	**5A**
	5B	**4B**	**4B**	**5B**	**5B**	**5A**
Control AA 7075 T6	5B	4B	4B	**1B**	**2B**	**1A**
	5B	**3B**	4B	**1B**	4B	5A
	2B	**3B**	4B	**1B**	5B	**1A**
HAFB AA 7075 T6	5B	4B	4B	5B	5B	4A
	5B	4B	4B	4B	5B	5A
	5B	4B	4B	5B	5B	4A
Negative Control AA 7075 T6	5B	4B	5B	5B	5B	4A
	5B	4B	4B	5B	5B	**3A**
	5B	4B	4B	4B	5B	4A
Mg-Rich AA 7075 T6	**5B**	**4B**	**4B**	**5B**	**5B**	**5A**
	5B	**4B**	**4B**	**5B**	**5B**	**5A**
	5B	**4B**	**4B**	**5B**	**5B**	**5A**

C3.6.2 Pencil Hardness

The pencil hardness ratings for MIL-PRF-32239 require the coating system to not soften more than two hardness levels after exposure in fluids. The Mg-Rich primer (Systems D) passed when used over AA 2024-T3 substrate, but did not pass when used over AA 7075-T6. System D softened three hardness levels after exposure to JP8 + 100 jet fuel and softened an average of 3.3 hardness levels after water exposure. The results are in **Table C11**.

Table C11: Pencil Hardness Results. (Rating Scale shown)

		6B 5B 4B 3B 2B B HB F H 2H 3H 4H 5H 6H ←→ **Soft** … **Hard**							
System and Substrate	**Initial**	JP8 + 100	JP8 +100 Change	Water	Water Change	Hydraulic Fluid	Hydraulic Fluid Change	Lubricating Oil	Lubricating Oil Change
Control AA 2024 T3 (A)	**B**	3B	-2	2B	-1	B	0	2B	-1
	B	3B	-2	2B	-1	B	0	2B	-1
	B	3B	-2	2B	-1	B	0	2B	-1
HAFB AA 2024 T3 (B)	**4H**	H	-3	3H	-1	5H	1	3H	-1
	4H	H	-3	3H	-1	5H	1	3H	-1
	4H	H	-3	3H	-1	5H	1	4H	0
Negative Control AA 2024 T3 (C)	**2H**	F	-2	F	-2	2H	0	2H	0
	2H	F	-2	F	-2	2H	0	2H	0
	2H	F	-2	F	-2	2H	0	2H	0
Mg-Rich AA 2024 T3 (D)	**2H**	F	-2	F	-2	3H	1	F	-2
	2H	F	-2	F	-2	3H	1	F	-2
	2H	F	-2	F	-2	3H	1	F	-2
Control AA 7075 T6 (A)	**2B**	2B	0	2B	0	2B	0	2B	0
	B	2B	1	2B	-1	2B	-1	2B	-1
	B	2B	1	2B	-1	2B	-1	2B	-1
HAFB AA 7075 T6 (B)	**3H**	F	-3	3H	0	5H	2	3H	0
	3H	F	-3	3H	0	5H	2	3H	0
	3H	F	-3	3H	0	5H	2	3H	0
Negative Control AA 7075 T6 (C)	**2H**	F	-2	F	0	2H	0	F	-2
	2H	F	-2	F	0	2H	0	F	-2
	2H	F	-2	F	0	2H	0	F	-2
Mg-Rich AA 7075 T6 (D)	**3H**	F	-3	F	-3	3H	0	2H	-1
	3H	F	-3	HB	-4	3H	0	2H	-1
	3H	F	-3	F	-3	3H	0	2H	-1

C3.7 Flexibility and Elongation (GE Reverse Impact)
All coating systems passed the flexibility and elongation tests with the results in **Table C12**.

Table C12: Flexibility Results.

Low Temperature Flexibility		**Room Temperature Flexibility**	
Control AA 2024 T3	**No Cracking**	Control AA 2024 T3	**No Cracking**
	No Cracking		**No Cracking**
	No Cracking		**No Cracking**
HAFB AA 2024 T3	**No Cracking**	HAFB AA 2024 T3	**No Cracking**
	No Cracking		**No Cracking**
	No Cracking		**No Cracking**
Negative Control AA 2024 T3	**No Cracking**	Negative Control AA 2024 T3	**No Cracking**
	No Cracking		**No Cracking**
	No Cracking		**No Cracking**
Mg-Rich AA 2024 T3	**No Cracking**	**Mg-Rich AA 2024 T3**	**No Cracking**
	No Cracking		**No Cracking**
	No Cracking		No Cracking

The MIL-PRF-32239 specification states that for Class 1 coating systems: *"When tested in accordance with paragraphs 4.6.15.1, the coating system shall exhibit a minimum impact elongation of… 40 percent for camouflage coating systems…"*
The controls (positive and negative) passed the elongation test (GE reverse impact) with the Mg-Rich primer (System D) achieving at least a 40% elongation using the visual check or the pinhole detector. In contrast, the Mg-Rich primer (System D) achieved a 20%. The final results for elongation are in **Table C13**.

Table C13: Elongation Results (GE Reverse Impact).

Coating System	***Visual Inspection with 10 X Microscope****	***Examination with Elcometer Pin Hole Detector*****
Control AA 2024 T3	40%	40%
	40%	40%
	40%	40%
HAFB AA 2024 T3	40%	40%
	40%	40%
	40%	40%
Negative Control AA 2024 T3	40%	40%
	40%	60%
	40%	60%
Mg-Rich AA 2024 T3	20%	20%
	20%	20%
	20%	20%

** The percent elongation is determined from the largest segment indentation that did not produce cracking.*
*** Pinhole detection is determined from the largest segment indentation that did not produce an audible tone.*

C4.0 Conclusion

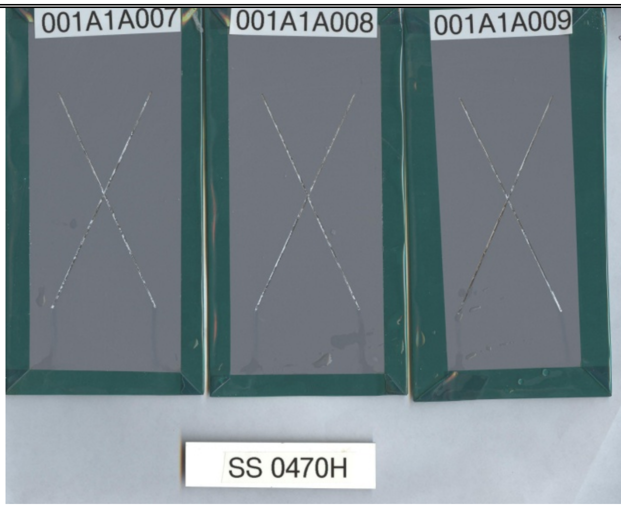
The Mg-Rich primer performed well in most of the coating tests: adhesion, flexibility, and color and gloss (xenon arc exposure). Salt spray performance was better than the chrome controls, although it did not quite meet the MIL-PRF-32239 specification. The material had some deficiencies in fluid resistance, elongation, and filiform corrosion. Based on this data, a decision will be made on whether or not to move forward with a field trial. Because of the importance to eliminate chrome from Air Force coating systems, the Mg-Rich primer coating system, even with a few deficiencies, appears to be a viable candidate for a field trial.

A summary of the complete test results is in **Table C14**. None of the coating systems performed well enough to pass the MIL-PRF-32239 specification. If this is the case with the best performing non-chrome coating system then the MIL-PRF-32239 specification may be extremely difficult to pass, especially a completely non-chrome coating system.

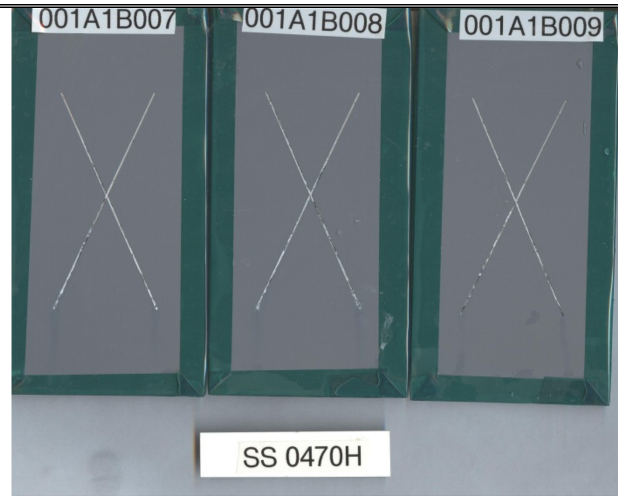
Table C14: Final Data Summary.

Test	**Control System A**	**Hill AFB System B**	**Negative Control System C**	**Mg-Rich System D**
Viscosity				
Color				
Gloss				
60° Angle of Incidence				
85° Angle of Incidence		500 Hours		
ASTM B117 Salt Spray	500 Hours	1000 Hours	500 Hours	2000 Hours
Filiform				
Adhesion				
Initial				
After JP8+100				
After Water				
After Hydraulic Fluid				
After Lubricating Oil				
Wet Tape (Modified X)				
Pencil Hardness				
Initial				
After JP8+100				
After Water				
After Hydraulic Fluid				
After Lubricating Oil				
Flexibility				
Elongation				

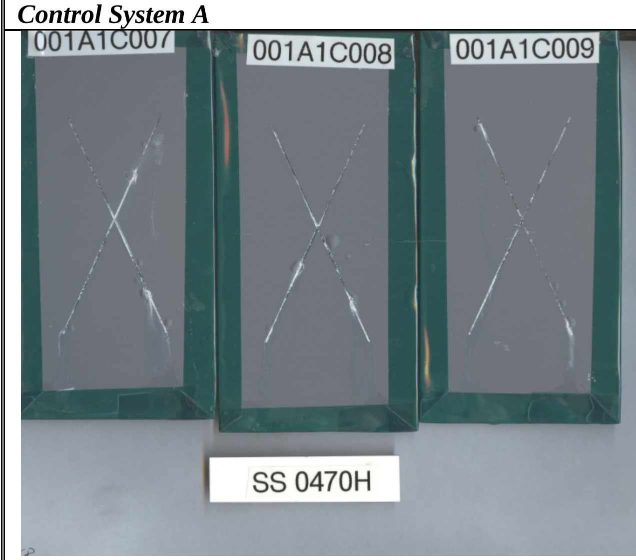
C Appendix – ASTM B 117 Photos



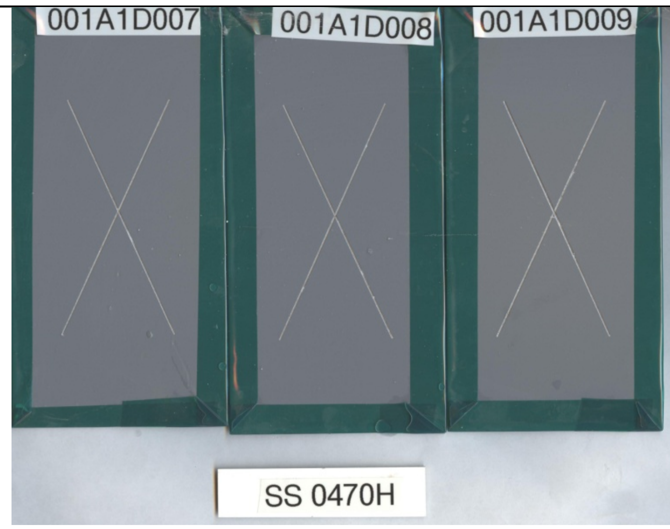
Control System A



HAFB Coating System B

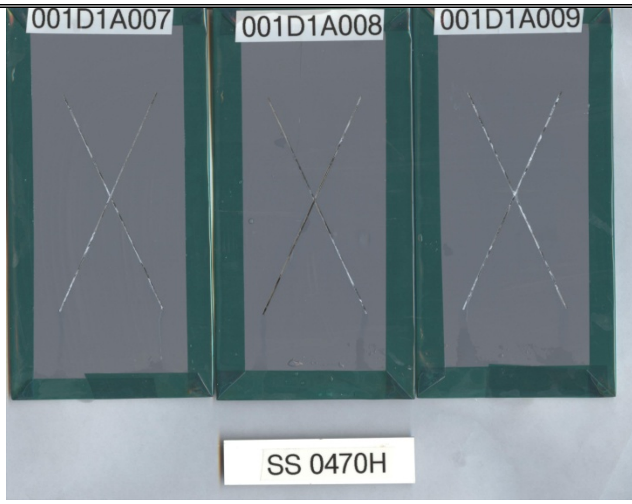


Negative Blank System C



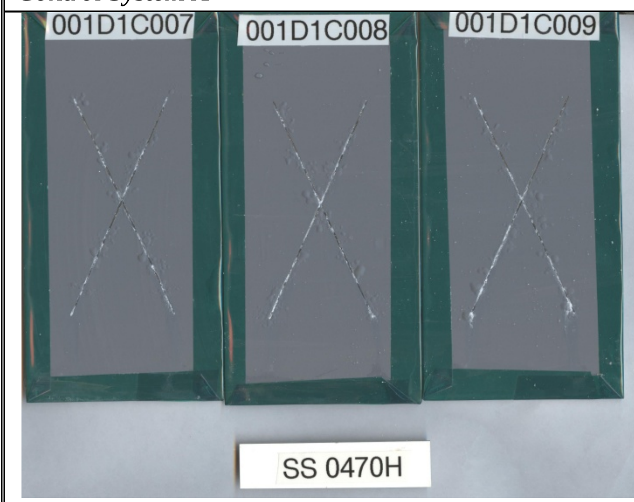
Mg-Rich Primer System D

Photo C1: 470 Hours ASTM B117 Salt Spray – AA 2024 T3.

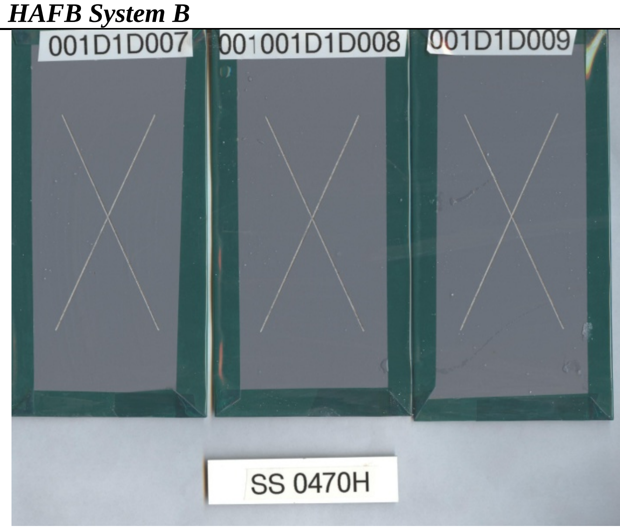


Control System A

HAFB System B

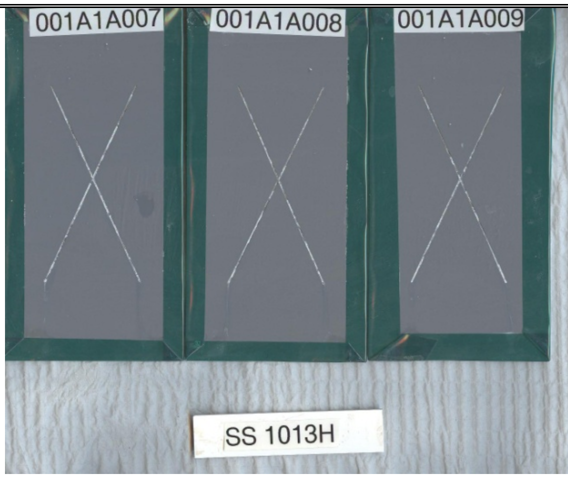


Negative Control System C

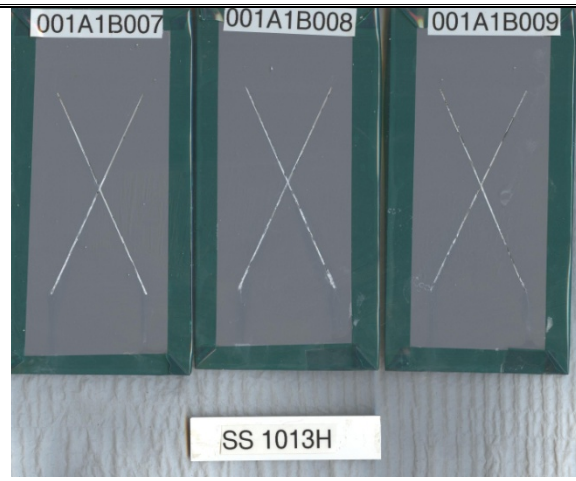


Mg-Rich Primer System D

Photo C2: 470 Hours ASTM B117 Salt Spray – AA 7075 T6.

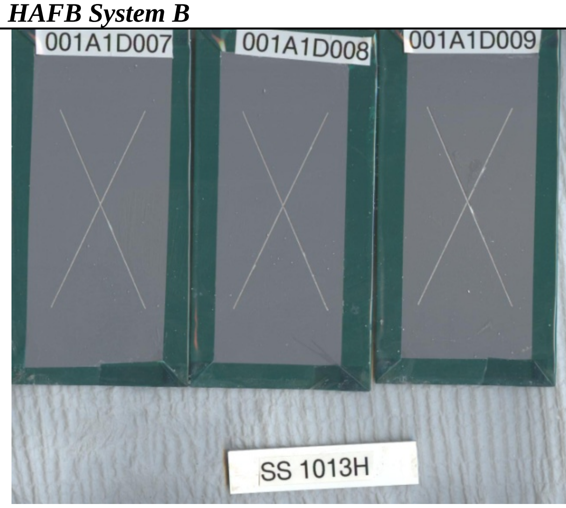


Control System A



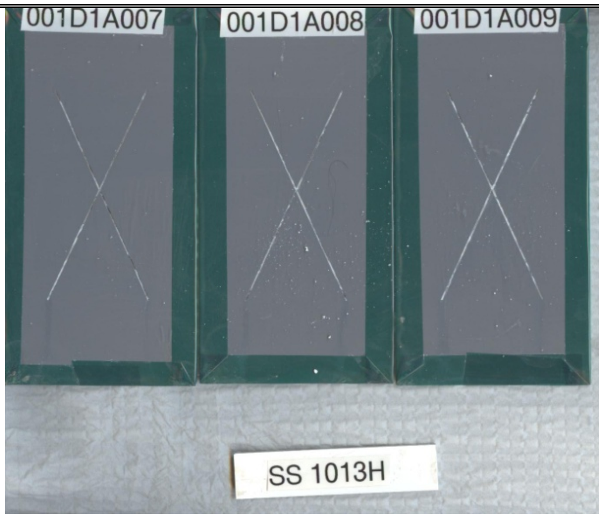
HAFB System B

Negative Control System C

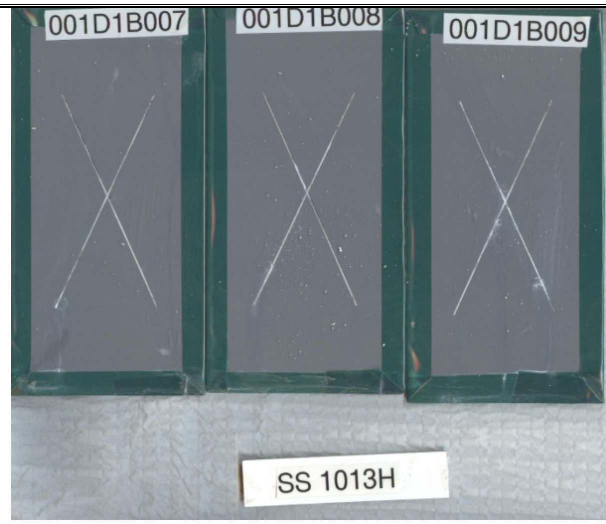


Mg-Rich Primer System D

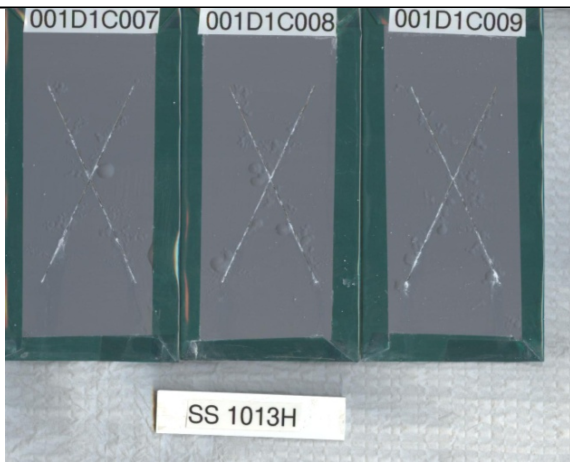
Photo C3: 1013 Hours ASTM B117 Salt Spray – AA 2024 T3



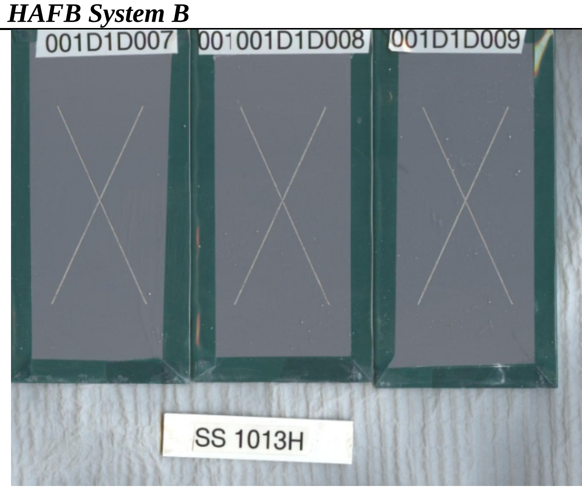
Control System A



HAFB System B

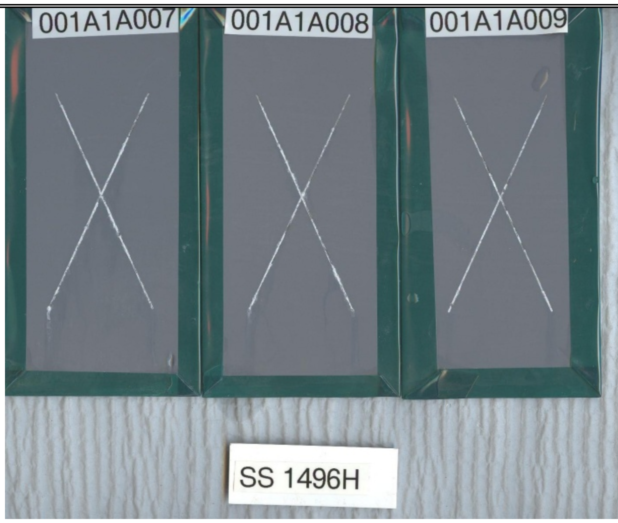


Negative Control System C

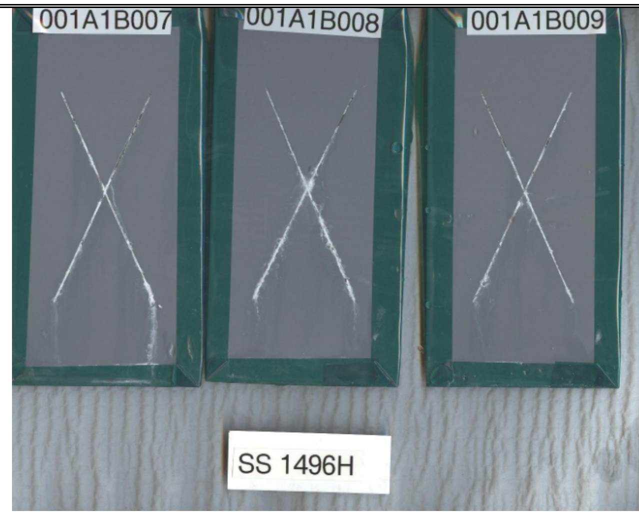


Mg-Rich Primer System D

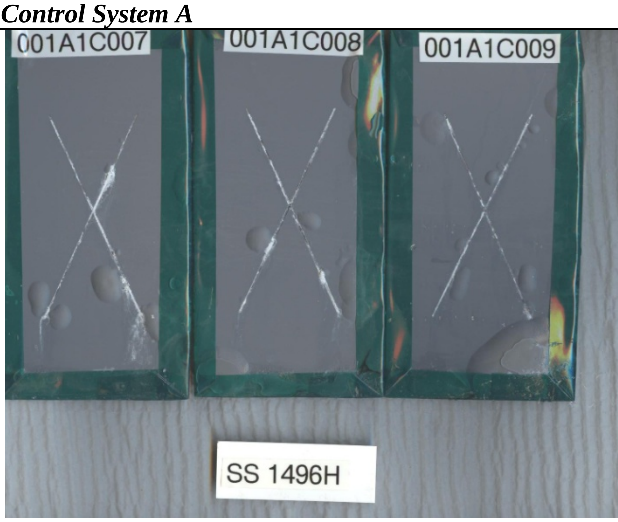
Photo C4: 1013 Hours ASTM B117 Salt Spray – AA 7075 T6



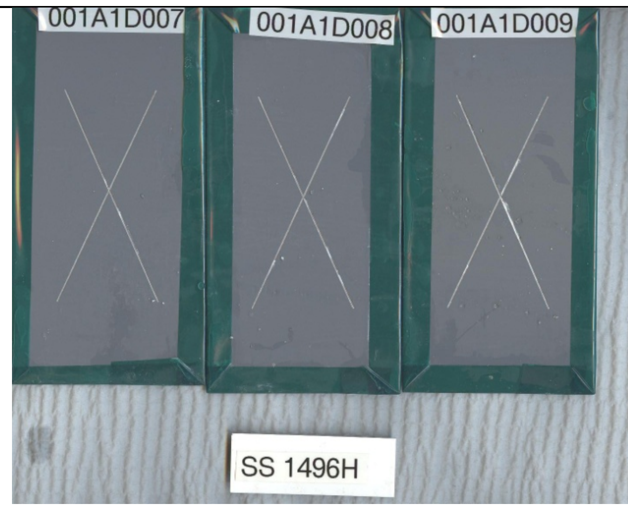
Control System A



HAFB System B

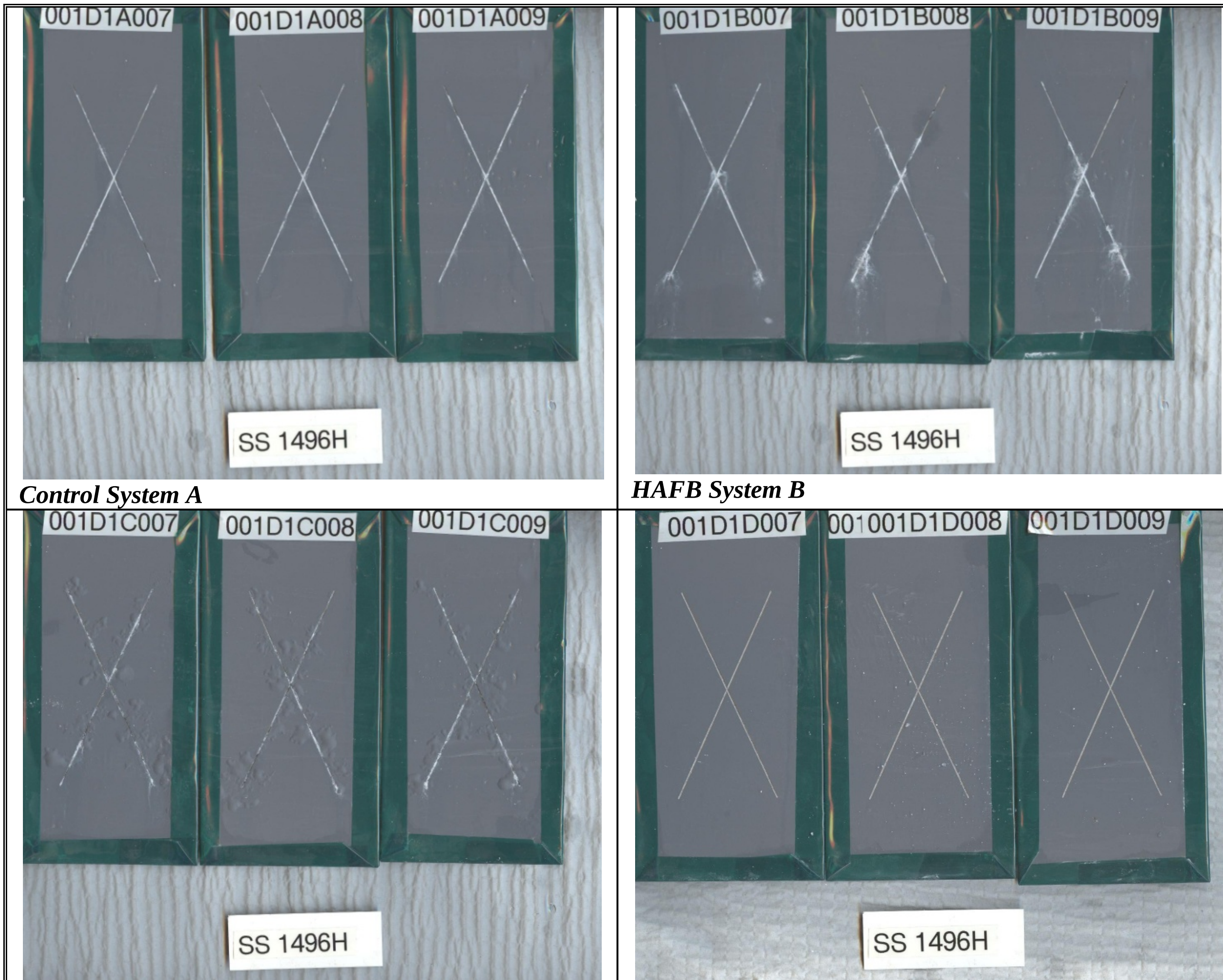


Negative Control System C



Mg-Rich Primer System D

Photo C5: 1496 Hours ASTM B117 Salt Spray – AA 2024 T3.



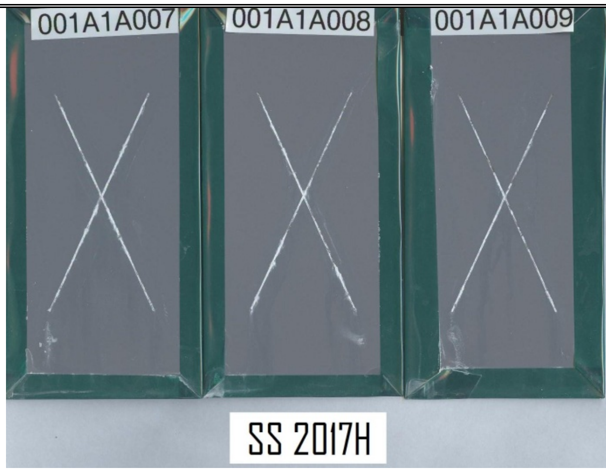
Control System A

HAFB System B

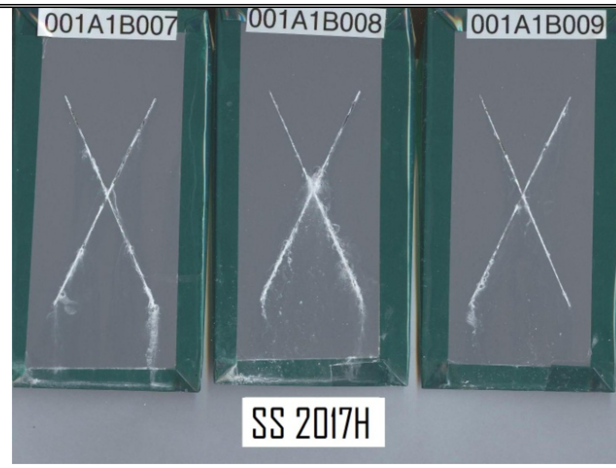
Negative Control System C

Mg-Rich Primer System D

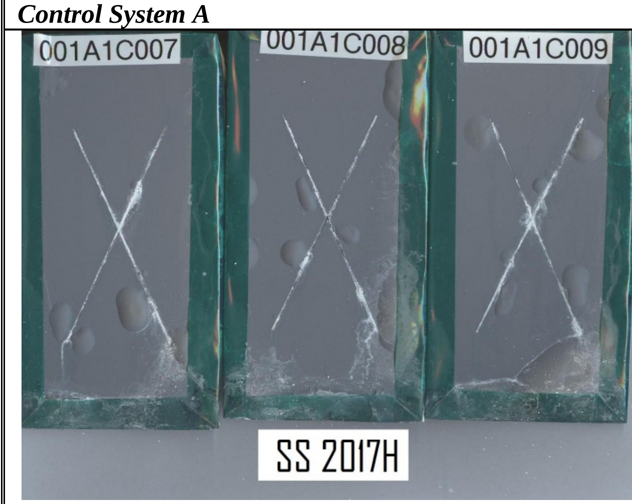
Photo C6: 1496 Hours ASTM B117 Salt Spray – AA 7075 T6.



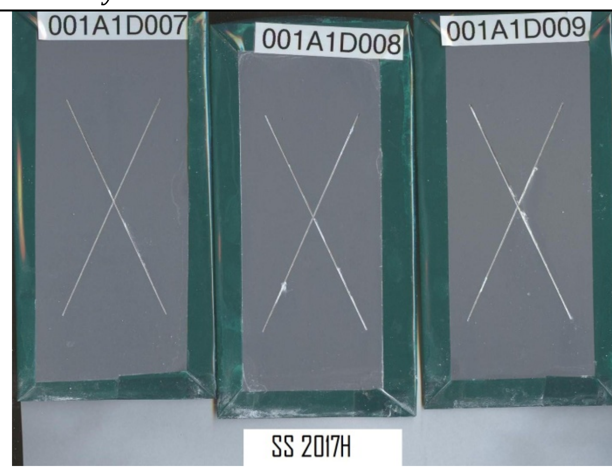
Control System A



HAFB System B

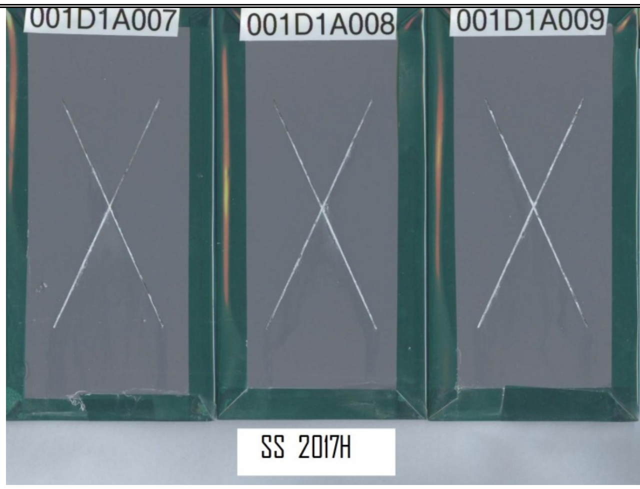


Negative Control System C

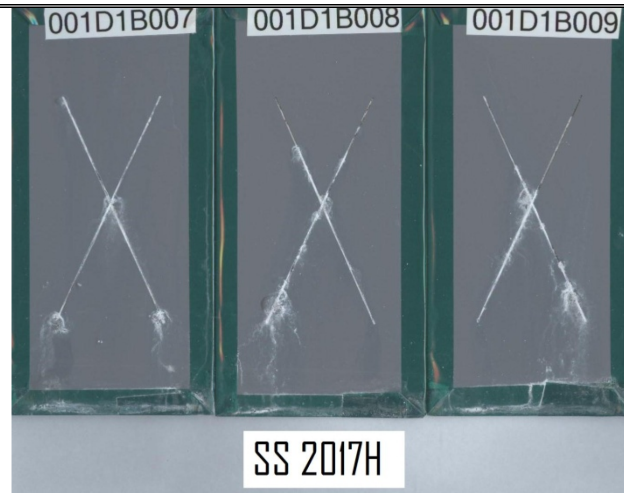


Mg-Rich Primer System D

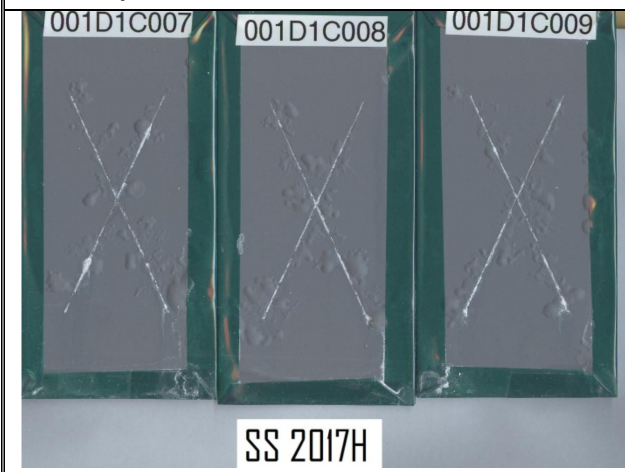
Photo C7: 2017 Hours ASTM B117 Salt Spray – AA 2024 T3.



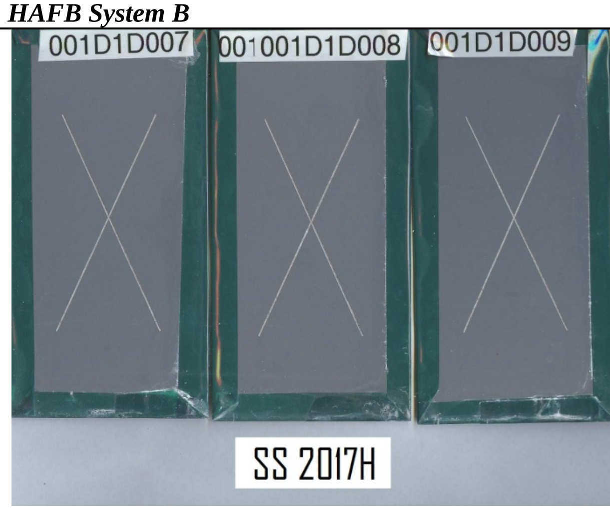
Control System A



HAFB System B

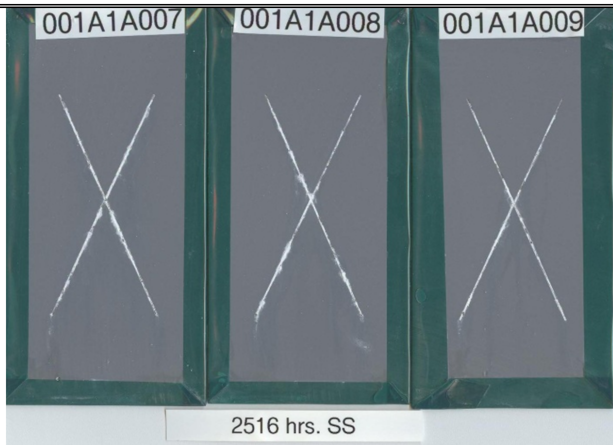


Negative Control System C

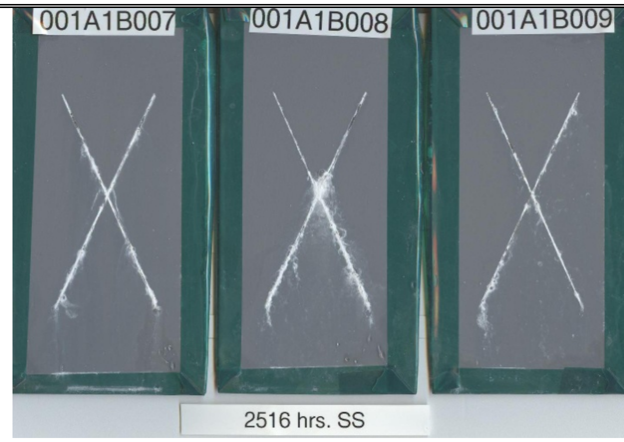


Mg-Rich Primer System D

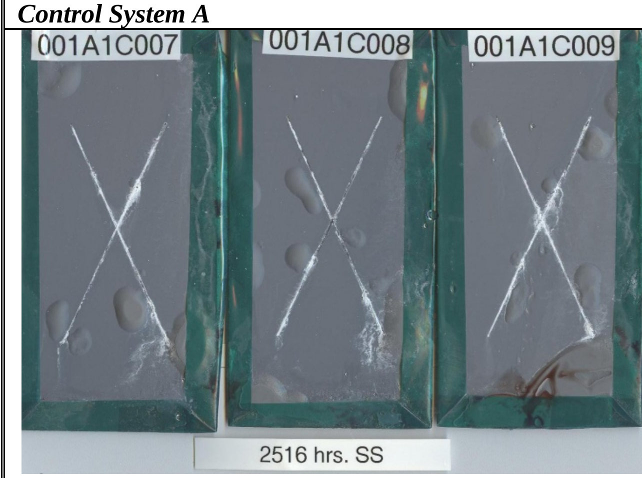
Photo C8: 2017 Hours ASTM B117 Salt Spray – AA 7075 T6.



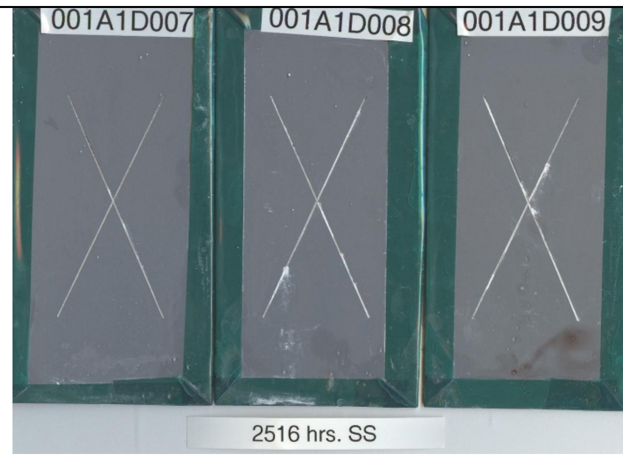
Control System A



HAFB System B

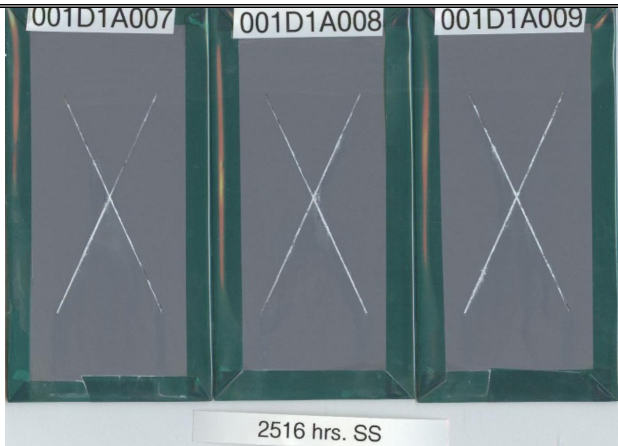


Negative Control System C

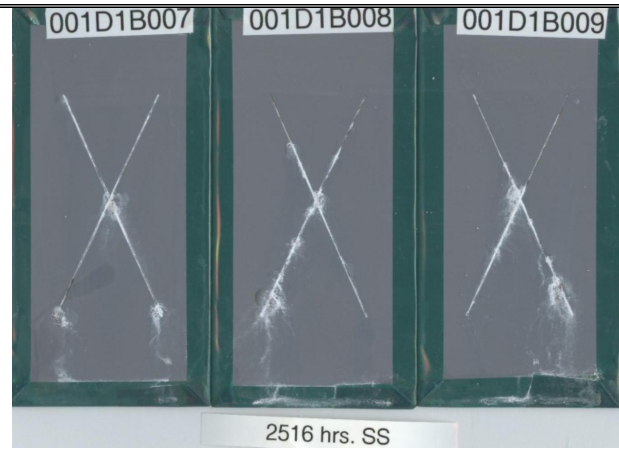


Mg-Rich Primer System D

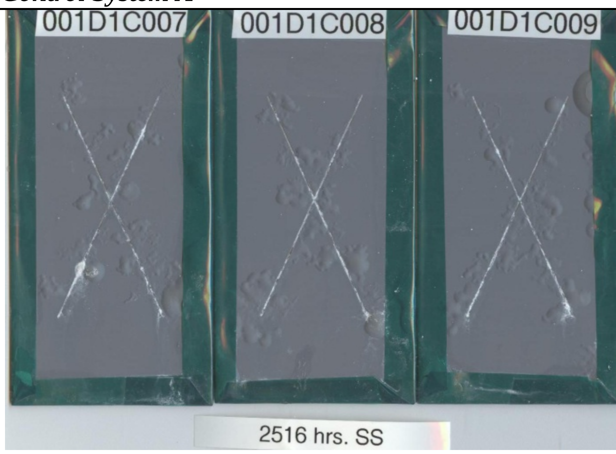
Photo C9: 2516 Hours ASTM B117 Salt Spray – AA 2024 T3.



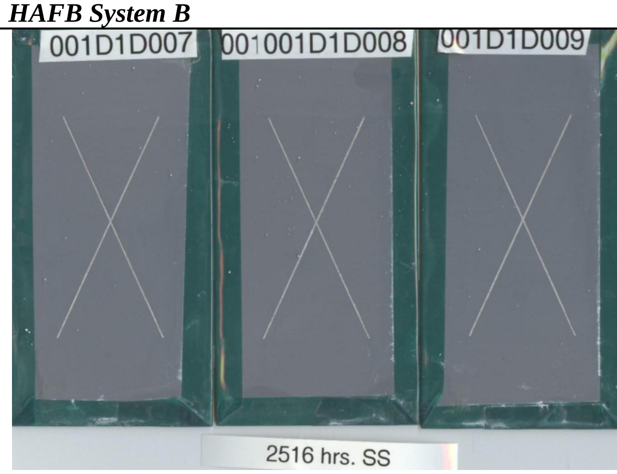
Control System A



HAFB System B

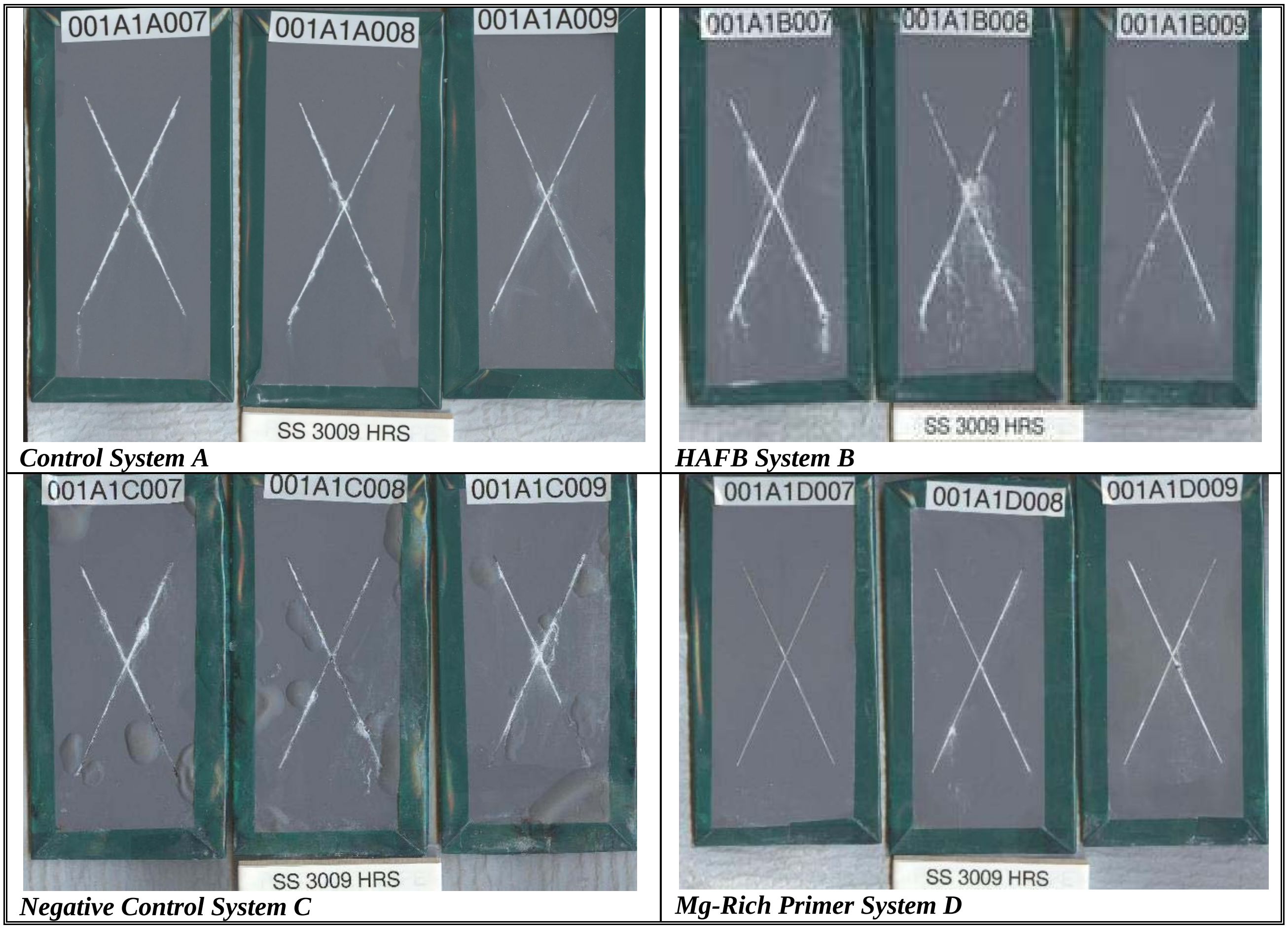


Negative Control System C



Mg-Rich Primer System D

Photo C10: 2516 Hours ASTM B117 Salt Spray – AA 7075 T6.



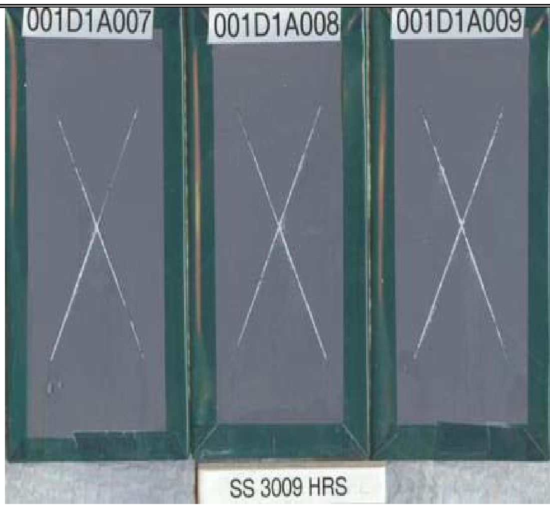
Control System A

HAFB System B

Negative Control System C

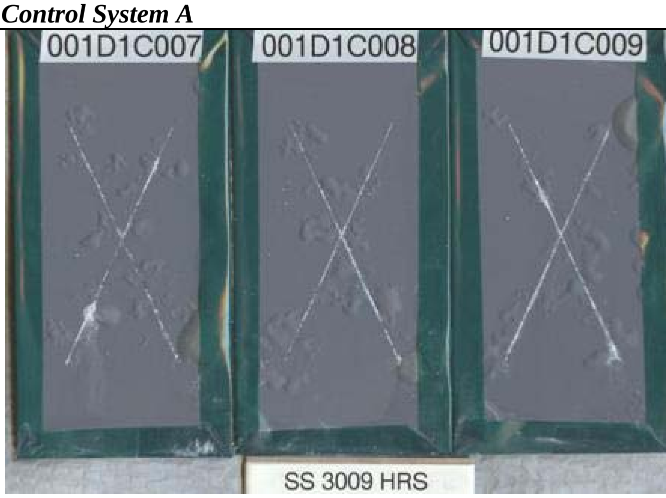
Mg-Rich Primer System D

Photo C11: 3024 Hours ASTM B117 Salt Spray – AA 2024 T3.

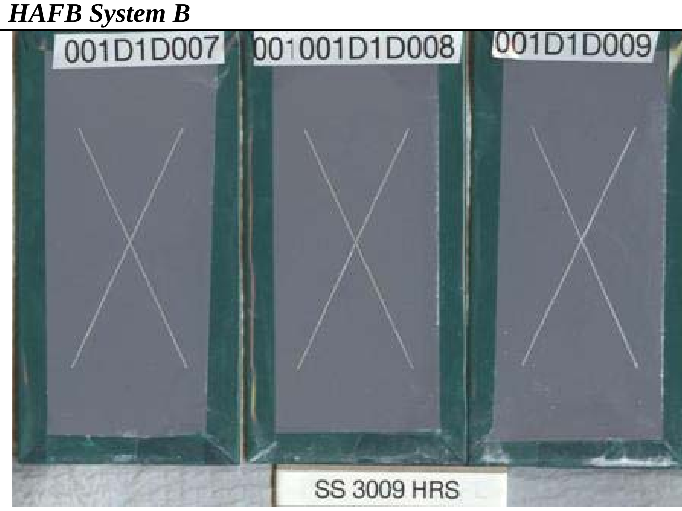


Control System A

HAFB System B



Negative Control System C



Mg-Rich Primer System D

Photo C12: 3024 Hours ASTM B117 Salt Spray – AA 7075 T6

END OF REPORT

Appendix D:
Comprehensive Non-Chromate Primer Test Matrix

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-2-1	ASTM B 117	2024-T3	PreKote	23377 Ty I, Cl N	none
10-3-2-2				23377 Ty I, Cl N	none
10-3-2-3				23377 Ty I, Cl N	none
10-3-2-4				23377 Ty I, Cl N	yes
10-3-2-5				23377 Ty I, Cl N	yes
10-3-2-6				23377 Ty I, Cl N	yes
10-3-2-7				NAVAIR 002+	none
10-3-2-8				NAVAIR 002+	none
10-3-2-9				NAVAIR 002+	none
10-3-2-10				NAVAIR 002+	yes
10-3-2-11				NAVAIR 002+	yes
10-3-2-12				NAVAIR 002+	yes
10-3-2-13				85582 Ty I, Cl N	none
10-3-2-14				85582 Ty I, Cl N	none
10-3-2-15				85582 Ty I, Cl N	none
10-3-2-16				85582 Ty I, Cl N	yes
10-3-2-17				85582 Ty I, Cl N	yes
10-3-2-18				85582 Ty I, Cl N	yes
10-3-2-19				ANAC's P2100P003	none
10-3-2-20				ANAC's P2100P003	none
10-3-2-21				ANAC's P2100P003	none
10-3-2-22				ANAC's P2100P003	yes
10-3-2-23				ANAC's P2100P003	yes
10-3-2-24				ANAC's P2100P003	yes
10-3-2-25				23377 Ty I, Cl C	none
10-3-2-26				23377 Ty I, Cl C	none
10-3-2-27				23377 Ty I, Cl C	none
10-3-2-28				23377 Ty I, Cl C	yes
10-3-2-29				23377 Ty I, Cl C	yes
10-3-2-30				23377 Ty I, Cl C	yes
10-3-2-31				85582 Ty I, Cl C	none
10-3-2-32				85582 Ty I, Cl C	none
10-3-2-33				85582 Ty I, Cl C	none
10-3-2-34				85582 Ty I, Cl C	yes
10-3-2-35				85582 Ty I, Cl C	yes
10-3-2-36				85582 Ty I, Cl C	yes
10-3-2-37				27737 Ty II, Cl C	none
10-3-2-38				27737 Ty II, Cl C	none
10-3-2-39				27737 Ty II, Cl C	none
10-3-2-40				27737 Ty II, Cl C	yes
10-3-2-41				27737 Ty II, Cl C	yes
10-3-2-42				27737 Ty II, Cl C	yes
10-3-2-43			BoeGel	23377 Ty I, Cl N	none

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-2-44				23377 Ty I, Cl N	none
10-3-2-45				23377 Ty I, Cl N	none
10-3-2-46				23377 Ty I, Cl N	yes
10-3-2-47				23377 Ty I, Cl N	yes
10-3-2-48				23377 Ty I, Cl N	yes
10-3-2-49				NAVAIR 002+	none
10-3-2-50				NAVAIR 002+	none
10-3-2-51				NAVAIR 002+	none
10-3-2-52				NAVAIR 002+	yes
10-3-2-53				NAVAIR 002+	yes
10-3-2-54				NAVAIR 002+	yes
10-3-2-55				85582 Ty I, Cl N	none
10-3-2-56				85582 Ty I, Cl N	none
10-3-2-57				85582 Ty I, Cl N	none
10-3-2-58				85582 Ty I, Cl N	yes
10-3-2-59				85582 Ty I, Cl N	yes
10-3-2-60				85582 Ty I, Cl N	yes
10-3-2-61				ANAC's P2100P003	none
10-3-2-62				ANAC's P2100P003	none
10-3-2-63				ANAC's P2100P003	none
10-3-2-64				ANAC's P2100P003	yes
10-3-2-65				ANAC's P2100P003	yes
10-3-2-66				ANAC's P2100P003	yes
10-3-2-67				23377 Ty I, Cl C	none
10-3-2-68				23377 Ty I, Cl C	none
10-3-2-69				23377 Ty I, Cl C	none
10-3-2-70				23377 Ty I, Cl C	yes
10-3-2-71				23377 Ty I, Cl C	yes
10-3-2-72				23377 Ty I, Cl C	yes
10-3-2-73				85582 Ty I, Cl C	none
10-3-2-74				85582 Ty I, Cl C	none
10-3-2-75				85582 Ty I, Cl C	none
10-3-2-76				85582 Ty I, Cl C	yes
10-3-2-77				85582 Ty I, Cl C	yes
10-3-2-78				85582 Ty I, Cl C	yes
10-3-2-79				27737 Ty II, Cl C	none
10-3-2-80				27737 Ty II, Cl C	none
10-3-2-81				27737 Ty II, Cl C	none
10-3-2-82				27737 Ty II, Cl C	yes
10-3-2-83				27737 Ty II, Cl C	yes
10-3-2-84				27737 Ty II, Cl C	yes
10-3-2-85			81706 Ty II	23377 Ty I, Cl N	none
10-3-2-86				23377 Ty I, Cl N	none
10-3-2-87				23377 Ty I, Cl N	none
10-3-2-88				23377 Ty I, Cl N	yes
10-3-2-89				23377 Ty I, Cl N	yes

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-2-90				23377 Ty I, Cl N	yes
10-3-2-91				NAVAIR 002+	none
10-3-2-92				NAVAIR 002+	none
10-3-2-93				NAVAIR 002+	none
10-3-2-94				NAVAIR 002+	yes
10-3-2-95				NAVAIR 002+	yes
10-3-2-96				NAVAIR 002+	yes
10-3-2-97				85582 Ty I, Cl N	none
10-3-2-98				85582 Ty I, Cl N	none
10-3-2-99				85582 Ty I, Cl N	none
10-3-2-100				85582 Ty I, Cl N	yes
10-3-2-101				85582 Ty I, Cl N	yes
10-3-2-102				85582 Ty I, Cl N	yes
10-3-2-103				ANAC's P2100P003	none
10-3-2-104				ANAC's P2100P003	none
10-3-2-105				ANAC's P2100P003	none
10-3-2-106				ANAC's P2100P003	yes
10-3-2-107				ANAC's P2100P003	yes
10-3-2-108				ANAC's P2100P003	yes
10-3-2-109				23377 Ty I, Cl C	none
10-3-2-110				23377 Ty I, Cl C	none
10-3-2-111				23377 Ty I, Cl C	none
10-3-2-112				23377 Ty I, Cl C	yes
10-3-2-113				23377 Ty I, Cl C	yes
10-3-2-114				23377 Ty I, Cl C	yes
10-3-2-115				85582 Ty I, Cl C	none
10-3-2-116				85582 Ty I, Cl C	none
10-3-2-117				85582 Ty I, Cl C	none
10-3-2-118				85582 Ty I, Cl C	yes
10-3-2-119				85582 Ty I, Cl C	yes
10-3-2-120				85582 Ty I, Cl C	yes
10-3-2-121				27737 Ty II, Cl C	none
10-3-2-122				27737 Ty II, Cl C	none
10-3-2-123				27737 Ty II, Cl C	none
10-3-2-124				27737 Ty II, Cl C	yes
10-3-2-125				27737 Ty II, Cl C	yes
10-3-2-126				27737 Ty II, Cl C	yes
10-3-2-127			81706 Ty I	23377 Ty I, Cl N	none
10-3-2-128				23377 Ty I, Cl N	none
10-3-2-129				23377 Ty I, Cl N	none
10-3-2-130				23377 Ty I, Cl N	yes
10-3-2-131				23377 Ty I, Cl N	yes
10-3-2-132				23377 Ty I, Cl N	yes
10-3-2-133				NAVAIR 002+	none
10-3-2-134				NAVAIR 002+	none
10-3-2-135				NAVAIR 002+	none

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-2-136				NAVAIR 002+	yes
10-3-2-137				NAVAIR 002+	yes
10-3-2-138				NAVAIR 002+	yes
10-3-2-139				85582 Ty I, Cl N	none
10-3-2-140				85582 Ty I, Cl N	none
10-3-2-141				85582 Ty I, Cl N	none
10-3-2-142				85582 Ty I, Cl N	yes
10-3-2-143				85582 Ty I, Cl N	yes
10-3-2-144				85582 Ty I, Cl N	yes
10-3-2-145				ANAC's P2100P003	none
10-3-2-146				ANAC's P2100P003	none
10-3-2-147				ANAC's P2100P003	none
10-3-2-148				ANAC's P2100P003	yes
10-3-2-149				ANAC's P2100P003	yes
10-3-2-150				ANAC's P2100P003	yes
10-3-2-151				23377 Ty I, Cl C	none
10-3-2-152				23377 Ty I, Cl C	none
10-3-2-153				23377 Ty I, Cl C	none
10-3-2-154				23377 Ty I, Cl C	yes
10-3-2-155				23377 Ty I, Cl C	yes
10-3-2-156				23377 Ty I, Cl C	yes
10-3-2-157				85582 Ty I, Cl C	none
10-3-2-158				85582 Ty I, Cl C	none
10-3-2-159				85582 Ty I, Cl C	none
10-3-2-160				85582 Ty I, Cl C	yes
10-3-2-161				85582 Ty I, Cl C	yes
10-3-2-162				85582 Ty I, Cl C	yes
10-3-2-163				27737 Ty II, Cl C	none
10-3-2-164				27737 Ty II, Cl C	none
10-3-2-165				27737 Ty II, Cl C	none
10-3-2-166				27737 Ty II, Cl C	yes
10-3-2-167				27737 Ty II, Cl C	yes
10-3-2-168				27737 Ty II, Cl C	yes
10-3-2-169			8625 Ty IC	23377 Ty I, Cl N	none
10-3-2-170				23377 Ty I, Cl N	none
10-3-2-171				23377 Ty I, Cl N	none
10-3-2-172				23377 Ty I, Cl N	yes
10-3-2-173				23377 Ty I, Cl N	yes
10-3-2-174				23377 Ty I, Cl N	yes
10-3-2-175				NAVAIR 002+	none
10-3-2-176				NAVAIR 002+	none
10-3-2-177				NAVAIR 002+	none
10-3-2-178				NAVAIR 002+	yes
10-3-2-179				NAVAIR 002+	yes
10-3-2-180				NAVAIR 002+	yes
10-3-2-181				85582 Ty I, Cl N	none

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-2-182				85582 Ty I, Cl N	none
10-3-2-183				85582 Ty I, Cl N	none
10-3-2-184				85582 Ty I, Cl N	yes
10-3-2-185				85582 Ty I, Cl N	yes
10-3-2-186				85582 Ty I, Cl N	yes
10-3-2-187				ANAC's P2100P003	none
10-3-2-188				ANAC's P2100P003	none
10-3-2-189				ANAC's P2100P003	none
10-3-2-190				ANAC's P2100P003	yes
10-3-2-191				ANAC's P2100P003	yes
10-3-2-192				ANAC's P2100P003	yes
10-3-2-193				23377 Ty I, Cl C	none
10-3-2-194				23377 Ty I, Cl C	none
10-3-2-195				23377 Ty I, Cl C	none
10-3-2-196				23377 Ty I, Cl C	yes
10-3-2-197				23377 Ty I, Cl C	yes
10-3-2-198				23377 Ty I, Cl C	yes
10-3-2-199				85582 Ty I, Cl C	none
10-3-2-200				85582 Ty I, Cl C	none
10-3-2-201				85582 Ty I, Cl C	none
10-3-2-202				85582 Ty I, Cl C	yes
10-3-2-203				85582 Ty I, Cl C	yes
10-3-2-204				85582 Ty I, Cl C	yes
10-3-2-205				27737 Ty II, Cl C	none
10-3-2-206				27737 Ty II, Cl C	none
10-3-2-207				27737 Ty II, Cl C	none
10-3-2-208				27737 Ty II, Cl C	yes
10-3-2-209				27737 Ty II, Cl C	yes
10-3-2-210				27737 Ty II, Cl C	yes
10-3-7-1		7075-T6	PreKote	23377 Ty I, Cl N	none
10-3-7-2				23377 Ty I, Cl N	none
10-3-7-3				23377 Ty I, Cl N	none
10-3-7-4				23377 Ty I, Cl N	yes
10-3-7-5				23377 Ty I, Cl N	yes
10-3-7-6				23377 Ty I, Cl N	yes
10-3-7-7				NAVAIR 002+	none
10-3-7-8				NAVAIR 002+	none
10-3-7-9				NAVAIR 002+	none
10-3-7-10				NAVAIR 002+	yes
10-3-7-11				NAVAIR 002+	yes
10-3-7-12				NAVAIR 002+	yes
10-3-7-13				85582 Ty I, Cl N	none
10-3-7-14				85582 Ty I, Cl N	none
10-3-7-15				85582 Ty I, Cl N	none
10-3-7-16				85582 Ty I, Cl N	yes
10-3-7-17				85582 Ty I, Cl N	yes

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-7-18				85582 Ty I, Cl N	yes
10-3-7-19				ANAC's P2100P003	none
10-3-7-20				ANAC's P2100P003	none
10-3-7-21				ANAC's P2100P003	none
10-3-7-22				ANAC's P2100P003	yes
10-3-7-23				ANAC's P2100P003	yes
10-3-7-24				ANAC's P2100P003	yes
10-3-7-25				23377 Ty I, Cl C	none
10-3-7-26				23377 Ty I, Cl C	none
10-3-7-27				23377 Ty I, Cl C	none
10-3-7-28				23377 Ty I, Cl C	yes
10-3-7-29				23377 Ty I, Cl C	yes
10-3-7-30				23377 Ty I, Cl C	yes
10-3-7-31				85582 Ty I, Cl C	none
10-3-7-32				85582 Ty I, Cl C	none
10-3-7-33				85582 Ty I, Cl C	none
10-3-7-34				85582 Ty I, Cl C	yes
10-3-7-35				85582 Ty I, Cl C	yes
10-3-7-36				85582 Ty I, Cl C	yes
10-3-7-37				27737 Ty II, Cl C	none
10-3-7-38				27737 Ty II, Cl C	none
10-3-7-39				27737 Ty II, Cl C	none
10-3-7-40				27737 Ty II, Cl C	yes
10-3-7-41				27737 Ty II, Cl C	yes
10-3-7-42				27737 Ty II, Cl C	yes
10-3-7-43			BoeGel	23377 Ty I, Cl N	none
10-3-7-44				23377 Ty I, Cl N	none
10-3-7-45				23377 Ty I, Cl N	none
10-3-7-46				23377 Ty I, Cl N	yes
10-3-7-47				23377 Ty I, Cl N	yes
10-3-7-48				23377 Ty I, Cl N	yes
10-3-7-49				NAVAIR 002+	none
10-3-7-50				NAVAIR 002+	none
10-3-7-51				NAVAIR 002+	none
10-3-7-52				NAVAIR 002+	yes
10-3-7-53				NAVAIR 002+	yes
10-3-7-54				NAVAIR 002+	yes
10-3-7-55				85582 Ty I, Cl N	none
10-3-7-56				85582 Ty I, Cl N	none
10-3-7-57				85582 Ty I, Cl N	none
10-3-7-58				85582 Ty I, Cl N	yes
10-3-7-59				85582 Ty I, Cl N	yes
10-3-7-60				85582 Ty I, Cl N	yes
10-3-7-61				ANAC's P2100P003	none
10-3-7-62				ANAC's P2100P003	none
10-3-7-63				ANAC's P2100P003	none

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-7-64				ANAC's P2100P003	yes
10-3-7-65				ANAC's P2100P003	yes
10-3-7-66				ANAC's P2100P003	yes
10-3-7-67				23377 Ty I, Cl C	none
10-3-7-68				23377 Ty I, Cl C	none
10-3-7-69				23377 Ty I, Cl C	none
10-3-7-70				23377 Ty I, Cl C	yes
10-3-7-71				23377 Ty I, Cl C	yes
10-3-7-72				23377 Ty I, Cl C	yes
10-3-7-73				85582 Ty I, Cl C	none
10-3-7-74				85582 Ty I, Cl C	none
10-3-7-75				85582 Ty I, Cl C	none
10-3-7-76				85582 Ty I, Cl C	yes
10-3-7-77				85582 Ty I, Cl C	yes
10-3-7-78				85582 Ty I, Cl C	yes
10-3-7-79				27737 Ty II, Cl C	none
10-3-7-80				27737 Ty II, Cl C	none
10-3-7-81				27737 Ty II, Cl C	none
10-3-7-82				27737 Ty II, Cl C	yes
10-3-7-83				27737 Ty II, Cl C	yes
10-3-7-84				27737 Ty II, Cl C	yes
10-3-7-85			81706 Ty II	23377 Ty I, Cl N	none
10-3-7-86				23377 Ty I, Cl N	none
10-3-7-87				23377 Ty I, Cl N	none
10-3-7-88				23377 Ty I, Cl N	yes
10-3-7-89				23377 Ty I, Cl N	yes
10-3-7-90				23377 Ty I, Cl N	yes
10-3-7-91				NAVAIR 002+	none
10-3-7-92				NAVAIR 002+	none
10-3-7-93				NAVAIR 002+	none
10-3-7-94				NAVAIR 002+	yes
10-3-7-95				NAVAIR 002+	yes
10-3-7-96				NAVAIR 002+	yes
10-3-7-97				85582 Ty I, Cl N	none
10-3-7-98				85582 Ty I, Cl N	none
10-3-7-99				85582 Ty I, Cl N	none
10-3-7-100				85582 Ty I, Cl N	yes
10-3-7-101				85582 Ty I, Cl N	yes
10-3-7-102				85582 Ty I, Cl N	yes
10-3-7-103				ANAC's P2100P003	none
10-3-7-104				ANAC's P2100P003	none
10-3-7-105				ANAC's P2100P003	none
10-3-7-106				ANAC's P2100P003	yes
10-3-7-107				ANAC's P2100P003	yes
10-3-7-108				ANAC's P2100P003	yes
10-3-7-109				23377 Ty I, Cl C	none

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-7-110				23377 Ty I, Cl C	none
10-3-7-111				23377 Ty I, Cl C	none
10-3-7-112				23377 Ty I, Cl C	yes
10-3-7-113				23377 Ty I, Cl C	yes
10-3-7-114				23377 Ty I, Cl C	yes
10-3-7-115				85582 Ty I, Cl C	none
10-3-7-116				85582 Ty I, Cl C	none
10-3-7-117				85582 Ty I, Cl C	none
10-3-7-118				85582 Ty I, Cl C	yes
10-3-7-119				85582 Ty I, Cl C	yes
10-3-7-120				85582 Ty I, Cl C	yes
10-3-7-121				27737 Ty II, Cl C	none
10-3-7-122				27737 Ty II, Cl C	none
10-3-7-123				27737 Ty II, Cl C	none
10-3-7-124				27737 Ty II, Cl C	yes
10-3-7-125				27737 Ty II, Cl C	yes
10-3-7-126				27737 Ty II, Cl C	yes
10-3-7-127			81706 Ty I	23377 Ty I, Cl N	none
10-3-7-128				23377 Ty I, Cl N	none
10-3-7-129				23377 Ty I, Cl N	none
10-3-7-130				23377 Ty I, Cl N	yes
10-3-7-131				23377 Ty I, Cl N	yes
10-3-7-132				23377 Ty I, Cl N	yes
10-3-7-133				NAVAIR 002+	none
10-3-7-134				NAVAIR 002+	none
10-3-7-135				NAVAIR 002+	none
10-3-7-136				NAVAIR 002+	yes
10-3-7-137				NAVAIR 002+	yes
10-3-7-138				NAVAIR 002+	yes
10-3-7-139				85582 Ty I, Cl N	none
10-3-7-140				85582 Ty I, Cl N	none
10-3-7-141				85582 Ty I, Cl N	none
10-3-7-142				85582 Ty I, Cl N	yes
10-3-7-143				85582 Ty I, Cl N	yes
10-3-7-144				85582 Ty I, Cl N	yes
10-3-7-145				ANAC's P2100P003	none
10-3-7-146				ANAC's P2100P003	none
10-3-7-147				ANAC's P2100P003	none
10-3-7-148				ANAC's P2100P003	yes
10-3-7-149				ANAC's P2100P003	yes
10-3-7-150				ANAC's P2100P003	yes
10-3-7-151				23377 Ty I, Cl C	none
10-3-7-152				23377 Ty I, Cl C	none
10-3-7-153				23377 Ty I, Cl C	none
10-3-7-154				23377 Ty I, Cl C	yes
10-3-7-155				23377 Ty I, Cl C	yes

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-7-156				23377 Ty I, Cl C	yes
10-3-7-157				85582 Ty I, Cl C	none
10-3-7-158				85582 Ty I, Cl C	none
10-3-7-159				85582 Ty I, Cl C	none
10-3-7-160				85582 Ty I, Cl C	yes
10-3-7-161				85582 Ty I, Cl C	yes
10-3-7-162				85582 Ty I, Cl C	yes
10-3-7-163				27737 Ty II, Cl C	none
10-3-7-164				27737 Ty II, Cl C	none
10-3-7-165				27737 Ty II, Cl C	none
10-3-7-166				27737 Ty II, Cl C	yes
10-3-7-167				27737 Ty II, Cl C	yes
10-3-7-168				27737 Ty II, Cl C	yes
10-3-7-169			8625 Ty IC	23377 Ty I, Cl N	none
10-3-7-170				23377 Ty I, Cl N	none
10-3-7-171				23377 Ty I, Cl N	none
10-3-7-172				23377 Ty I, Cl N	yes
10-3-7-173				23377 Ty I, Cl N	yes
10-3-7-174				23377 Ty I, Cl N	yes
10-3-7-175				NAVAIR 002+	none
10-3-7-176				NAVAIR 002+	none
10-3-7-177				NAVAIR 002+	none
10-3-7-178				NAVAIR 002+	yes
10-3-7-179				NAVAIR 002+	yes
10-3-7-180				NAVAIR 002+	yes
10-3-7-181				85582 Ty I, Cl N	none
10-3-7-182				85582 Ty I, Cl N	none
10-3-7-183				85582 Ty I, Cl N	none
10-3-7-184				85582 Ty I, Cl N	yes
10-3-7-185				85582 Ty I, Cl N	yes
10-3-7-186				85582 Ty I, Cl N	yes
10-3-7-187				ANAC's P2100P003	none
10-3-7-188				ANAC's P2100P003	none
10-3-7-189				ANAC's P2100P003	none
10-3-7-190				ANAC's P2100P003	yes
10-3-7-191				ANAC's P2100P003	yes
10-3-7-192				ANAC's P2100P003	yes
10-3-7-193				23377 Ty I, Cl C	none
10-3-7-194				23377 Ty I, Cl C	none
10-3-7-195				23377 Ty I, Cl C	none
10-3-7-196				23377 Ty I, Cl C	yes
10-3-7-197				23377 Ty I, Cl C	yes
10-3-7-198				23377 Ty I, Cl C	yes
10-3-7-199				85582 Ty I, Cl C	none
10-3-7-200				85582 Ty I, Cl C	none
10-3-7-201				85582 Ty I, Cl C	none

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-7-202				85582 Ty I, Cl C	yes
10-3-7-203				85582 Ty I, Cl C	yes
10-3-7-204				85582 Ty I, Cl C	yes
10-3-7-205				27737 Ty II, Cl C	none
10-3-7-206				27737 Ty II, Cl C	none
10-3-7-207				27737 Ty II, Cl C	none
10-3-7-208				27737 Ty II, Cl C	yes
10-3-7-209				27737 Ty II, Cl C	yes
10-3-7-210				27737 Ty II, Cl C	yes
10-3-G-1		Galvanic	PreKote	23377 Ty I, Cl N	half
10-3-G-2				NAVAIR 002+	half
10-3-G-3				85582 Ty I, Cl N	half
10-3-G-4				ANAC's P2100P003	half
10-3-G-5				23377 Ty I, Cl C	half
10-3-G-6				85582 Ty I, Cl C	half
10-3-G-7				27737 Ty II, Cl C	half
10-3-G-8			BoeGel	23377 Ty I, Cl N	half
10-3-G-9				NAVAIR 002+	half
10-3-G-10				85582 Ty I, Cl N	half
10-3-G-11				ANAC's P2100P003	half
10-3-G-12				23377 Ty I, Cl C	half
10-3-G-13				85582 Ty I, Cl C	half
10-3-G-14				27737 Ty II, Cl C	half
10-3-G-15			81706 Ty II	23377 Ty I, Cl N	half
10-3-G-16				NAVAIR 002+	half
10-3-G-17				85582 Ty I, Cl N	half
10-3-G-18				ANAC's P2100P003	half
10-3-G-19				23377 Ty I, Cl C	half
10-3-G-20				85582 Ty I, Cl C	half
10-3-G-21				27737 Ty II, Cl C	half
10-3-G-22			81706 Ty I	23377 Ty I, Cl N	half
10-3-G-23				NAVAIR 002+	half
10-3-G-24				85582 Ty I, Cl N	half
10-3-G-25				ANAC's P2100P003	half
10-3-G-26				23377 Ty I, Cl C	half
10-3-G-27				85582 Ty I, Cl C	half
10-3-G-28				27737 Ty II, Cl C	half
10-3-G-29			8625 Ty IC	23377 Ty I, Cl N	half
10-3-G-30				NAVAIR 002+	half
10-3-G-31				85582 Ty I, Cl N	half
10-3-G-32				ANAC's P2100P003	half
10-3-G-33				23377 Ty I, Cl C	half
10-3-G-34				85582 Ty I, Cl C	half
10-3-G-35				27737 Ty II, Cl C	half
10-3-2-211	ASTM G 85	2024-T3	PreKote	23377 Ty I, Cl N	none
10-3-2-212				23377 Ty I, Cl N	none

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-2-213				23377 Ty I, Cl N	none
10-3-2-214				23377 Ty I, Cl N	yes
10-3-2-215				23377 Ty I, Cl N	yes
10-3-2-216				23377 Ty I, Cl N	yes
10-3-2-217				NAVAIR 002+	none
10-3-2-218				NAVAIR 002+	none
10-3-2-219				NAVAIR 002+	none
10-3-2-220				NAVAIR 002+	yes
10-3-2-221				NAVAIR 002+	yes
10-3-2-222				NAVAIR 002+	yes
10-3-2-223				85582 Ty I, Cl N	none
10-3-2-224				85582 Ty I, Cl N	none
10-3-2-225				85582 Ty I, Cl N	none
10-3-2-226				85582 Ty I, Cl N	yes
10-3-2-227				85582 Ty I, Cl N	yes
10-3-2-228				85582 Ty I, Cl N	yes
10-3-2-229				ANAC's P2100P003	none
10-3-2-230				ANAC's P2100P003	none
10-3-2-231				ANAC's P2100P003	none
10-3-2-232				ANAC's P2100P003	yes
10-3-2-233				ANAC's P2100P003	yes
10-3-2-234				ANAC's P2100P003	yes
10-3-2-235				23377 Ty I, Cl C	none
10-3-2-236				23377 Ty I, Cl C	none
10-3-2-237				23377 Ty I, Cl C	none
10-3-2-238				23377 Ty I, Cl C	yes
10-3-2-239				23377 Ty I, Cl C	yes
10-3-2-240				23377 Ty I, Cl C	yes
10-3-2-241				85582 Ty I, Cl C	none
10-3-2-242				85582 Ty I, Cl C	none
10-3-2-243				85582 Ty I, Cl C	none
10-3-2-244				85582 Ty I, Cl C	yes
10-3-2-245				85582 Ty I, Cl C	yes
10-3-2-246				85582 Ty I, Cl C	yes
10-3-2-247A				27737 Ty II, Cl C	none
10-3-2-248A				27737 Ty II, Cl C	none
10-3-2-249A				27737 Ty II, Cl C	none
10-3-2-247B				27737 Ty II, Cl C	none
10-3-2-248B				27737 Ty II, Cl C	none
10-3-2-249B				27737 Ty II, Cl C	none
10-3-2-250				27737 Ty II, Cl C	yes
10-3-2-251				27737 Ty II, Cl C	yes
10-3-2-252				27737 Ty II, Cl C	yes
10-3-2-253			BoeGel	23377 Ty I, Cl N	none
10-3-2-254				23377 Ty I, Cl N	none
10-3-2-255				23377 Ty I, Cl N	none

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-2-256				23377 Ty I, Cl N	yes
10-3-2-257				23377 Ty I, Cl N	yes
10-3-2-258				23377 Ty I, Cl N	yes
10-3-2-259				NAVAIR 002+	none
10-3-2-260				NAVAIR 002+	none
10-3-2-261				NAVAIR 002+	none
10-3-2-262				NAVAIR 002+	yes
10-3-2-263				NAVAIR 002+	yes
10-3-2-264				NAVAIR 002+	yes
10-3-2-265				85582 Ty I, Cl N	none
10-3-2-266				85582 Ty I, Cl N	none
10-3-2-267				85582 Ty I, Cl N	none
10-3-2-268				85582 Ty I, Cl N	yes
10-3-2-269				85582 Ty I, Cl N	yes
10-3-2-270				85582 Ty I, Cl N	yes
10-3-2-271				ANAC's P2100P003	none
10-3-2-272				ANAC's P2100P003	none
10-3-2-273				ANAC's P2100P003	none
10-3-2-274				ANAC's P2100P003	yes
10-3-2-275				ANAC's P2100P003	yes
10-3-2-276				ANAC's P2100P003	yes
10-3-2-277				23377 Ty I, Cl C	none
10-3-2-278				23377 Ty I, Cl C	none
10-3-2-279				23377 Ty I, Cl C	none
10-3-2-280				23377 Ty I, Cl C	yes
10-3-2-281				23377 Ty I, Cl C	yes
10-3-2-282				23377 Ty I, Cl C	yes
10-3-2-283				85582 Ty I, Cl C	none
10-3-2-284				85582 Ty I, Cl C	none
10-3-2-285				85582 Ty I, Cl C	none
10-3-2-286				85582 Ty I, Cl C	yes
10-3-2-287				85582 Ty I, Cl C	yes
10-3-2-288				85582 Ty I, Cl C	yes
10-3-2-289				27737 Ty II, Cl C	none
10-3-2-290				27737 Ty II, Cl C	none
10-3-2-291				27737 Ty II, Cl C	none
10-3-2-292				27737 Ty II, Cl C	yes
10-3-2-293				27737 Ty II, Cl C	yes
10-3-2-294				27737 Ty II, Cl C	yes
10-3-2-295			81706 Ty II	23377 Ty I, Cl N	none
10-3-2-296				23377 Ty I, Cl N	none
10-3-2-297				23377 Ty I, Cl N	none
10-3-2-298				23377 Ty I, Cl N	yes
10-3-2-299				23377 Ty I, Cl N	yes
10-3-2-300				23377 Ty I, Cl N	yes
10-3-2-301				NAVAIR 002+	none

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-2-302				NAVAIR 002+	none
10-3-2-303				NAVAIR 002+	none
10-3-2-304				NAVAIR 002+	yes
10-3-2-305				NAVAIR 002+	yes
10-3-2-306				NAVAIR 002+	yes
10-3-2-307				85582 Ty I, Cl N	none
10-3-2-308				85582 Ty I, Cl N	none
10-3-2-309				85582 Ty I, Cl N	none
10-3-2-310				85582 Ty I, Cl N	yes
10-3-2-311				85582 Ty I, Cl N	yes
10-3-2-312				85582 Ty I, Cl N	yes
10-3-2-313				ANAC's P2100P003	none
10-3-2-314				ANAC's P2100P003	none
10-3-2-315				ANAC's P2100P003	none
10-3-2-316				ANAC's P2100P003	yes
10-3-2-317				ANAC's P2100P003	yes
10-3-2-318				ANAC's P2100P003	yes
10-3-2-319				23377 Ty I, Cl C	none
10-3-2-320				23377 Ty I, Cl C	none
10-3-2-321				23377 Ty I, Cl C	none
10-3-2-322				23377 Ty I, Cl C	yes
10-3-2-323				23377 Ty I, Cl C	yes
10-3-2-324				23377 Ty I, Cl C	yes
10-3-2-325				85582 Ty I, Cl C	none
10-3-2-326				85582 Ty I, Cl C	none
10-3-2-327				85582 Ty I, Cl C	none
10-3-2-328				85582 Ty I, Cl C	yes
10-3-2-329				85582 Ty I, Cl C	yes
10-3-2-330				85582 Ty I, Cl C	yes
10-3-2-331				27737 Ty II, Cl C	none
10-3-2-332				27737 Ty II, Cl C	none
10-3-2-333				27737 Ty II, Cl C	none
10-3-2-334				27737 Ty II, Cl C	yes
10-3-2-335				27737 Ty II, Cl C	yes
10-3-2-336				27737 Ty II, Cl C	yes
10-3-2-337			81706 Ty I	23377 Ty I, Cl N	none
10-3-2-338				23377 Ty I, Cl N	none
10-3-2-339				23377 Ty I, Cl N	none
10-3-2-340				23377 Ty I, Cl N	yes
10-3-2-341				23377 Ty I, Cl N	yes
10-3-2-342				23377 Ty I, Cl N	yes
10-3-2-343				NAVAIR 002+	none
10-3-2-344				NAVAIR 002+	none
10-3-2-345				NAVAIR 002+	none
10-3-2-346				NAVAIR 002+	yes
10-3-2-347				NAVAIR 002+	yes

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-2-348				NAVAIR 002+	yes
10-3-2-349				85582 Ty I, Cl N	none
10-3-2-350				85582 Ty I, Cl N	none
10-3-2-351				85582 Ty I, Cl N	none
10-3-2-352				85582 Ty I, Cl N	yes
10-3-2-353				85582 Ty I, Cl N	yes
10-3-2-354				85582 Ty I, Cl N	yes
10-3-2-355				ANAC's P2100P003	none
10-3-2-356				ANAC's P2100P003	none
10-3-2-357				ANAC's P2100P003	none
10-3-2-358				ANAC's P2100P003	yes
10-3-2-359				ANAC's P2100P003	yes
10-3-2-360				23377 Ty I, Cl C	none
10-3-2-361				23377 Ty I, Cl C	none
10-3-2-362				23377 Ty I, Cl C	none
10-3-2-363				23377 Ty I, Cl C	yes
10-3-2-364				23377 Ty I, Cl C	yes
10-3-2-365				23377 Ty I, Cl C	yes
10-3-2-366				85582 Ty I, Cl C	none
10-3-2-367				85582 Ty I, Cl C	none
10-3-2-368				85582 Ty I, Cl C	none
10-3-2-369				85582 Ty I, Cl C	yes
10-3-2-370				85582 Ty I, Cl C	yes
10-3-2-371				85582 Ty I, Cl C	yes
10-3-2-372				27737 Ty II, Cl C	none
10-3-2-373				27737 Ty II, Cl C	none
10-3-2-374				27737 Ty II, Cl C	none
10-3-2-375				27737 Ty II, Cl C	yes
10-3-2-376				27737 Ty II, Cl C	yes
10-3-2-377				27737 Ty II, Cl C	yes
10-3-2-378				27737 Ty II, Cl C	yes
10-3-2-379			8625 Ty IC	23377 Ty I, Cl N	none
10-3-2-380				23377 Ty I, Cl N	none
10-3-2-381				23377 Ty I, Cl N	none
10-3-2-382				23377 Ty I, Cl N	yes
10-3-2-383				23377 Ty I, Cl N	yes
10-3-2-384				23377 Ty I, Cl N	yes
10-3-2-385				NAVAIR 002+	none
10-3-2-386				NAVAIR 002+	none
10-3-2-387				NAVAIR 002+	none
10-3-2-388				NAVAIR 002+	yes
10-3-2-389				NAVAIR 002+	yes
10-3-2-390				NAVAIR 002+	yes
10-3-2-391				85582 Ty I, Cl N	none
10-3-2-392				85582 Ty I, Cl N	none
10-3-2-393				85582 Ty I, Cl N	none

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-2-394				85582 Ty I, Cl N	yes
10-3-2-395				85582 Ty I, Cl N	yes
10-3-2-396				85582 Ty I, Cl N	yes
10-3-2-397				ANAC's P2100P003	none
10-3-2-398				ANAC's P2100P003	none
10-3-2-399				ANAC's P2100P003	none
10-3-2-400				ANAC's P2100P003	yes
10-3-2-401				ANAC's P2100P003	yes
10-3-2-402				ANAC's P2100P003	yes
10-3-2-403				23377 Ty I, Cl C	none
10-3-2-404				23377 Ty I, Cl C	none
10-3-2-405				23377 Ty I, Cl C	none
10-3-2-406				23377 Ty I, Cl C	yes
10-3-2-407				23377 Ty I, Cl C	yes
10-3-2-408				23377 Ty I, Cl C	yes
10-3-2-409				85582 Ty I, Cl C	none
10-3-2-410				85582 Ty I, Cl C	none
10-3-2-411				85582 Ty I, Cl C	none
10-3-2-412				85582 Ty I, Cl C	yes
10-3-2-413				85582 Ty I, Cl C	yes
10-3-2-414				85582 Ty I, Cl C	yes
10-3-2-415				27737 Ty II, Cl C	none
10-3-2-416				27737 Ty II, Cl C	none
10-3-2-417				27737 Ty II, Cl C	none
10-3-2-418				27737 Ty II, Cl C	yes
10-3-2-419				27737 Ty II, Cl C	yes
10-3-2-420				27737 Ty II, Cl C	yes
10-3-7-211		7075-T6	PreKote	23377 Ty I, Cl N	none
10-3-7-212				23377 Ty I, Cl N	none
10-3-7-213				23377 Ty I, Cl N	none
10-3-7-214				23377 Ty I, Cl N	yes
10-3-7-215				23377 Ty I, Cl N	yes
10-3-7-216				23377 Ty I, Cl N	yes
10-3-7-217				NAVAIR 002+	none
10-3-7-218				NAVAIR 002+	none
10-3-7-219				NAVAIR 002+	none
10-3-7-220				NAVAIR 002+	yes
10-3-7-221				NAVAIR 002+	yes
10-3-7-222				NAVAIR 002+	yes
10-3-7-223				85582 Ty I, Cl N	none
10-3-7-224				85582 Ty I, Cl N	none
10-3-7-225				85582 Ty I, Cl N	none
10-3-7-226				85582 Ty I, Cl N	yes
10-3-7-227				85582 Ty I, Cl N	yes
10-3-7-228				85582 Ty I, Cl N	yes
10-3-7-229				ANAC's P2100P003	none

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-7-230				ANAC's P2100P003	none
10-3-7-231				ANAC's P2100P003	none
10-3-7-232				ANAC's P2100P003	yes
10-3-7-233				ANAC's P2100P003	yes
10-3-7-234				ANAC's P2100P003	yes
10-3-7-235				23377 Ty I, Cl C	none
10-3-7-236				23377 Ty I, Cl C	none
10-3-7-237				23377 Ty I, Cl C	none
10-3-7-238				23377 Ty I, Cl C	yes
10-3-7-239				23377 Ty I, Cl C	yes
10-3-7-240				23377 Ty I, Cl C	yes
10-3-7-241				85582 Ty I, Cl C	none
10-3-7-242				85582 Ty I, Cl C	none
10-3-7-243				85582 Ty I, Cl C	none
10-3-7-244				85582 Ty I, Cl C	yes
10-3-7-245				85582 Ty I, Cl C	yes
10-3-7-246				85582 Ty I, Cl C	yes
10-3-7-247				27737 Ty II, Cl C	none
10-3-7-248				27737 Ty II, Cl C	none
10-3-7-249				27737 Ty II, Cl C	none
10-3-7-250				27737 Ty II, Cl C	yes
10-3-7-251				27737 Ty II, Cl C	yes
10-3-7-252				27737 Ty II, Cl C	yes
10-3-7-253			BoeGel	23377 Ty I, Cl N	none
10-3-7-254				23377 Ty I, Cl N	none
10-3-7-255				23377 Ty I, Cl N	none
10-3-7-256				23377 Ty I, Cl N	yes
10-3-7-257				23377 Ty I, Cl N	yes
10-3-7-258				23377 Ty I, Cl N	yes
10-3-7-259				NAVAIR 002+	none
10-3-7-260				NAVAIR 002+	none
10-3-7-261				NAVAIR 002+	none
10-3-7-262				NAVAIR 002+	yes
10-3-7-263				NAVAIR 002+	yes
10-3-7-264				NAVAIR 002+	yes
10-3-7-265				85582 Ty I, Cl N	none
10-3-7-266				85582 Ty I, Cl N	none
10-3-7-267				85582 Ty I, Cl N	none
10-3-7-268				85582 Ty I, Cl N	yes
10-3-7-269				85582 Ty I, Cl N	yes
10-3-7-270				85582 Ty I, Cl N	yes
10-3-7-271				ANAC's P2100P003	none
10-3-7-272				ANAC's P2100P003	none
10-3-7-273				ANAC's P2100P003	none
10-3-7-274				ANAC's P2100P003	yes
10-3-7-275				ANAC's P2100P003	yes

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-7-276				ANAC's P2100P003	yes
10-3-7-277				23377 Ty I, Cl C	none
10-3-7-278				23377 Ty I, Cl C	none
10-3-7-279				23377 Ty I, Cl C	none
10-3-7-280				23377 Ty I, Cl C	yes
10-3-7-281				23377 Ty I, Cl C	yes
10-3-7-282				23377 Ty I, Cl C	yes
10-3-7-283				85582 Ty I, Cl C	none
10-3-7-284				85582 Ty I, Cl C	none
10-3-7-285				85582 Ty I, Cl C	none
10-3-7-286				85582 Ty I, Cl C	yes
10-3-7-287				85582 Ty I, Cl C	yes
10-3-7-288				85582 Ty I, Cl C	yes
10-3-7-289				27737 Ty II, Cl C	none
10-3-7-290				27737 Ty II, Cl C	none
10-3-7-291				27737 Ty II, Cl C	none
10-3-7-292				27737 Ty II, Cl C	yes
10-3-7-293				27737 Ty II, Cl C	yes
10-3-7-294				27737 Ty II, Cl C	yes
10-3-7-295			81706 Ty II	23377 Ty I, Cl N	none
10-3-7-296				23377 Ty I, Cl N	none
10-3-7-297				23377 Ty I, Cl N	none
10-3-7-298				23377 Ty I, Cl N	yes
10-3-7-299				23377 Ty I, Cl N	yes
10-3-7-300				23377 Ty I, Cl N	yes
10-3-7-301				NAVAIR 002+	none
10-3-7-302				NAVAIR 002+	none
10-3-7-303				NAVAIR 002+	none
10-3-7-304				NAVAIR 002+	yes
10-3-7-305				NAVAIR 002+	yes
10-3-7-306				NAVAIR 002+	yes
10-3-7-307				85582 Ty I, Cl N	none
10-3-7-308				85582 Ty I, Cl N	none
10-3-7-309				85582 Ty I, Cl N	none
10-3-7-310				85582 Ty I, Cl N	yes
10-3-7-311				85582 Ty I, Cl N	yes
10-3-7-312				85582 Ty I, Cl N	yes
10-3-7-313				ANAC's P2100P003	none
10-3-7-314				ANAC's P2100P003	none
10-3-7-315				ANAC's P2100P003	none
10-3-7-316				ANAC's P2100P003	yes
10-3-7-317				ANAC's P2100P003	yes
10-3-7-318				ANAC's P2100P003	yes
10-3-7-319				23377 Ty I, Cl C	none
10-3-7-320				23377 Ty I, Cl C	none
10-3-7-321				23377 Ty I, Cl C	none

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-7-322				23377 Ty I, Cl C	yes
10-3-7-323				23377 Ty I, Cl C	yes
10-3-7-324				23377 Ty I, Cl C	yes
10-3-7-325				85582 Ty I, Cl C	none
10-3-7-326				85582 Ty I, Cl C	none
10-3-7-327				85582 Ty I, Cl C	none
10-3-7-328				85582 Ty I, Cl C	yes
10-3-7-329				85582 Ty I, Cl C	yes
10-3-7-330				85582 Ty I, Cl C	yes
10-3-7-331				27737 Ty II, Cl C	none
10-3-7-332				27737 Ty II, Cl C	none
10-3-7-333				27737 Ty II, Cl C	none
10-3-7-334				27737 Ty II, Cl C	yes
10-3-7-335				27737 Ty II, Cl C	yes
10-3-7-336				27737 Ty II, Cl C	yes
10-3-7-337			81706 Ty I	23377 Ty I, Cl N	none
10-3-7-338				23377 Ty I, Cl N	none
10-3-7-339				23377 Ty I, Cl N	none
10-3-7-340				23377 Ty I, Cl N	yes
10-3-7-341				23377 Ty I, Cl N	yes
10-3-7-342				23377 Ty I, Cl N	yes
10-3-7-343				NAVAIR 002+	none
10-3-7-344				NAVAIR 002+	none
10-3-7-345				NAVAIR 002+	none
10-3-7-346				NAVAIR 002+	yes
10-3-7-347				NAVAIR 002+	yes
10-3-7-348				NAVAIR 002+	yes
10-3-7-349				85582 Ty I, Cl N	none
10-3-7-350				85582 Ty I, Cl N	none
10-3-7-351				85582 Ty I, Cl N	none
10-3-7-352				85582 Ty I, Cl N	yes
10-3-7-353				85582 Ty I, Cl N	yes
10-3-7-354				85582 Ty I, Cl N	yes
10-3-7-355				ANAC's P2100P003	none
10-3-7-356				ANAC's P2100P003	none
10-3-7-357				ANAC's P2100P003	none
10-3-7-358				ANAC's P2100P003	yes
10-3-7-359				ANAC's P2100P003	yes
10-3-7-360				ANAC's P2100P003	yes
10-3-7-361				23377 Ty I, Cl C	none
10-3-7-362				23377 Ty I, Cl C	none
10-3-7-363				23377 Ty I, Cl C	none
10-3-7-364				23377 Ty I, Cl C	yes
10-3-7-365				23377 Ty I, Cl C	yes
10-3-7-366				23377 Ty I, Cl C	yes
10-3-7-367				85582 Ty I, Cl C	none

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-7-368				85582 Ty I, Cl C	none
10-3-7-369				85582 Ty I, Cl C	none
10-3-7-370				85582 Ty I, Cl C	yes
10-3-7-371				85582 Ty I, Cl C	yes
10-3-7-372				85582 Ty I, Cl C	yes
10-3-7-373				27737 Ty II, Cl C	none
10-3-7-374				27737 Ty II, Cl C	none
10-3-7-375				27737 Ty II, Cl C	none
10-3-7-376				27737 Ty II, Cl C	yes
10-3-7-377				27737 Ty II, Cl C	yes
10-3-7-378				27737 Ty II, Cl C	yes
10-3-7-379			8625 Ty IC	23377 Ty I, Cl N	none
10-3-7-380				23377 Ty I, Cl N	none
10-3-7-381				23377 Ty I, Cl N	none
10-3-7-382				23377 Ty I, Cl N	yes
10-3-7-383				23377 Ty I, Cl N	yes
10-3-7-384				23377 Ty I, Cl N	yes
10-3-7-385				NAVAIR 002+	none
10-3-7-386				NAVAIR 002+	none
10-3-7-387				NAVAIR 002+	none
10-3-7-388				NAVAIR 002+	yes
10-3-7-389				NAVAIR 002+	yes
10-3-7-390				NAVAIR 002+	yes
10-3-7-391				85582 Ty I, Cl N	none
10-3-7-392				85582 Ty I, Cl N	none
10-3-7-393				85582 Ty I, Cl N	none
10-3-7-394				85582 Ty I, Cl N	yes
10-3-7-395				85582 Ty I, Cl N	yes
10-3-7-396				85582 Ty I, Cl N	yes
10-3-7-397				ANAC's P2100P003	none
10-3-7-398				ANAC's P2100P003	none
10-3-7-399				ANAC's P2100P003	none
10-3-7-400				ANAC's P2100P003	yes
10-3-7-401				ANAC's P2100P003	yes
10-3-7-402				ANAC's P2100P003	yes
10-3-7-403				23377 Ty I, Cl C	none
10-3-7-404				23377 Ty I, Cl C	none
10-3-7-405				23377 Ty I, Cl C	none
10-3-7-406				23377 Ty I, Cl C	yes
10-3-7-407				23377 Ty I, Cl C	yes
10-3-7-408				23377 Ty I, Cl C	yes
10-3-7-409				85582 Ty I, Cl C	none
10-3-7-410				85582 Ty I, Cl C	none
10-3-7-411				85582 Ty I, Cl C	none
10-3-7-412				85582 Ty I, Cl C	yes
10-3-7-413				85582 Ty I, Cl C	yes

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-7-414				85582 Ty I, Cl C	yes
10-3-7-415				27737 Ty II, Cl C	none
10-3-7-416				27737 Ty II, Cl C	none
10-3-7-417				27737 Ty II, Cl C	none
10-3-7-418				27737 Ty II, Cl C	yes
10-3-7-419				27737 Ty II, Cl C	yes
10-3-7-420				27737 Ty II, Cl C	yes
10-3-G-36		Galvanic	PreKote	23377 Ty I, Cl N	half
10-3-G-37				NAVAIR 002+	half
10-3-G-38				85582 Ty I, Cl N	half
10-3-G-39				ANAC's P2100P003	half
10-3-G-40				23377 Ty I, Cl C	half
10-3-G-41				85582 Ty I, Cl C	half
10-3-G-42				27737 Ty II, Cl C	half
10-3-G-43			BoeGel	23377 Ty I, Cl N	half
10-3-G-44				NAVAIR 002+	half
10-3-G-45				85582 Ty I, Cl N	half
10-3-G-46				ANAC's P2100P003	half
10-3-G-47				23377 Ty I, Cl C	half
10-3-G-48				85582 Ty I, Cl C	half
10-3-G-49				27737 Ty II, Cl C	half
10-3-G-50			81706 Ty II	23377 Ty I, Cl N	half
10-3-G-51				NAVAIR 002+	half
10-3-G-52				85582 Ty I, Cl N	half
10-3-G-53				ANAC's P2100P003	half
10-3-G-54				23377 Ty I, Cl C	half
10-3-G-55				85582 Ty I, Cl C	half
10-3-G-56				27737 Ty II, Cl C	half
10-3-G-57			81706 Ty I	23377 Ty I, Cl N	half
10-3-G-58				NAVAIR 002+	half
10-3-G-59				85582 Ty I, Cl N	half
10-3-G-60				ANAC's P2100P003	half
10-3-G-61				23377 Ty I, Cl C	half
10-3-G-62				85582 Ty I, Cl C	half
10-3-G-63				27737 Ty II, Cl C	half
10-3-G-64			8625 Ty IC	23377 Ty I, Cl N	half
10-3-G-65				NAVAIR 002+	half
10-3-G-66				85582 Ty I, Cl N	half
10-3-G-67				ANAC's P2100P003	half
10-3-G-68				23377 Ty I, Cl C	half
10-3-G-69				85582 Ty I, Cl C	half
10-3-G-70				27737 Ty II, Cl C	half
10-3-G-71	KSC Beach	Galvanic	PreKote	23377 Ty I, Cl N	half
10-3-G-72				NAVAIR 002+	half
10-3-G-73				85582 Ty I, Cl N	half
10-3-G-74				ANAC's P2100P003	half

Panel ID	Test	Substrate	Surface Treatment	Primer	Topcoat
10-3-G-75				23377 Ty I, Cl C	half
10-3-G-76				85582 Ty I, Cl C	half
10-3-G-77				27737 Ty II, Cl C	half
10-3-G-78			BoeGel	23377 Ty I, Cl N	half
10-3-G-79				NAVAIR 002+	half
10-3-G-80				85582 Ty I, Cl N	half
10-3-G-81				ANAC's P2100P003	half
10-3-G-82				23377 Ty I, Cl C	half
10-3-G-83				85582 Ty I, Cl C	half
10-3-G-84				27737 Ty II, Cl C	half
10-3-G-85			81706 Ty II	23377 Ty I, Cl N	half
10-3-G-86				NAVAIR 002+	half
10-3-G-87				85582 Ty I, Cl N	half
10-3-G-88				ANAC's P2100P003	half
10-3-G-89				23377 Ty I, Cl C	half
10-3-G-90				85582 Ty I, Cl C	half
10-3-G-91				27737 Ty II, Cl C	half
10-3-G-92			81706 Ty I	23377 Ty I, Cl N	half
10-3-G-93				NAVAIR 002+	half
10-3-G-94				85582 Ty I, Cl N	half
10-3-G-95				ANAC's P2100P003	half
10-3-G-96				23377 Ty I, Cl C	half
10-3-G-97				85582 Ty I, Cl C	half
10-3-G-98				27737 Ty II, Cl C	half
10-3-G-99			8625 Ty IC	23377 Ty I, Cl N	half
10-3-G-100				NAVAIR 002+	half
10-3-G-101				85582 Ty I, Cl N	half
10-3-G-102				ANAC's P2100P003	half
10-3-G-103				23377 Ty I, Cl C	half
10-3-G-104				85582 Ty I, Cl C	half
10-3-G-105				27737 Ty II, Cl C	half