Non-Chromate Aluminum Pretreatments

FINAL REPORT

Project WP-200025

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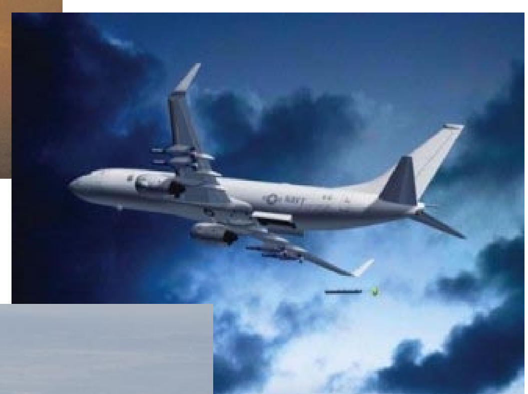

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14. ABSTRACT
Aluminum finishing in Department of Defense applications utilizes chromate chemistries for anodizing, anodic sealing, and pretreatment (both for conversion coating aluminum substrates and for treating aluminum-based coatings deposited on steel). The most ubiquitous use of chromate coatings is in the conversion coating of aluminum alloys for use as-deposited or prior to organic coating application. These coatings are very thin, inexpensive to produced, and can be applied by immersion, spray and wipe techniques. However, chromate conversion coatings contain hexavalent chromium, a known carcinogen. National and international regulations are restricting the use of this material. This report presents the results of laboratory and field tests to demonstrate and validate several non-chromate aluminum pretreatments. All of the alternatives were aqueous solutions designed to deposit a conversion coating on aluminum alloy substrates to enhance paint adhesion and painted corrosion performance. Some of these alternatives are currently being implemented on several

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DISCLAIMER

Due to the critical nature of DoD weapons systems coating performance and because of NAVAIR's interest and involvement in the trivalent chromium process (TCP) the reports and results from this project were reviewed for technical content, accuracy, and fairness by the following: the Air Force Corrosion Prevention and Control Office (AFCPCO), the Army Research Laboratory (ARL) Coatings and Corrosion Branch, the Naval Air Systems Command (NAVAIR) Materials Division, the Naval Sea Systems Command (NAVSEA) Materials Division, the Office of the Program Manager Combat Systems (PMCS), the Office of the Direct Reporting Program Manager Advanced Amphibious Assault (DRPM AAA), the US Army Aviation and Missile Command (AMCOM) Environmental, Engineering, and Logistics Office (EELO), United Defense, General Dynamics Amphibious Systems, and Boeing Commercial Airplanes.

ACRONYMS AND ABBREVIATIONS

AA – Aluminum Alloy
AAA – Advanced Amphibious Assault
AACP – Advanced Aircraft Corrosion Protection
AAV – Amphibious Assault Vehicle
ACU – Assault Craft Unit
AETC – Air Education and Training Command
AFB – Air Force Base
AFRL – Air Force Research Laboratory
AFCPCO – Air Force Corrosion Prevention and Control Office
AMCOM – Aviation and Missile Command
APG – Aberdeen Proving Grounds
ARL – Army Research Laboratory
ASTM – American Society for Testing and Materials
AVCRAD – Aviation Classification Repair Activity Depot
AVTB – Amphibious Vehicle Test Branch
BASC – Boeing Aircraft Support Center
BFIST – Bradley Fire Support Team
BFV – Bradley Fighting Vehicle
BUNO – Bureau Number
CARC – Chemical Agent Resistant Coating
CCAD – Corpus Christi Army Depot
CCC – Chromate Conversion Coating
COMNAVSEASYSCOM – NAVSEA Commander
CONSTRKFIGHTWINGLANT – Commander Atlantic Strike Fighter Wing
CPC – Corrosion Preventative Compounds
CTC – Coatings Technology Center
CY – Calendar Year
DEM/VAL – Demonstration/Validation
DFT – Dry Film Thickness
DI – Deionized
DoD – Department of Defense
DRPM – Direct Reporting Program Manager
DTM – Direct to Metal
DUSD-ES – Deputy Undersecretary of Defense for Environmental Security
E1 – First Experimental Vehicle – USMC EFV
EELO – Environmental, Engineering, & Logistics Oversight
EFV – Expeditionary Fighting Vehicle
EMI – Electromagnetic Interference

EMT – Environmental Management Team
EPA – Environmental Protection Agency
ESOH – Environmental, Safety and Occupational Health
ESTCP – Environmental Security Technology Certification Program
FSE – Floor Support Engineering
GDAMS – General Dynamics Amphibious Systems
GDLS – General Dynamics Land Systems
HazMat – Hazardous Material
HSTNA – Henkel Surface Technologies North America
HSU – Hydraulic Suspension Unit
IARC – International Agency for Research on Cancer
ICT – Inorganic Coatings Team
IETM – Integrated Electronic Technical Manual
JG-PP – Joint Group on Pollution Prevention
JLC – Joint Logistics Commander
JTP – Joint Test Protocol
KM – kilometers
KSC – Kennedy Space Center
ksi – kilopounds per Square Inch
LATP – Lima Army Tank Plant
LCAC – Landing Craft Air Cushion
LEX – Leading Edge Extension
LRIP – Low Rate Initial Production
MCB – Marine Corps Base
MCAS – Marine Corps Air Station
MEK – Methyl Ethyl Ketone
MIL-C – Military Control Specification
MIL-DTL – Military Detail Specification
MIL-H – Military Hydraulic Fluid Specification
MIL-P – Military Paint Specification
MIL-PRF – Military Performance Specification
MIL-SPEC – Military Specification
MSDS – Material Safety Data Sheet
NADEP – Naval Aviation Depot
NAS – Naval Air Station
NASA – National Aeronautics and Space Administration
NAVAIR – Naval Air Systems Command
NAVMSG – Navy Message

NAVSEA – Naval Sea Systems Command
NAWCAD – Naval Air Warfare Center Aircraft Division
NCAP – Non-Chromated Aluminum Pretreatment
NORIS – North Island Naval Depot
NSF – Neutral Salt Fog
NSWC – Naval Surface Warfare Center
OEM – Original Equipment Manufacturer
OOALC – Ogden Air Logistics Center
OSHA – Occupational Safety and Health Administration
P1 – First Prototype Vehicle – USMC EFV
PAX – Patuxent River Naval Air Station
PEO – Program Executive Office
PEL – Permissible Exposure Limit
PM – Program Manager
PMA – Program Management Activity
PMB – Plastic Media Blasting
PM CS – Program Manager Army Ground Combat Systems
PMI – Planned Maintenance Interval
POC – Point of Contact
psi – pounds per square inch
QA – Quality Analysis
QC – Quality Control
QOT&E – Qualification Operational Test and Evaluation
QPL – Qualified Products List
RRAD – Red River Army Depot
RH – Relative Humidity
SAE-AMS – Society of Automotive Engineers - Aerospace Material Specification
SCC – Stress Corrosion Cracking
SDLM – Standard Depot Level Maintenance
SDD – System Design and Development
SPO – Systems Program Office
SPT – Self Priming Topcoat
SRB – Solid Rocket Booster
TCP – Trivalent Chromium Pretreatment
TO – Technical Order
UDLP – United Defense
USMC – United States Marine Corps
WESTPAC – Western Pacific
YPG – Yuma Proving Grounds

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This project has been executed under the generous support of the Environmental Security Technology Certification Program (ESTCP) and the Office of the Deputy Undersecretary of Defense for Environmental Security (DUSD-ES). The effort was led by the Naval Aviation Systems Command (NAVAIR) Materials Division Patuxent River and coordinated with Joint Group on Pollution Prevention (JG-PP). This project was initiated by Craig Matzdorf, Code 4.3.4, NAVAIR Materials Engineering Division, Patuxent River, MD. The principal investigator for this project is Bill Nickerson, Code 4.3.4, NAVAIR Materials Engineering Division, Patuxent River, MD. Leveraged efforts were supported by their respective services.

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SUMMARY

Current light metal finishing procedures for industrial, automotive, aerospace, and Department of Defense (DoD) applications center around the use of hexavalent-chromium based chemistries for the enhancing corrosion resistance and paint adhesion. Aluminum finishing, in particular, utilizes chromate chemistries for anodizing, anodic sealing, and pretreatment (both for conversion coating aluminum substrates and for treating aluminum-based coatings deposited on steel). The most ubiquitous use of chromate coatings is in the conversion coating of aluminum alloys for use as-deposited or prior to organic coating application. These coatings are very thin, inexpensive to produce, extremely process flexible, and can be applied by immersion, spray and wipe techniques.

Chromate conversion coatings offer many advantages; however, the downside is that they contain hexavalent chromium, or chromate, species that are known to be carcinogenic. The occupational safety and health issues arising from risk of worker exposure to these chemicals, as well as the costs and the potential liabilities resulting from an accidental leak to the environment and waste disposal issues from normal finishing operations are making the use of chromate-based conversion coatings unattractive to the metal finishing industry.

Additionally, new Occupational Safety and Health Administration Permissible Exposure Limit (OSHA PEL) changes for hexavalent chromium have made the regulatory cost of using chromate very expensive. The final ruling, delivered in 2006, dropped the PEL from 100 $\mu g/m^3$ (for hexavalent chromium in the form of chromic acid) to 5 $\mu g/m^3$ with an action level of half that. An aerospace special rule was also delivered at this time, reducing the PEL to 25 1 $\mu g/m^3$ (however, this does not cover all of DoD operations, only the aircraft). As well as US OSHA regulations, new and stricter rules within the international community, especially the EU Restriction of Hazardous Substances (RoSH), End of Vehicle Life (ELV), and WEEE initiatives have placed additional hardship on the continued use of chromated chemistries.

1.0 – INTRODUCTION

1.1 – PROJECT BACKGROUND

The Environmental Security Technology Certification Program (ESTCP), established in December 1993, is managed by the Office of the Deputy Undersecretary of Defense for Environmental Security (DUSD-ES). The ESTCP demonstrates and validates laboratory-proven technologies that target the DoD's most urgent environmental needs. These technologies provide a return on investment through reduced environmental, safety, and occupational health (ESOH) risks; cost savings; and improved efficiency. The new technologies typically have broad application to both the DoD community and industry.

ESTCP selected the Non-Chromate Aluminum Pretreatment (NCAP) project, led by the Naval Air Systems Command (NAVAIR) and coordinated with JG-PP, to assist in the mitigation of the significant ESOH risks that are associated with the use of chromate conversion coatings. Chromate conversion coatings contain hexavalent chromium, a known human carcinogen that is strictly regulated. The project's stated objective was to achieve the goal of reducing or eliminating the use of hexavalent chromium in aluminum finishing by demonstrating and validating the performance of alternatives in accordance with the technical requirements and tests identified in the Joint Test Protocol (JTP).

The key benefit of the non-chromated pretreatment alternatives reported on here is the elimination or absence of hexavalent chromium from the process chemicals and as-deposited coating. Eliminating chromates from the conversion coating or pretreatment operations will drastically reduce user liability and risk in the life cycle of the platform or parts being coated. The key challenge for the alternatives was, and remains today, to match the technical performance of chromate conversion coatings in a cost-effective manner.

1.2 – OBJECTIVE AND SCOPE OF WORK

The Phase I Report, dated July 2003, presents an evaluation of laboratory coupon testing of non-chromate aluminum pretreatment alternatives through accelerated tests on flat coupons. Phase I of this effort focused on the laboratory evaluation of several possible non-chromate alternative technologies. The results of the analysis were used to support field testing in Phase II on components and in-service platforms where technical performance is highly dependant on service environment and overall platform design and use. The NCAP Phase I Report from 2003 details the adhesion and accelerated corrosion performance of these alternatives. Phase I examined the behavior of several alloy, coating, and paint system combinations. The data was generated in accordance with the NCAP JTP, dated 13 December 2000, to determine the potential effectiveness of the alternatives as replacements for chromate conversion coatings.

In the Phase I Report, Matzdorf, et al., reported that, "Each alternative tested shows acceptable performance in some selected cases that may be satisfactory for a given user, depending on operating environment and business cases involved. The only compositions that come close to matching the technical, process, cost, and flexibility of chromates are based on trivalent chromium. Although trivalent chromium is present in the solution and coating, toxicity studies, International Agency for Research on Cancer (IARC) regulations, and OSHA PELs suggest that the use of Trivalent Chromium Product (TCP) is acceptable, especially given its well-rounded performance. The next best product in testing was Alodine™ 5200/5700. Alodine™ 5200/5700 contains no chromium, is process flexible and can be applied like chromate conversion coatings. The remaining alternatives performed variably in the evaluation."

Out of the Phase I Laboratory testing, the potential alternative technologies were down-selected for field demonstration and validation testing by the respective services and program offices based upon their unique performance and operational environment requirements. The main advantage of any alternative is the elimination of hexavalent chromium. In most cases, the alternatives are trying to match the process and technical performance of the chromate solutions and coatings.

The Phase II Interim Report, details the field testing efforts at that time to validate the feasibility of applying and maintaining, i.e. utilizing and repairing, these conversion coatings in lieu of conventional chromate-based technologies. Testing was conducted with various organic coatings systems, according to the particular service and platform requirements. This variety in field testing helps assure that potential candidates to hexavalent chromium are applicable as alternatives in their own right, without the necessity of specifying the use of only one or two possible primers/paint systems. The field test phase of this project was constructed to cover the broadest range of aluminum alloys, processing methods and conditions, and the operational environments experienced by fielded platforms across DoD.

This Final Report provides a detailed description of the laboratory and field testing conducted during the project as well as a summary of the transition and implementation status of the alternatives as of the date of project completion. Appendix A presents the results of the 8-year beach exposure corrosion testing, Appendix B presents the Phase II Interim Report in its entirety, and Appendix C presents the Phase I Laboratory Report in its entirety.

2.0 – SELECTED DEMOSTRATION / VALIDATION

Pretreatment	DoD Service	Platform(s)	Facilities
Alodine 5700 TCP - Color	US Army Ground Combat	Bradley Fighting Vehicle	Red River Army Depot United Defense - York
Alodine 5700 TCP	US Army Aviation	CH-47, H-60	Corpus Christi Ct AVCRAD
Alodine 5700 TCP	USMC Amphibious Assault	Expeditionary Fighting Vehicle	General Dynamics – Lima AVTB – Camp Pendleton
PreKote	US Air Force	F-16, C-130	Hill AFB
TCP	NAVAIR	CH-46, S-3, F-18	NADEP's CP, NI
TCP	NAVSEA	Landing Craft, Air Cushioned	NSWC – Little Creek, VA

Table 2.0 – Selected Pretreatments for Dem/Val efforts

2.1 – PHASE II EFFORTS SUMMARY

Field testing of the TCP was underway with NAVAIR when the ESTCP project began and the two efforts were leveraged together. In addition, Navy Sea Systems Command (NAVSEA) had begun an independent evaluation of the TCP for the Landing Craft, Air Cushioned (LCAC). As a result, the Navy supported its aircraft and LCAC demonstrations, and the Air Force (AF) took the lead on the PreKote™ demonstration with the F-16 and C-130 platforms. As a result of these initial, leveraged efforts, field testing opportunities outside the Navy were selected for the NCAP project to more broadly cover the potential applications and operational environments. ESTCP funded the Phase II efforts for the USMC Expeditionary Fighting Vehicle (EFV), the US Army Bradley Fighting Vehicle (BFV), and the US Army Aviation and Missile Command (AMCOM) platforms. NAVAIR, Boeing, and NASA have been demonstrating the AC-131™ for pre-paint and bonding applications. The EFV demonstration/validation effort was conducted with General Dynamics Amphibious Systems (GDAMS), General Dynamics Land Systems (GDLS), and the Direct Reporting Program Manager (DRPM AAA) personnel. The BFV demonstration/validation was conducted with BAE Ground Systems (BAE) and the office of the Program Manager Combat Systems (PMCS), using TCP-C, a modified TCP chemistry that imparts a dark purple-blue to brown color to the as-deposited conversion coating. The selection of TCP-C over the baseline TCP was made at the request of BAE and PMCS engineering because of the desire for visual quality control assurance from a practical color change. Based on panel testing data generated at ARL, Aberdeen Proving Ground (APG), MD; the Red River Army Depot (RRAD) installed and currently maintains an

Alodine^{TM} 5700 immersion bath for conversion coating of aluminum road wheels for US Army ground combat vehicle platforms. RRAD obtained an approval letter for use of Alodine^{TM} 5700 on aluminum road wheels, and is currently applying the coating on re-work vehicles via an immersion process. US Army Aviation efforts selected the Connecticut Aviation Classification Repair Activity Depot (AVCRAD) and Corpus Christi Army Depot (CCAD), TX as the demonstration and implementation sites. The Program Executive Office (PEO) Aviation, along with the individual Program Management Activities (PMA's) from Army Aviation has implementation authority for these efforts.

3.0 – ONGOING MARINE ATMOSPHERE EXPOSURE TESTING

3.1 – BACKGROUND

Phase I testing included outdoor, beachside exposure testing at the Corrosion Technology Testbed, Kennedy Space Center, FL. The testing is being completed by NASA and contractor personnel at the Kennedy Space Center (KSC), FL. 3”x5” aluminum coupons were pretreated with the alternative conversion coatings being examined, primed, top-coated, and shipped to KSC for testing in 2001. The rankings presented here are from the 5 year evaluations, completed in December 2006. High performing systems have remained in testing to further the long-term performance data.

As stated in the Phase I report, performance ratings are measured by ASTM D 1654 Procedure A; and any rating below “3” is considered failed and the panel removed from testing. NASA’s test facility is located 1.5 miles south of Launch Complex 39A. Test stands are located 30 meters (100 feet) from the mean high-tide line and face the water. Test coupons are installed on yellow, painted steel test stands using porcelain insulator stand-offs. The rack angle of the coupons is 30 degrees from horizontal. An “X” incision was scribed through the coating so that the smaller angle of the “X” was 30 to 45-degrees, making sure that the coating was scribed all the way to the substrate. The scribe had a 45-degree bevel, and each line of the “X” was approximately 4-inches long. The back and edges of the coupon were primed to prevent undercutting and corrosion products from contaminating the test stands.

The coupons were evaluated for surface corrosion and creepage from the scribe at 6-month intervals. Remaining coatings are still being evaluated, now at greater than 9 years of beach exposure. NAVAIR is conducting correlation and statistical analysis on the coatings’ stack-ups, and will publish those results in conference proceedings as appropriate.

9.0-10	BEST
8.0-8.9	GOOD
7.0-7.9	FAIR
5.0-6.9	OK
3.0-4.9	POOR
0.0-2.9	FAIL

Figure 1: 8-year beach exposure average rating categories.

3.2 – RESULTS

The beach panel testing is still ongoing, and as of the time of this report, the results from a full eight years of exposure at the Kennedy Space Center (KSC) corrosion facility were available. Many coating combinations of pretreatment and primer systems had failed ratings long before the eight year exposure contained here; please see earlier reports for the one and three year beach exposure results.

The results are averaged across the 5 panel set for each pretreatment and primer combination (APPENDIX A). The results are presented as averages across all four test alloys for each pretreatment: by primer system, by aviation or ground coating system average, and finally as a total average for all coating systems and alloys.

An overall assessment shows that across the different aluminum alloys and with both chromated and non-chromated primers, only the Trivalent Chromium Process (TCP) and Alodine™ 5200/5700 alternatives perform comparably to the Alodine™ 1200S control, none of the other alternatives fared as well. The use of Class C chromated primer clearly reduces the impact of the pretreatment choice, allowing for comparable performance from two of the better organic-based pretreatments, the Bi-K Aklimate™ and the AC Technologies AC-131. The superior performance of TCP and 5200/5700 is strongly evident in the non-chromate primer systems where no other alternative consistently approaches the level of performance.

Another general trend is the superior corrosion protection of the inorganic-based pretreatments (1200S, TCP, and 5700). This is hypothesized to be due to their passivation of the active aluminum surface by a covalently bonded oxide layer which improves both adhesion and corrosion resistance. In contrast, the organic-based pretreatments, while offering excellent adhesion promotion in some instances, do not reduce the activity of the aluminum surface, and this creates a situation where the primer inhibitor is protecting not just the small areas where the oxide layer has degraded, but the entire coated surface. More recent results with next generation Class N primers not available at the time of this project have continued to validate this observation.

Other trends of interest include the slight advantage of the high-solids epoxy primer – MIL-PRF-23377 Class C2 over the water-reducible epoxy primer – MIL-PRF-85582 Class C1. This is potentially from the difference in barrier properties and moisture permeability between the two resin systems. This resin property effect has been clearly shown in more recently reported ESTCP Class N primer efforts as well. Both the difference in leach rate of the Class C2 strontium chromate inhibitor vs. the Class C1 barium chromate inhibitor and the relative amounts of inhibitor incorporated into high-solids vs. water-reducible resin systems may also play a role. Like the previous corrosion tests, the chromate-based primer systems offer superior performance to non-chromated systems, especially the Army CARC primers which were formulated for the protection of ferrous alloys (this effect is masked in some evaluations that have been presented, by improperly comparing aviation primers at aircraft thickness requirements, 0.6-0.9 mils, with CARC primers at ground vehicle thickness, 2.0-3.5 mils).

Regardless of alloy, from this data set, the conclusion may be drawn that the CARC primers be the primary choice for ferrous substrates, but that applications on aluminum surfaces, even such as AA5083 used for ground vehicles and support equipment, are replaced with aviation Class N primers. The non-chromate systems, on average, rank lower than the chromate systems especially with the poorer performing surface preparation alternatives. There are two notable exceptions in this test.

The performance of the 85582 Class N primer with Alodine™ 1200S, TCP and Alodine™ 5200/5700 differs little from their performance with the sister chromate primers. The performance of the TCP and Alodine™ 5200/5700 with the non-chromate epoxy primers, 53022 and 53030 is equivalent or better than Alodine™ 1200S with the same primers. The aluminum alloy trend is that AA5083 is easier to protect than the others, and that AA2219 is the most difficult to protect across the coating systems; at least in this data set, which only compares stand-alone aluminum substrates, uncoupled from any galvanic/dissimilar material corrosion drivers.

4.0 – LEVERAGED EFFORTS

4.1 – AF F-16/C-130

4.1.1 – BACKGROUND

A multi-year effort at Hill Air Force Base (AFB) was under taken in 2000, with the oversight of the Air Force Corrosion Prevention and Control Office (AFCPCO), to reduce or eliminate the use of chromate compounds in the paint preparation process for aircraft. Pantheon Chemicals PreKote conversion coating was selected for transition through the T.O. 1-1-8. The application process used in the Qualification Operational Test and Evaluation (QOT&E) process is called the "three-step" process. Step 1: the surface of the aircraft is scrubbed with PreKote and rinsed after scrubbing. Step 2: PreKote is applied to the surface again and agitated, and allowed to completely dry on the aircraft surface. Step 3, PreKote is applied to the surface again and agitated to remove the residue from Step 2.

4.1.2 – STATUS

As of February 2004, AFCPCO has approved PreKote as a surface treatment alternative to chromate conversion coating prior to exterior painting of USAF aircraft. The process was added to T.O. 1-1-8, "Application and Removal of Organic Coatings, Aerospace and Non-Aerospace Equipment," and includes specific process steps. The use of PreKote on AF aircraft requires System Program Office (SPO) approval, and the use of a chromated primer. The F-16, T-37, T-38 and T-1 SPO's have now approved the use of PreKote, and Headquarters Air Education and Training Command (HQ AETC) has mandated its use on all AETC aircraft for which it's approved. If a base, MAJCOM, or ALC decides to pursue using PreKote in their paint processes on other systems, it must obtain approval from the appropriate SPO's. AFCPCO will provide existing test results upon request to assist SPO's with the engineering decision whether to approve PreKote.

However, the AFCPCO has noted some areas of consideration in the use of PreKote. Since application of PreKote is largely a manual process, the consistency of the process may be important to an overall satisfactory result. To achieve results equal to other weapon systems, they recommend adhering closely to application practices that have already been established. Note that all test results to date, current SPO approvals, and the assessment of low risk, are contingent on the use of a qualified chromated primer. When PreKote is used, corrosion inhibition comes only from the chromated primer. The AFCPCO strongly recommends against the use of PreKote with non-chromated primers.

4.2 – NAVAIR S-3

4.2.1 – BACKGROUND

The US Navy's S-3 support aircraft are currently sprayed with a chromate conversion coating during de-paint/re-paint operations while undergoing Standard Depot Level Maintenance (SDLM) at the Fleet Readiness Center (FRC) Southwest, North Island facility. Four aircraft were sprayed with TCP for the S-3 demonstration; the first two were treated with TCP on the aft (tail) section only. The 3rd and 4th aircraft were completely treated with TCP. The aircraft were then painted with the TT-P-2756 Self-Priming Topcoat (SPT), a non-chromated, polyurethane topcoat that is used without an underlying primer.

4.2.2 – STATUS

The US Navy's S-3 platform has been phased out of service, and no additional rework efforts are being conducted at the depots. Additionally, due to documented poor laboratory and field performance, the TT-P-2756 product is no longer authorized for use on US Navy aircraft, regardless of pretreatment.

4.3 – NAVAIR F/A-18 C/D

4.3.1 – BACKGROUND

Naval Aviation experiences the harshest possible environment for aluminum corrosion, in that most fielded strike and support aircraft are deployed shipboard on aircraft carriers. Current protection schemes are focused around the use of chromate materials, both for inorganic conversion coatings and secondary primer applications. Even with the current hexavalent chromium coating system, corrosion is a very large driver for operations and maintenance costs and severely impacts operational readiness. As the US Navy's premier attack strike fighter aircraft, anything affecting the flight hours to maintenance down-time is a critical issue. For this reason, any possible alternatives must at the very least meet the performance of current, less environmentally friendly systems, even while we continue to strive for better than the current corrosion protection.

4.3.4 – STATUS

Overall, the TCP technology performed at least as well as the standard chromate conversion coating in this demonstration. These aircraft had at least three carrier deployments and may have had a fourth. Maintenance personnel were enthusiastic about new technologies due to their environmental and health benefits. The TCP aircraft are performing on par with the that are discussed in Section 4.4, NAVAIR Materials has authorized the use of TCP (MIL-DTL-81706 Type II qualified products) under chromated primers.

4.4 – NAVAIR CH-46

4.4.1 – BACKGROUND

NAVAIR's fleet of H-46 helicopters undergoes depot-level rework at Fleet Readiness Center (FRC) East, Cherry Point, NC. Due to severe environmental restrictions placed on the conventional spray-on/rinse-off chemical processing methods, the FRC had utilized a hand application wipe-on/wipe-off method for chromate conversion coating their aircraft. This procedure was used for all pre-paint surface preparation of aluminum skins. In 2000, the Environmental Affairs Office in Cherry Point determined that the NAVAIR TCP process does not fall under the environmental and health and safety regulations that govern the hexavalent chromium processes. This is due to trivalent chromium being non-carcinogenic, unlike hexavalent chromium.

Cherry Point decided to field test the TCP on the H-46 platform, on the basis of being able to spray apply TCP. A conventional spray application conversion coating process allows for faster turn around time for aircraft undergoing Standard Depot Level Maintenance (SDLM). The old hand application method required between 4 and 6 man-hours of labor to conversion coat one CH-46 airframe. The spray process reduced this process time by half, affording a noticeable reduction in labor-hour costs.

4.4.2 – STATUS

The inspection results for the CH-46's indicate that TCP performed at least as well as the chromated pretreatment materials for aluminum alloys in these tests. In January 2006, FRC East, Cherry Point implemented MIL-DTL-81706 Type II materials for interior and exterior spray processing operations. All rotary wing repaint operations being conducted at FRC East now use the non-chromated TCP material.

4.5 – NASA SOLID ROCKET BOOSTERS

4.5.1 – BACKGROUND

The Space Shuttle Solid Rocket Booster (SRB) had only one set of coatings and one type of pretreatment qualified for protection of aluminum hardware. All of the materials contained chromate compounds. A NASA project was conducted to identify and qualify alternatives for the currently qualified coating system and pretreatment. The coatings were evaluated for corrosion protection, bond strength, compatibility with other SRB materials, batch-to-batch consistency, and thermal environments stability. Two pretreatments and two coating systems met the SRB program criteria. The selected products were the Henkel Alodine 5700 and the MacDermid Chemidize 727 ND. These pretreatments were used in conjunction with non-chromate epoxy primers provided by Hentzen and by Lord Coatings. The coating systems were tested in both a primer only and a primer/topcoat configuration. Both were found to be acceptable for flight. The Alodine 5700 had very robust processing parameters and was down-selected for the first implementation as a pretreatment alternate.

4.5.2 – STATUS

NASA implemented the Hentzen / Alodine 5700 system in June 2002. This change affected all structural aluminum (AA2219, AA6061, and AA7075) parts of the solid rocket boosters. No issues have been reported with this system. The SRB is a one-time use application; additional work is still ongoing to identify pretreatments with inherent corrosion protection for use on longer service life components.

4.6 – BOEING/AIR FORCE/NAVY

4.6.1 – BACKGROUND

The US Air Force and Boeing conducted evaluations using the surface treatment system, AC-131 from Advanced Chemistry and Technology in Garden Grove, CA. AC-131 is based on technology developed at Boeing as "Boe-gel" sol-gel chemistry-based conversion coating. AC-131 is intended for use as an adhesion promoter for pre-paint applications on a variety of metallic substrates. This effort began in September 2002.

The project focused on two main evaluations to determine validity for field demonstration. The first significant milestone of the project was to investigate ways to make Boegel/AC-131 visibly inspectable. Several colored dyes were successfully added to the conversion coating promoting color definition. The second milestone was to validate the adhesion promoting characteristics of AC-131 on a variety of aluminum substrates and surface conditions. Similar adhesion performance was observed for both the AC-131 and the Alodine 1200S chromate control in wet tape and pull-off adhesion testing. The performance of coating systems with AC-131/Boegel in laboratory adhesion testing has been reported to be equivalent or sometimes better than the performance of coating systems with conventional chromate conversion coatings.

4.6.2 – STATUS

Boeing-Seattle has implemented the AC-131 product for use in pre-paint operations on the commercial aircraft line, under chromated primer. The AFCPCO has added the AC-131 to the T.O. 1-1-8 as an acceptable surface preparation for paint adhesion.

5.0 – ESTCP NCAP EFFORTS

5.1 – US NAVY LANDING CRAFT, AIR CUSHIONED

5.1.1 – BACKGROUND

The pre-paint procedure for the Landing Craft, Air Cushioned (LCAC) amphibious vehicle hulls, which are composed primarily of AA5456-H116, involved abrasive blasting with garnet to achieve a surface profile of 3 mils. Painting is then conducted with a solvent-reducible, non-chromated epoxy primer, MIL-DTL-24441B Type III, Formula 150, to a dry film thickness (DFT) of 3-4 mils and then over-coated with MIL-DTL-24441B Type III, Formula 151 for a final DFT of 6-8 mils. Hexavalent chromium chemistry was suspended by NAVSEA in August 1991 and an alternative to abrasive blasting for surface preparation is desired.

Several issues have arisen with the current direct-to-metal process, one of which is adhesion loss due to undercutting and undercutting exacerbated by crevice corrosion between substrate and coating, and another being coating cracking due to craft flex and vibration.

Surface preparation is a key concern, as MIL-DTL-24441B exhibits poor adhesion when the nominal surface profile is less then 3-mils. This can be achieved by grit-blasting, but not by other mechanical surface preparation methods, such as shot-peening or grit-impregnated sanders. AA5456-H116 has a tendency to polish after approximately 2 mils of profile have been achieved by mechanical methods. Additionally, both Assault Craft Unit Four (ACU-4) and ACU-5 are prohibited by NAVSEA from sailors performing abrasive blasting due to dust generation. This adversely affects the coatings performance of any maintenance and repair efforts conducted at the unit level. With respect to CRAFTALT installation as performed by contractors, production schedule analysis has indicated that implementation of TCP in place of the current abrasive blast process could reduce production time by 23 man-days and hangar time by 8 days.

These tests were initiated and overseen by Mr. Paul Dobias, NSWC Carderock Division, Materials Process and Engineering Branch. The LCAC program began testing TCP as a potential surface preparation method, allowing a substitution for abrasive blasting as a pre-paint process. The TCP was chosen for demonstration because of the potential for realizing a time/cost savings, as well as improved adhesion and corrosion performance when compared to a direct-to-metal process.

5.1.2 – STATUS

In December 2002, the test coupons were evaluated for surface pitting and general corrosion. Both the garnet blasted coupons and the coupons treated with TCP performed better than those with no surface preparation, which were now bare due to all of the coating having lost adhesion. The overall evaluation was that TCP reduced the incidence of pitting corrosion comparative to other surface preparation methods. The two painted TCP components were evaluated after 4 years of service on LCAC #26: no corrosion, undercutting, or adhesion failures were noted. This demonstrated the adhesion performance when subjected to both corrosive and vibration/flexing environments. NAVSEA PEO SHIPS, PMS 377 has indicated that they will authorize TCP for pretreatment of aluminum alloys of LCAC pending concurrence from the Technical Warrant Holder (TWH).

5.2 – USMC EXPEDITIONARY FIGHTING VEHICLE

5.2.1 – BACKGROUND

The Expeditionary Fighting Vehicle (EFV) program was originally designated the AAAV – Armored Amphibious Assault Vehicle. A new armor alloy, AA2519, was chosen for improvements in the strength/weight ratio and ballistic properties compared to legacy 5000 series alloys. The AA2519 is a high copper alloy very susceptible to pitting and exfoliation corrosion. Due to the extremely harsh operating environment experienced by the EFV; the corrosion control coatings and materials must be as robust at possible. At the outset of this new acquisition program, the PM made the executive decision to comply with the strictures of an environmentally "green" program. Included in this is the full prohibition of the use of hexavalent chromium containing coatings.

Originally, the EFV prototype vehicles were prepared and coated using a grit-blast/wash primer process that had shown good performance characteristics on high-strength and armor steel alloys. During initial field testing with the first prototype vehicle, serious problems arose with the coating system and its corrosion performance. These corrosion and adhesion issues needed to be addressed for the unique performance and operational requirements of AA2519-T87. The initial coating procedure was wash with a standard alkaline steel cleaner, abrasive blast with alumina to a 1.5-2.0 mil surface profile, wash prime with a water-reducible non-chrome primer, prime with a solvent-reducible, epoxy CARC, and finally topcoat with a water-reducible, polyurethane CARC. It was suggested that the program look into a chemical process and conversion coat surface preparation in lieu of the mechanical surface preparation/wash primer process.

5.2.2 – CURRENT PROCESS – LRIP

The chemical process for the production phase will be as finalized in the SDD prototype phase.

Alkaline Cleaner	Aerowash 10% vol. 100 F
Deoxidizer	Ridoline 4450 10-15 minute dwell
Pretreatment	TCP 30-50% vol. 10-15 minute dwell
Primer	MIL-PRF-23377 Type I, Class N
Topcoat (Interior)	MIL-C-22750 seafoam green
Topcoat (Exterior)	MIL-DTL-64159 TyII CARC 383 Green or Tan

Table 5.1: Target coating system for EFV LRIP

5.2.3 – STATUS

The EFV program has not yet begun the scheduled LRIP phase due to some mechanical reliability concerns still being addressed. The LRIP and FRP coating systems have been finalized, and the finishing specification revised to reflect the fully non-chromated coating system. Henkel Alodine T5900 (TCP) has been selected as the pretreatment for the processing of the hulls and turrets. Both TCP and Alodine 5200/5700 have been approved for use on components by GDAMS and their vendors. The USMC AVTB is currently using Alodine 5700 pre-saturated wipes for coating system maintenance and repair touch-up applications on the SDD vehicles fielded there.

5.3 –US ARMY BRADLEY FIGHTING VEHICLE

5.3.1 – INTRODUCTION

The US Army's M2 Bradley Fighting Vehicle entered production by United Defense (now BAE Ground Systems) in 1980. Originally, this program utilized a chromate conversion coating applied by immersion process to enhance corrosion resistance and paint adhesion on aluminum hull, turret, and armor components.

The BAE facility possessed an automated hoist and immersion system, whereby an entire hull could be lifted and dipped through the 32,000-gallon process tank line in 2.5 – 3 hours. The process line utilized Chemetall-Oakite™ brand chemicals, and consisted of a mildly alkaline non-silicated cleaner, a hot phosphoric acid etch, a ferric sulfate/nitric acid based de-smut, and finally the chromate conversion coating. Each step in the process was followed by a halo-spray, clear water rinse.

BAE-York, PA, the OEM, is still upgrading and retrofitting BFV's to the new M2A3, M3A3 variations. In depot maintenance and rework efforts, it was noticed that the aluminum armor alloy, AA7039, evidenced severe intrametallic delamination probably caused by environmentally assisted stress corrosion cracking (SCC). The decision was made to move to a manual surface prep method, as it was thought that the immersion process trapped moisture in small cracks and tight areas on the vehicles, thereby accelerating the delamination. The PM Heavy Brigade Combat Team (PMHBCT) Environmental Management Team (EMT) had suggested an SCC evaluation of AA7039 with the current process versus an immersion process using both chromate control and TCP to ascertain the differences, if any, between the chemical immersion and manual surface preparation methods. The SCC evaluation studies were conducted simultaneously with the component field testing.

The technical challenge was to determine the effect, if any, of chemical processing (specifically the TCP) on stress-corrosion cracking (SCC). Samples were prepared at NAVAIR Patuxent River, MD and evaluated by BAE Systems, San Jose, CA. The assessment was that there was no difference in SCC if the samples were or were not force dried. As a result of this testing, the York facility was able to eliminate the oven drying of Bradley structures which saved at least 4 hours cycle time per unit.

Direct-to-Metal	Chemical Processing
Abrasive blast – Paint removal	Abrasive blast
Weld repair cracks	Weld repair cracks
Perform weld and machining modifications	Perform weld and machining modifications
X Steam clean/pressure wash	
X Bake hulls prior to paint at 180-200F	
X Abrasive blast – Surface Prep	→ Immersion application of MIL-C-5541 TCP
Prime	Prime
Topcoat	Topcoat

TABLE 5.2 – Process parameters for SCC evaluation.

5.3.2 – STATUS

PM Heavy Brigade Combat Team (Formerly PM Abrams and PM Bradley) has approved the use of TCP for any vendor that would like to use it, including both General Dynamics Land Systems (GDLS) and BAE Ground Systems and their sub vendors. TCP has been promulgated in all new programs except where not technically practical. Many Sub Vendors are in the process of updating lines in order to accommodate TCP. For some, there are only minor adjustments and additions that need to be made to their current lines. For others, there are much larger changes that need to be incorporated or new lines that need to be built. One Vendor in particular will purchase Tanks (2), chemicals, put in the plumbing and decking, perform the necessary engineering and pull the necessary permits in order to begin the TCP process for all small parts they supply to BAE Systems.

An additional benefit to note is that the TCP coating does not have thermal stability concerns that have to be taken into account with chromate films. This has led to the implementation of powder-coat paints for use on TCP treated components, since the bake cure would have detrimentally affected a chromate coating but is fully compatible with the TCP coating. The additional benefit comes from being able to reduce VOC's and HAP's associated with traditional liquid primers and paints by switching to powder coating.

5.4 – US ARMY AVIATION

5.4.1 – BACKGROUND

In August of 2003, the Environmental, Engineering, and Logistics Oversight (EELO) office at AMCOM in Huntsville, AL put together a comprehensive panel test matrix to identify a non-chromate system for demonstration as a potential replacement coating system for their current chromate-based pretreatment and primer process. At that time, the current system was to spray chromate conversion coating, and paint with MIL-PRF-23377 Class C2 primer and MIL-C-46168 Type IV CARC, a 2-component, polyurethane topcoat. All testing and evaluation was conducted under the oversight of PEO Aviation, AMCOM Materials, EELO, ARL, and NAVAIR.

The three alternative pretreatments selected for aluminum alloy testing were Alodine 5700, NAVAIR TCP, and PreKote. These pretreatments were evaluated over AA2024-T351 and AA7075-T651 alloys. The non-chrome primer alternative evaluated was MIL-PRF-85582 Class N since no qualified version of MIL-PRF-23377 Class N was available at the start of testing. All three pretreatments were evaluated under chromated primers (MIL-PRF-23377 Class C2 and MIL-PRF-85582 Class C1) and the non-chromate MIL-PRF-85582 Class N. The potential replacement primers, MIL-PRF-85582 Class C1 and Class N were coated with the latest generation CARC topcoats, MIL-C-53039A Low VOC and MIL-DTL-64159 Type II to evaluate the coating "system" performance. Testing was conducted by ARL at APG, MD by the Coatings and Corrosion Branch. Corrosion testing was conducted according to ASTM B117 neutral salt fog and GM9540P cyclic corrosion. All corrosion tests were run out to 3,000 hours, with regular evaluations by ARL and AMCOM. Adhesion testing was conducted according to ASTM D4541-95 pull-off and ASTM D3359 wet tape testing. Adhesion Testing was completed in early 2004 and corrosion testing was completed in July 2004.

The initial field testing was conducted at the Connecticut Aviation Classification Repair Depot (AVCRAD) in October 2005. The CH-47 served as the demonstration platform for the initial processing and painting validation. The test system consisted of Henkel product line, since those were the legacy products already in use at the CT AVCRAD. The aircraft was stripped of old paint by Plastic Media Blasting (PMB) in preparation for recoating. The chemical spray process consisted of the following: Aerowash Cleaner at 25-50% dilution for general surfaces, and at full strength for specific areas with high levels of fuel or oil contamination, then deoxidized with Ridoline 4450, and pretreated with Alodine T5900 (TCP). Two epoxy primers were used for this platform. The upper portion of the aircraft was primed with MIL-PRF-85582 Class C1 product from Deft, Inc. (44GN072) and the lower portion was primed with MIL-PRF-23377 Class N product from Hentzen Coatings, Inc. (16708TEP). The entire aircraft was then topcoated with MIL-DTL-64159 Type II CARC polyurethane paint.

5.4.2 – GENERAL GUIDELINES – AIRCRAFT CLEANING, SURFACE TREATMENT AND COATING

Aircraft will be inspected to identify coating problems and recorded in the aircraft coating test log (provided). Obvious corrosion, missing rivets, loose/flaking paint, etc. should all be noted. Aircraft shall be cleaned per normal operations at the facility and required maintenance accomplished prior to preparation for de-painting/painting operations.

Components normally removed prior to de-painting shall be removed and de-painted in accordance with normal procedures. Any aluminum substrate components removed for hand de-painting and processing shall follow the guidelines below for surface preparation and conversion coating of the aluminum substrate. Other non-aluminum components shall be prepared per normal procedures.

Once stripped, the aircraft shall be inspected for corrosion, and localized corrosion removed by hand abrasion (bristle disk, sander or hand sanding) no steel or iron abrasive should be used for removing corrosion on aluminum substrates, products like steel wool, stainless steel shot or grinding/abrading wheels, etc. should be avoided. Other identified flaws shall be repaired per normal procedures.

Cleaning of the aircraft is one of the most critical aspects of the TCP application and each step shall be closely followed to ensure a properly prepared surface prior to TCP application. All surfaces to be treated with TCP shall be cleaned to a water-break-free surface with a mild alkaline (pH 8-9, nothing over 9.5) cleaner conforming to MIL-PRF-85570 Type II or MIL-PRF-87937 Type II. Cleaners shall be diluted to the proper strength using deionized (DI) water to eliminate potential ion deposition on the cleaned substrate. If obvious signs of surface contamination remain, the cleaning process shall be repeated until a water-break-free surface is obtained. If there are signs of "acrylic smear" from Type V PMB an appropriate cleaner shall be substituted that will remove the contamination or the contaminants should be removed using medium grit Scotchbrite pads and an aqueous cleaner. Any alternate cleaner selection must be coordinated with the Research, Development Engineering Center, Materials Branch prior to use. Personnel shall avoid the use of high pH, strong alkaline cleaners to prevent damage to the aluminum substrates. Rinse water shall be deionized to eliminate conductive ions being trapped on the bare substrate creating potential corrosion initiation sites or sites where the TCP will not properly adhere. A deoxidation step may follow substrate cleaning for final surface preparation prior to TCP application. If a deoxidation process is used, the final rinse will also use DI water.

Following cleaning (and deoxidation, if used) the surface shall be treated with TCP. TCP shall be applied by hand sprayer ensuring the entire surface to be treated is completely coated with the TCP solution. The nominal dwell time prior to rinsing the TCP from the surface shall be 10-15 minutes. (Note: There is no obvious color change to the treated surface like Alodine 1200 series chromate conversion coatings. However, experienced personnel will be able to tell when the rinse should be performed. Properly applied, TCP leaves the treated surface with a subtle, iridescent blue-lavender color.) DI water shall be used for the TCP rinse step.

Following TCP treatment, the substrate shall be allowed to dehydrate for 16-24 hours. This is the proper "cure" time for the pretreatment. If scheduling is tight, a 4-hour dry time after processing can be implemented. Following dehydration, the aircraft shall be masked and coated with the proper primer and top-coating as required.

5.4.3 – STATUS

The Aviation and Missile Life Cycle Management Command's (AMCOM LCMC) G-4 Environmental Office has replaced the EELO in February 2006. G-4 personnel have continued to provide regular update briefings to potential users of the new coating systems. In October 2005 the initial test aircraft was selected and the 1109th Aviation Classification Repair Activity Depot (AVCRAD) in Groton CT was identified as the facility to apply the test coating. Based on Aviation Engineering Directorate (AED) recommendations, the test coating was to be standardized as TCP (MIL-DTL-81706 Type II), MIL-PFR-23377 Class N and either of the two new CARC coatings. The test coating was applied in October 2005 and AVCRAD personnel have periodically inspected this aircraft and reported no significant detectable coating issues. The use of the new, low mar chemical agent resistant coatings (CARC), the Class N primer and the MIL-DTL-81706 Type II pretreatments have resulted in a significantly improved coating system. Following this initial successful demonstration, 1109th AVCRAD personnel have continued to apply this coating system since mid-2006 to all aircraft coated at their facility with excellent results. The 1109th AVCRAD has had minimal problems transitioning to the new coating system and all personnel have enthusiastically reported their happiness with the new coatings.

The AMCOM AED has closely followed this test program since its inception and in the summer of 2007 provided final approval to begin implementation of the new coating system on Army Aviation assets. Since receiving this approval, AMCOM G-4 has worked closely with the General Services Agency (GSA) to obtain National Stock Numbers (NSN) for the Class N epoxy primers and the new non-hexavalent chromium conversion coatings. AMCOM LCMC will be issuing a new Maintenance Information Message (MIM) as soon as it has been approved that will initiate the transition for all subordinate organizations to either the MIL-PRF-23377 Class N (preferred) or MIL-PRF-85582 Class N primers. When NSNs have been assigned and notification from GSA has been received for the new conversion coatings, a second MIM will be drafted and distributed to appropriate AMCOM subordinate organizations to initiate the transition to the new MIL-DTL-81706 Type II conversion coatings.

The transition to the new pretreatment and primer coatings will be phased in as existing stocks are depleted. It is anticipated that as the new materials are implemented for the first time, AMCOM G-4 and technical representatives will be on-site to ensure minimal transition difficulties. Initial processing will be done under the oversight of AMCOM G-4 (at a minimum). NAVAIR will be requested as needed to aid in this transition for technical processing support. Mr. Kerry Blankenship, AMCOM G-4 Engineering Services Team Lead, Mr. Paul Robinson, Mr. Tim Helton, and/or Mr. Chuck Younger G-4 support contractors will continue to evaluate the in-service performance of the new coating system and provide feedback and technical guidance based on observed results. As new or improved pretreatments and primer coatings are developed, AMCOM G-4 personnel will evaluate the test data in coordination with AMCOM AED to ascertain their applicability to Army Aviation assets.

The 1109th Aviation Classification Repair Activity Depot in Groton CT has continued to apply the non-hexavalent chromium coating system to rotary wing aircraft since 2006 as the Army's "Lead the Fleet" activity. In 2008 the 1109th AVCRAD was selected as the Secretary of the Army's winner for their Pollution Prevention-Facility Environmental Award for their efforts. The Army's phase in of the MIL-DTL-81706 Type II (TCP) conversion coating is proceeding. National Stock Numbers have been obtained for the new products and the AMCOM G-4 has prepared and submitted for final staffing a Maintenance Information Message (MIM) for distribution to all affected commands and activities. Once distributed by the AMCOM Integrated Material Management Center, other AMCOM aviation maintenance and repair activities will begin the transition to the new conversion coating and Class N primers.

AMCOM G-4 also continues to work with aviation system Original Equipment Manufacturers (OEMs) to assist them in implementing the Type II conversion coatings and Class N primers. To date nearly all OEMs have selected and are performing final testing or have implemented the Class N primers as part of their standard coating systems. The use of the Type II conversion coatings is also being evaluated in detail and a final decision should be reached in the near future.

As new technologies mature and are identified for testing AMCOM G-4 will support and provide whatever assistance as can be made available. The need to ensure to best performing coating system on Army Aviation assets is crucial to minimize the affects of corrosion and the associated maintenance requirements to mitigate corrosion problems. Additional applications for the Type II conversion coatings for use on missile system ground vehicles are currently being evaluated. Potential systems where the TCP may be used include the Avenger, Patriot, Medium Extended Air Defense (MEADs), etc. and the expanded potential for the Type II conversion coatings for use over "mixed metal" substrates is also being assessed.

6.0 – IMPLEMENTATION OF ALTERNATIVES IN DoD AND NASA

6.1 – MILITARY AND INDUSTRIAL PRETREATMENT SPECIFICATIONS

MIL-DTL-81706B was released in October 2004. MIL-DTL-5541F was released in April 2006. These documents govern aluminum conversion coatings for military use. The DoD conversion coating specifications were revised and published to include a Type II designation for non-chromate chemistries. The proposed revisions were circulated through DoD and government contractors for comments and review, the inputs collated and organized, and a final revision written. Both revisions allow the qualification and use of any non-chromate aluminum pretreatment that can pass the performance requirements for qualification. No changes have been made to the corrosion and adhesion testing requirements for aluminum conversion coatings. Additional restrictions on the chemistries were not included in the Type II designation, simply that no hexavalent chromium may be present. Currently all four TCP licensees have qualified commercial products to QPD-81706. Additionally, the SAE-AMS Committee B has release AMS 3175 – Non-chromated Surface Pretreatment Prior to Painting, to test and qualify leading adhesion promoters such as AC-131, PreKote and Alodine 5200/5700. Note that this specification only covers the use of conversion coatings when used prior to paint application. Qualification testing will be underway for commercial products.

6.2 – ALODINE™ 5700

6.2.1 – NASA

NASA has implemented a non-chromate coating system for use on their aluminum alloy Solid Rocket Boosters (SRB). The Space Shuttle SRB conducted a project to identify and qualify alternatives for the traditional, qualified chromate coating system and pretreatment. Testing gathered information on corrosion protection, bond strength, compatibility with other SRB materials, batch-to-batch consistency, and thermal environments data. Two pretreatments and two coating systems met the SRB program criteria. The recommended pretreatments were Henkel Alodine 5200/5700 and MacDermid Chemidize 727 ND. Alodine 5700 had very robust processing parameters and was recommended for first implementation as a pretreatment alternate.

NASA implemented a Hentzen non-chromate primer / Alodine 5700 pretreatment system in June 2002. This change affected all structural aluminum (2219, 6061, and 7075) parts of the solid rocket boosters. The first hardware flew in the fall of 2002.

6.2.2 – US Army TACOM

The US Army TACOM has implemented Alodine 5200/5700 conversion coating on AA2024-T4 and AA2014-T6 road wheels for the Bradley Fighting Vehicle, the M113, and the MLRS. TACOM has also implemented Alodine 5200/5700 on Aluminum tracks for the M1A1

Abrams Tank. This technology has been implemented in the US Army Red River Army Depot's (RRAD) Rubber Products Operations since early 2003.

6.3 – PREKOTE™

6.3.1 – USAF

As of Feb. 2004, the F-16, T-37, T-38 and T-1 SPOs have approved the use of PreKote, and HQ Air Education and Training Command (AETC) has mandated its use on all AETC aircraft for which it's approved. If a base, MAJCOM, or ALC decides to pursue using PreKote in their paint processes on other systems, it must obtain approval from the appropriate SPOs. AFCPCO will provide existing test results upon request to assist SPOs with the engineering decision whether to approve PreKote.

AFCPCO continues to recommend chromated conversion coatings for optimum corrosion protection. Multiple laboratory tests, by various organizations, indicate PreKote is one of the best performing non-chromated surface treatments, but its corrosion protection is still less than that of chromated Alodine 1200S. Several other candidate materials are also being tested as possible alternatives to Alodine. It is likely that more than one material will meet AF needs. In cases where chromate cannot be used due to environmental restrictions, PreKote provides a low risk alternative. Note that all test results to date, current SPO approvals, and the assessment of low risk, are contingent on the use of a qualified chromated primer. When PreKote is used, corrosion inhibition comes only from the chromated primer. Past performance of non-chrome paint systems in AF use has been poor; and AFCPCO strongly recommends against the use of PreKote with non-chromated primers. Since application of PreKote is largely a manual process, the consistency of the process may be important to an overall satisfactory result. To achieve results equal to other weapon systems, we recommend adhering closely to application practices that have already been established.

6.4 – TCP

6.4.1 – NAVSEA

Based on the results of the outdoor exposure panel testing and the multi-year field demonstration at ACU-4, NSWCCD Materials has indicated that they are in progress to implement the TCP for pretreatment of aluminum alloys on the LCAC using commercially qualified product to MIL-DTL-81706B. NAVSEA Materials has been provided a copy of the NAVAIR TCP approval letter.

6.4.2 – USMC

The Expeditionary Fighting Vehicle is approaching the end of the SDD phase. Environmental, safety and health restrictions have led the program office to mandate the use of chromate and cadmium free coating systems. The program is scheduled to begin LRIP in FY09. TCP has been selected as the pretreatment for the processing of the AA2519 hull and turret structures. Both the TCP and Alodine 5200/5700 have been approved by the PM for use on aluminum components by GDAMS and their vendors. The Marines' AVTB is currently using Alodine 5700 pre-saturated wipes for coating system maintenance and repair touch-up applications on the SDD vehicles fielded there.

6.4.3 – NAVAIR

NAVAIR has approved the use of MIL-DTL-81706 Type II technology for aluminum conversion coating. The Fleet Readiness Center-East, Cherry Point, NC implemented TCP in January 2006. All spray processing operations since have been conducted with qualified commercial TCP. NAVAIR does not currently have a qualification for Class N primers direct to metal, regardless of pretreatment type. Additional field testing is underway to assess leading Class N primers, including usage over MIL-DTL-81706 Type II pretreatment.

6.4.4 – AMCOM

AMCOM Materials has authorized the use of Type II conversion coatings under qualified Class N aviation primers. The Connecticut AVCRAD has implemented TCP with Class N primer as of 2006. The Corpus Christi Army Depot has implemented Class N primers as of 2007, and is in progress to transition to the TCP pretreatment in conjunction with the Class N primers. This transition is planned for late FY08.

6.5 – AC-130/131

6.5.1 – BOEING/AF

Boeing Commercial Airplanes is using AC-131 on chromated aluminum rivets for B737 aircraft to improve paint adhesion to the rivets. The chromate plus AC-131 coating is applied to the rivets at the rivet manufacturer. Boeing Commercial Airplanes traditionally utilized Alodine 1000™ clear, chromate conversion coating for pretreatment of aluminum rivets on commercial aircraft. They were experiencing paint loss due to adhesion failure at the rivets. B737 aircraft produced since the spring of 2004 have had the chromate/AC-131 coated rivets used in the fuselage. The incidence of paint adhesion failures to the rivets has been significantly decreased with the new coating system. Boeing Commercial Airplanes has also performed scale-up trials of AC-131 and transitioned this product for pretreatment prior to Class C primer application.

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7.0 – CONCLUSIONS AND RECOMMENDATIONS

All the alternatives being demonstrated are aqueous solutions designed to deposit a conversion coating on aluminum alloy substrates to enhance paint adhesion and painted corrosion performance. Alternatives face the challenge of the low cost and ease of application of the chromate conversion coatings while providing a coating that provides acceptable technical performance. Along with technical performance, processing and toxicity issues are important to consider in capturing the overall impact of an alternative. The general trend is that no one test methodology is sufficient to predict good field performance, but that good correlation can be found to identify the top performing systems. The key to the accelerated testing is that multiple methods, such as ASTM B117 and G85 Annex 4, and GM9540P must be used in conjunction to determine top performers. While individual coating systems may do well in one or two test or particular stack-ups, early analysis suggests very high correlation between the ordinal rankings across the laboratory testing when compared with the beach exposure (our closest test condition to mimic on platform field use). That is, the coatings that consistently performed the best on average across the alloy, primer and accelerated test methods are the same coatings that consistently performed the best in extended beach exposure testing.

There are currently four non-chromate alternatives in various stages of validation or implementation. Alodine 5200/5700, PreKote, and AC-130/131 provide paint adhesion and painted corrosion protection, and are all non-chromium chemistries. The TCP provides both painted and unpainted corrosion protection as well as electrical conductivity in corrosive environments. However, TCP does contain trivalent chromium, and users will need to balance total chromium waste-water requirements with technical performance requirements when deciding on implementation of TCP. TCP and Alodine 5200/5700 provide the most process flexibility, as they can be applied like a chromate conversion coating, by immersion, spray, or wipe-on methods. AC-130/131 can be used in spray applications. PreKote must be manually applied for proper coating performance.

All of the demonstration coatings have shown good paint adhesion and corrosion performance when used under chromated primers and in moderate environments. The PreKote and the AC-130/131 have not demonstrated acceptable performance when combined with non-chromate primers in high corrosion environments. The TCP and Alodine 5200/5700 have shown good paint adhesion and painted corrosion performance when used under both chromated and non-chromated primers. TCP and Alodine 5200/5700 have performed well in high corrosion environment testing.

It is therefore critical with any new non-chromate material that it be tested to failure against the chromated control. Additionally, any new coating application should be demonstrated and validated by field-testing for each operational environment where implementation is being considered. Only then can the complete technical performance of a coating or coating system be determined. Implementation of any alternative must take into consideration the costs, process, health and safety, laboratory and field testing performance, and the specific coating system application and operational environment.

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APPENDIX A – 8-YEAR BEACH EXPOSURE RESULTS

Pretreatment	AA2024				AA7075				AA5083				AA2219				All Alloys Average			
	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8
Alodine 1200S	10.0	10.0	9.6	8.8	10.0	10.0	10.0	9.9	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.0	10.0	10.0	9.9	9.4
Alodine 5200/5700	10.0	10.0	10.0	10.0	9.2	8.2	8.0	8.0	10.0	10.0	10.0	10.0	10.0	10.0	9.8	9.8	9.8	9.6	9.5	9.5
Bi-K Aklimate	10.0	10.0	9.8	9.4	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.8	9.8	9.8	9.8	10.0	10.0	9.9	9.8
AC - 131	10.0	10.0	9.0	9.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.3	9.3	8.0	3.3	9.8	9.8	9.3	8.1
Chemidize 727ND	10.0	9.8	9.0	8.0	10.0	10.0	10.0	9.6	10.0	10.0	10.0	10.0	7.6	6.4	4.8	3.4	9.4	9.1	8.5	7.8
Oxsilan Al-0500	9.6	9.6	9.6	9.6	10.0	10.0	9.8	9.5	10.0	10.0	10.0	10.0	9.8	9.8	9.8	9.4	9.9	9.9	9.8	9.6
Sanchem 7000	9.6	8.2	0.0	0.0	10.0	9.8	9.8	9.4	10.0	10.0	10.0	10.0	4.2	0.6	0.0	0.0	8.5	7.2	5.0	4.9
TCP	10.0	10.0	10.0	9.4	8.0	8.0	8.0	8.0	10.0	10.0	10.0	10.0	10.0	9.0	7.2	6.4	9.5	9.3	8.8	8.5
PreKote	10.0	10.0	9.6	9.2	10.0	10.0	9.6	9.4	10.0	10.0	10.0	10.0	10.0	7.2	0.0	0.0	10.0	9.3	7.3	7.2

Average Corrosion Creep (ASTM D 1654 - 5 panel) for Aluminum Alloys Coated with MIL-PRF-23377 Type I, Class C2 Primer / MIL-PRF-85285 Type I Topcoat

All Alloy Average	BEST: Bi-K, Al-500, A5700, A1200S	GOOD: TCP, AC-131	FAIR: 727ND, PreKote	OK:	POOR: S7000	FAIL:

Pretreatment	AA2024				AA7075				AA5083				AA2219				All Alloys Average			
	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8
Alodine 1200S	10.0	10.0	10.0	9.8	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Alodine 5200/5700	10.0	10.0	9.4	9.4	8.8	8.8	8.0	8.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.7	9.7	9.4	9.4
Bi-K Aklimate	10.0	10.0	9.6	8.2	10.0	10.0	8.4	6.8	10.0	10.0	10.0	10.0	9.8	9.4	9.0	9.0	10.0	9.9	9.3	8.5
AC - 131	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.7	10.0	10.0	10.0	9.9
Chemidize 727ND	9.8	9.8	5.8	4.2	7.6	7.6	0.0	0.0	10.0	10.0	10.0	10.0	9.0	9.0	6.8	6.6	9.1	9.1	5.7	5.2
Oxsilan Al-0500	9.6	9.6	9.2	9.0	7.6	6.6	5.8	0.0	10.0	10.0	10.0	10.0	9.4	9.2	9.2	9.0	9.2	8.9	8.6	7.0
Sanchem 7000	0.0	0.0	0.0	0.0	3.2	2.4	0.0	0.0	10.0	9.4	9.4	9.4	6.4	6.4	0.0	0.0	4.9	4.6	2.4	2.4
TCP	10.0	10.0	10.0	9.6	10.0	10.0	9.8	9.6	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.9	10.0	10.0	10.0	9.8
PreKote	10.0	10.0	9.6	6.2	10.0	10.0	9.8	9.4	10.0	10.0	9.8	9.8	9.8	9.6	3.4	0.0	10.0	9.9	8.2	6.4

Average Corrosion Creep (ASTM D 1654 - 5 panel) for Aluminum Alloys Coated with MIL-PRF-85582 Type I, Class C1 Primer / MIL-PRF-85285 Type I Topcoat

All Alloy Average	BEST: A1200S, AC-131, TCP, A5700	GOOD: Bi-K	FAIR: Al-500	OK: PreKote, 727ND	POOR:	FAIL: S7000

Pretreatment	AA2024				AA7075				AA5083				AA2219				All Alloys Average			
	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8
Alodine 1200S	10.0	10.0	9.8	9.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.2	10.0	10.0	10.0	9.6
Alodine 5200/5700	10.0	9.8	9.4	8.2	8.8	8.0	8.0	8.0	10.0	10.0	10.0	10.0	9.4	9.4	9.4	8.8	9.6	9.3	9.2	8.8
Bi-K Aklimate	0.8	0.0	0.0	0.0	1.0	0.0	0.0	0.0	10.0	9.4	7.0	2.8	0.0	0.0	0.0	0.0	3.0	2.4	1.8	0.7
AC - 131	5.3	5.0	0.0	0.0	7.3	4.7	0.0	0.0	10.0	10.0	10.0	9.0	0.0	0.0	0.0	0.0	5.7	4.9	2.5	2.3
Chemidize 727ND	0.8	0.0	0.0	0.0	1.2	0.0	0.0	0.0	10.0	9.4	5.2	2.8	0.0	0.0	0.0	0.0	3.0	2.4	1.3	0.7
Oxsilan Al-0500	7.6	7.2	5.0	0.0	9.2	9.0	9.0	6.6	10.0	9.8	9.8	9.4	2.8	0.0	0.0	0.0	7.4	6.5	6.0	4.0
Sanchem 7000	0.0	0.0	0.0	0.0	5.4	0.0	0.0	0.0	9.2	8.8	5.8	4.2	0.0	0.0	0.0	0.0	3.7	2.2	1.5	1.1
TCP	10.0	10.0	9.6	9.0	9.6	9.2	8.6	8.6	10.0	10.0	10.0	10.0	9.6	9.6	9.6	8.2	9.8	9.7	9.5	9.0
PreKote	3.8	0.0	0.0	0.0	1.4	0.0	0.0	0.0	9.0	8.6	2.0	0.0	0.0	0.0	0.0	0.0	3.6	2.2	0.5	0.0

Average Corrosion Creep (ASTM D 1654 - 5 panel) for Aluminum Alloys Coated with MIL-PRF-85582 Type I, Class N Primer / MIL-PRF-85285 Type I Topcoat

All Alloy Average	BEST: A1200S, TCP	GOOD: A5700	FAIR:	OK:	POOR: Al-500	FAIL: AC-131, S7000, Bi-K, 727ND, PreKote

Pretreatment	AA2024				AA7075				AA5083				AA2219				All Alloys Average			
	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8
Alodine 1200S	10.0	10.0	6.6	2.8	9.8	9.8	9.4	9.0	10.0	10.0	10.0	10.0	2.4	0.0	0.0	0.0	8.1	7.5	6.5	5.5
Alodine 5200/5700	10.0	7.8	6.4	3.4	8.6	8.6	7.4	6.2	10.0	10.0	10.0	10.0	3.4	4.0	0.0	0.0	8.0	7.6	6.0	4.9
Bi-K Aklimate	0.8	0.0	0.0	0.0	9.4	0.0	0.0	0.0	9.8	9.4	6.4	4.7	0.0	0.0	0.0	0.0	5.0	2.4	1.6	1.2
AC - 131	5.7	3.0	0.0	0.0	4.7	0.0	0.0	0.0	10.0	10.0	10.0	10.0	0.0	0.0	0.0	0.0	5.1	3.3	2.5	2.5
Chemidize 727ND	4.8	0.0	0.0	0.0	5.8	0.0	0.0	0.0	10.0	10.0	9.8	9.4	0.0	0.0	0.0	0.0	5.2	2.5	2.5	2.4
Oxsilan Al-0500	5.8	2.0	0.0	0.0	9.2	1.8	0.0	0.0	10.0	9.8	7.6	5.8	0.0	0.0	0.0	0.0	6.3	3.4	1.9	1.5
Sanchem 7000	9.8	0.0	0.0	0.0	0.2	0.0	0.0	0.0	10.0	9.8	9.0	6.8	0.0	0.0	0.0	0.0	5.0	2.5	2.3	1.7
TCP	10.0	10.0	9.2	6.6	10.0	10.0	9.0	2.2	10.0	10.0	10.0	10.0	3.6	1.4	0.0	0.0	8.4	7.9	7.1	4.7
PreKote	4.2	0.0	0.0	0.0	6.0	0.0	0.0	0.0	10.0	10.0	8.8	8.4	0.0	0.0	0.0	0.0	5.1	2.5	2.2	2.1

Average Corrosion Creep (ASTM D 1654 - 5 panel) for Aluminum Alloys Coated with MIL-DTL-53030 Primer / MIL-DTL-53039 Type I Topcoat

All Alloy Average	BEST:	GOOD:	FAIR:	OK:	POOR: A1200S, A5700, TCP	FAIL: AC-131, 727ND, PreKote, S7000, Al-500, Bi-K

Pretreatment	AA2024				AA7075				AA5083				AA2219				All Alloys Average			
	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8
Alodine 1200S	10.0	10.0	7.2	0.0	9.8	9.6	4.0	0.0	10.0	9.8	9.8	9.6	0.4	0.0	0.0	0.0	7.6	7.4	5.3	2.4
Alodine 5200/5700	10.0	10.0	9.2	7.8	8.8	8.8	8.8	7.6	10.0	9.8	9.8	9.8	2.4	0.0	0.0	0.0	7.8	7.2	7.0	6.3
Bi-K Aklimate	3.2	0.0	0.0	0.0	6.4	0.0	0.0	0.0	10.0	9.6	7.6	7.4	0.0	0.0	0.0	0.0	4.9	2.4	1.9	1.9
AC - 131	9.5	9.0	6.7	0.0	1.3	0.0	0.0	0.0	10.0	10.0	10.0	10.0	1.0	0.0	0.0	0.0	5.5	4.8	4.2	2.5
Chemidize 727ND	6.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	9.2	8.4	7.0	5.4	0.0	0.0	0.0	0.0	4.4	2.1	1.8	1.4
Oxsilan Al-0500	9.4	2.8	0.0	0.0	7.6	1.8	0.0	0.0	10.0	10.0	9.8	9.8	0.8	0.0	0.0	0.0	7.0	3.7	2.5	2.5
Sanchem 7000	7.8	2.0	0.0	0.0	6.6	0.0	0.0	0.0	10.0	9.6	9.0	5.0	0.0	0.0	0.0	0.0	6.1	2.9	2.3	1.3
TCP	10.0	9.8	6.0	4.4	10.0	10.0	9.4	0.0	10.0	10.0	10.0	10.0	1.4	0.0	0.0	0.0	7.9	7.5	6.4	3.6
PreKote	3.4	0.0	0.0	0.0	2.6	0.0	0.0	0.0	10.0	9.6	5.2	3.2	0.0	0.0	0.0	0.0	4.0	2.4	1.3	0.8

Average Corrosion Creep (ASTM D 1654 - 5 panel) for Aluminum Alloys Coated with MIL-DTL-53022 Primer / MIL-DTL-53039 Type I Topcoat

All Alloy Average	BEST:	GOOD:	FAIR:	OK:	POOR: A5700, TCP	FAIL: Al-500, AC-131, A1200S, Bi-K, 727ND, S7000, PreKote

Pretreatment	23377C2				85582 C1				85582 NC				All Aviation Coatings			
	Yr 1	Yr 2	Yr 5	Yr 8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8
Alodine 1200S (Control)	10.0	10.0	9.9	9.4	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.6	10.0	10.0	10.0	9.6
Alodine 5200/5700	9.8	9.6	9.5	9.5	9.7	9.7	9.4	9.4	9.6	9.3	9.2	8.8	9.7	9.5	9.3	9.2
Bi-K Aklimate	10.0	10.0	9.9	9.8	10.0	9.9	9.3	8.5	3.0	2.4	1.8	0.7	7.6	7.4	7.0	6.3
AC - 131	9.8	9.8	9.3	8.1	10.0	10.0	10.0	9.9	5.7	4.9	2.5	2.3	8.5	8.3	7.3	6.8
Chemidize 727ND	9.4	9.1	8.5	7.8	9.1	9.1	5.7	5.2	3.0	2.4	1.3	0.7	7.2	6.8	5.1	4.6
Oxsilan Al-0500	9.9	9.9	9.8	9.6	9.2	8.9	8.6	7.0	7.4	6.5	6.0	4.0	8.8	8.4	8.1	6.9
Sanchem 7000	8.5	7.2	5.0	4.9	4.9	4.6	2.4	2.4	3.7	2.2	1.5	1.1	5.7	4.6	2.9	2.8
TCP	9.5	9.3	8.8	8.5	10.0	10.0	10.0	9.8	9.8	9.7	9.5	9.0	9.8	9.7	9.4	9.1
PreKote	10.0	9.3	7.3	7.2	10.0	9.9	8.2	6.4	3.6	2.2	0.5	0.0	7.8	7.1	5.3	4.5
AVERAGE	**9.6**	**9.3**	**8.6**	**8.3**	**9.2**	**9.1**	**8.1**	**7.6**	**6.2**	**5.5**	**4.7**	**4.0**	**8.3**	**8.0**	**7.2**	**6.6**

MIL-PRF-85285 Aircraft Polyurethane Topcoat

All Alloy Average	BEST: A1200S, A5700, TCP	GOOD:	FAIR:	OK: Al-500, AC-131, Bi-K
			POOR: 727ND, PreKote	FAIL: S7000

Pretreatment	53030				53022				All Ground Coatings			
	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8
Alodine 1200S (Control)	8.1	7.5	6.5	5.5	7.6	7.4	5.3	2.4	7.8	7.4	5.9	3.9
Alodine 5200/5700	8.0	7.6	6.0	4.9	7.8	7.2	7.0	6.3	7.9	7.4	6.5	5.6
Bi-K Aklimate	5.0	2.4	1.6	1.2	4.9	2.4	1.9	1.9	5.0	2.4	1.8	1.5
AC - 131	5.1	3.3	2.5	2.5	5.5	4.8	4.2	2.5	5.3	4.0	3.3	2.5
Chemidize 727ND	5.2	2.5	2.5	2.4	4.4	2.1	1.8	1.4	4.8	2.3	2.1	1.9
Oxsilan Al-0500	6.3	3.4	1.9	1.5	7.0	3.7	2.5	2.5	6.6	3.5	2.2	2.0
Sanchem 7000	5.0	2.5	2.3	1.7	6.1	2.9	2.3	1.3	5.6	2.7	2.3	1.5
TCP	8.4	7.9	7.1	4.7	7.9	7.5	6.4	3.6	8.1	7.7	6.7	4.2
PreKote	5.1	2.5	2.2	2.1	4.0	2.4	1.3	0.8	4.5	2.5	1.8	1.5
AVERAGE	**6.2**	**4.4**	**3.6**	**2.9**	**6.1**	**4.5**	**3.6**	**2.5**	**6.2**	**4.4**	**3.6**	**2.7**

MIL-DTL-53039 CARC Polyurea Topcoat

All Alloy Average	BEST:	GOOD:	FAIR:	OK:	POOR: A5700, TCP, A1200S
			FAIL: AC-131, Al-500, 727ND, Bi-K, S7000, PreKote		

Pretreatment	23377C2				85582 C1				85582 NC				53030				53022				All Coatings			
	Yr 1	Yr 2	Yr 5	Yr 8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8	Y1	Y2	Y5	Y8
Alodine 1200S (Control)	10.0	10.0	9.9	9.4	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.6	8.1	7.5	6.5	5.5	7.6	7.4	5.3	2.4	9.1	9.0	8.3	7.4
Alodine 5200/5700	9.8	9.6	9.5	9.5	9.7	9.7	9.4	9.4	9.6	9.3	9.2	8.8	8.0	7.6	6.0	4.9	7.8	7.2	7.0	6.3	9.0	8.7	8.2	7.8
Bi-K Aklimate	10.0	10.0	9.9	9.8	10.0	9.9	9.3	8.5	3.0	2.4	1.8	0.7	5.0	2.4	1.6	1.2	4.9	2.4	1.9	1.9	6.6	5.4	4.9	4.4
AC - 131	9.8	9.8	9.3	8.1	10.0	10.0	10.0	9.9	5.7	4.9	2.5	2.3	5.1	3.3	2.5	2.5	5.5	4.8	4.2	2.5	7.2	6.6	5.7	5.1
Chemidize 727ND	9.4	9.1	8.5	7.8	9.1	9.1	5.7	5.2	3.0	2.4	1.3	0.7	5.2	2.5	2.5	2.4	4.4	2.1	1.8	1.4	6.2	5.0	3.9	3.5
Oxsilan Al-0500	9.9	9.9	9.8	9.6	9.2	8.9	8.6	7.0	7.4	6.5	6.0	4.0	6.3	3.4	1.9	1.5	7.0	3.7	2.5	2.5	7.9	6.5	5.7	4.9
Sanchem 7000	8.5	7.2	5.0	4.9	4.9	4.6	2.4	2.4	3.7	2.2	1.5	1.1	5.0	2.5	2.3	1.7	6.1	2.9	2.3	1.3	5.6	3.9	2.7	2.2
TCP	9.5	9.3	8.8	8.5	10.0	10.0	10.0	9.8	9.8	9.7	9.5	9.0	8.4	7.9	7.1	4.7	7.9	7.5	6.4	3.6	9.1	8.9	8.3	7.1
PreKote	10.0	9.3	7.3	7.2	10.0	9.9	8.2	6.4	3.6	2.2	0.5	0.0	5.1	2.5	2.2	2.1	4.0	2.4	1.3	0.8	6.5	5.3	3.9	3.3
AVERAGE	**9.6**	**9.3**	**8.6**	**8.3**	**9.2**	**9.1**	**8.1**	**7.6**	**6.2**	**5.5**	**4.7**	**4.0**	**6.2**	**4.4**	**3.6**	**2.9**	**6.1**	**4.5**	**3.6**	**2.5**	**7.5**	**6.6**	**5.7**	**5.1**

MIL-PRF-85285 Aircraft Polyurethane Topcoat + MIL-DTL-64159 CARC Polyurea Topcoat

All Alloy Average	BEST:	GOOD:	FAIR: A5700, A1200S, TCP	OK: AC-131	POOR: Al-0500, Bi-K, 7272ND, PreKote	FAIL: S7000

APPENDIX B – PHASE II INTERIM REPORT

ESTCP
Environmental Security Technology Certification Program

Non-Chromate Aluminum Pretreatments
Phase II Interim Report
Project #PP0025

September 2004

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ESTCP
Environmental Security Technology Certification Program

Non-Chromate Aluminum Pretreatments
Phase II Interim Report

Project #PP0025

September 2004

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DISCLAIMER

Due to the critical nature of DoD weapons systems coating performance and because of NAVAIR's interest and involvement in the trivalent chromium process (TCP) this report has been reviewed for technical content, accuracy, and fairness by the following: the Air Force Corrosion Prevention and Control Office (AFCPCO), the Army Research Laboratory (ARL) Coatings and Corrosion Branch, the Naval Air Systems Command (NAVAIR) Materials Division, the Naval Sea Systems Command (NAVSEA) Materials Division, the Office of the Program Manager Combat Systems (PMCS), the Office of the Direct Reporting Program Manager Advanced Amphibious Assault (DRPM AAA), the US Army Aviation and Missile Command (AMCOM) Environmental, Engineering, and Logistics Office (EELO), United Defense, General Dynamics Amphibious Systems, and Boeing Commercial Airplanes.

ACRONYMS AND ABBREVIATIONS

AA – Aluminum Alloy
AAA – Advanced Amphibious Assault
AACP – Advanced Aircraft Corrosion Protection
AAV – Amphibious Assault Vehicle
ACU – Assault Craft Unit
AETC – Air Education and Training Command
AFB – Air Force Base
AFRL – Air Force Research Laboratory
AFCPCO – Air Force Corrosion Prevention and Control Office
AMCOM – Aviation and Missile Command
APG – Aberdeen Proving Grounds
ARL – Army Research Laboratory
ASTM – American Society for Testing and Materials
AVCRAD – Aviation Classification Repair Activity Depot
AVTB – Amphibious Vehicle Test Branch
BASC – Boeing Aircraft Support Center
BFIST – Bradley Fire Support Team
BFV – Bradley Fighting Vehicle
BUNO – Bureau Number
CARC – Chemical Agent Resistant Coating
CCAD – Corpus Christi Army Depot
CCC – Chromate Conversion Coating
COMNAVSEASYSCOM – NAVSEA Commander
CONSTRKFIGHTWINGLANT – Commander Atlantic Strike Fighter Wing
CPC – Corrosion Preventative Compounds
CTC – Coatings Technology Center
CY – Calendar Year
DEM/VAL – Demonstration/Validation
DFT – Dry Film Thickness
DI – Deionized
DoD – Department of Defense
DRPM – Direct Reporting Program Manager
DTM – Direct to Metal
DUSD-ES – Deputy Undersecretary of Defense for Environmental Security
E1 – First Experimental Vehicle – USMC EFV
EELO – Environmental, Engineering, & Logistics Oversight
EFV – Expeditionary Fighting Vehicle
EMI – Electromagnetic Interference
EMT – Environmental Management Team
EPA – Environmental Protection Agency

ESOH – Environmental, Safety and Occupational Health
ESTCP – Environmental Security Technology Certification Program
FSE – Floor Support Engineering
GDAMS – General Dynamics Amphibious Systems
GDLS – General Dynamics Land Systems
HazMat – Hazardous Material
HSTNA – Henkel Surface Technologies North America
HSU – Hydraulic Suspension Unit
IARC – International Agency for Research on Cancer
ICT – Inorganic Coatings Team
IETM – Integrated Electronic Technical Manual
JG-PP – Joint Group on Pollution Prevention
JLC – Joint Logistics Commander
JTP – Joint Test Protocol
KM – kilometers
KSC – Kennedy Space Center
ksi – kilopounds per Square Inch
LATP – Lima Army Tank Plant
LCAC – Landing Craft Air Cushion
LEX – Leading Edge Extension
LRIP – Low Rate Initial Production
MCB – Marine Corps Base
MCAS – Marine Corps Air Station
MEK – Methyl Ethyl Ketone
MIL-C – Military Control Specification
MIL-DTL – Military Detail Specification
MIL-H – Military Hydraulic Fluid Specification
MIL-P – Military Paint Specification
MIL-PRF – Military Performance Specification
MIL-SPEC – Military Specification
MSDS – Material Safety Data Sheet
NADEP – Naval Aviation Depot
NAS – Naval Air Station
NASA – National Aeronautics and Space Administration
NAVAIR – Naval Air Systems Command
NAVMSG – Navy Message
NAVSEA – Naval Sea Systems Command
NAWCAD – Naval Air Warfare Center Aircraft Division
NCAP – Non-Chromated Aluminum Pretreatment
NORIS – North Island Naval Depot
NSF – Neutral Salt Fog

NSWC – Naval Surface Warfare Center
OEM – Original Equipment Manufacturer
OOALC – Ogden Air Logistics Center
OSHA – Occupational Safety and Health Administration
P1 – First Prototype Vehicle – USMC EFV
PAX – Patuxent River Naval Air Station
PEO – Program Executive Office
PEL – Permissible Exposure Limit
PM – Program Manager
PMA – Program Management Activity
PMB – Plastic Media Blasting
PM CS – Program Manager Army Ground Combat Systems
PMI – Planned Maintenance Interval
POC – Point of Contact
psi – pounds per square inch
QA – Quality Analysis
QC – Quality Control
QOT&E – Qualification Operational Test and Evaluation
QPL – Qualified Products List
RRAD – Red River Army Depot
RH – Relative Humidity
SAE-AMS – Society of Automotive Engineers - Aerospace Material Specification
SCC – Stress Corrosion Cracking
SDLM – Standard Depot Level Maintenance
SDD – System Design and Development
SPO – Systems Program Office
SPT – Self Priming Topcoat
SRB – Solid Rocket Booster
TCP – Trivalent Chromium Pretreatment
TO – Technical Order
UDLP – United Defense
USMC – United States Marine Corps
WESTPAC – Western Pacific
YPG – Yuma Proving Grounds

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ACKNOWLEDGEMENTS

This project has been executed under the generous support of the Environmental Security Technology Certification Program (ESTCP) and the Office of the Deputy Undersecretary of Defense for Environmental Security (DUSD-ES). The effort was led by the Naval Aviation Systems Command (NAVAIR) Materials Division Patuxent River and coordinated with Joint Group on Pollution Prevention (JG-PP). This project was initiated by Craig Matzdorf, Code 4.9.7, NAVAIR Materials Engineering Division, Patuxent River, MD. The principal investigator for this project is Bill Nickerson, Code 4.9.7, NAVAIR Materials Engineering Division, Patuxent River, MD. Leveraged efforts were supported by their respective services.

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SUMMARY

Current light metal finishing procedures for industrial, automotive, aerospace, and Department of Defense (DoD) applications center around the use of hexavalent-chromium based chemistries for the enhancing corrosion resistance and paint adhesion. Aluminum finishing, in particular, utilizes chromate chemistries for anodizing, anodic sealing, and pretreatment (both for conversion coating aluminum substrates and for treating aluminum-based coatings deposited on steel). The most ubiquitous use of chromate coatings is in the conversion coating of aluminum alloys for use as-deposited or prior to organic coating application. These coatings are very thin, inexpensive to produce, extremely process flexible, and can be applied by immersion, spray and wipe techniques.

Chromate conversion coatings offer many advantages, however, the downside is that they contain hexavalent chromium, or chromate, species that are known to be carcinogenic. The occupational safety and health issues arising from risk of worker exposure to these chemicals, as well as the costs and the potential liabilities resulting from an accidental leak to the environment and waste disposal issues from normal finishing operations are making the use of chromate-based conversion coatings unattractive to the metal finishing industry.

Additionally, proposed Occupational Safety and Health Administration Permissible Exposure Limit (OSHA PEL) changes for hexavalent chromium would make the use of chromate very costly. A final ruling on the PEL is scheduled for the beginning of 2006, and under the current proposal, would drop the PEL from 100 $\mu g/m^3$ (for hexavalent chromium in the form of chromic acid) to 10 $\mu g/m^3$ at the highest; or possibly as low as 0.5 or 1 $\mu g/m^3$. This change would be especially hard for medium to small sized plating and coating contractors to comply with in a cost-effective manner.

1.0 – INTRODUCTION

1.1 – PROJECT BACKGROUND

The Environmental Security Technology Certification Program (ESTCP), established in December 1993, is managed by the Office of the Deputy Undersecretary of Defense for Environmental Security (DUSD-ES). The ESTCP demonstrates and validates laboratory-proven technologies that target the DoD's most urgent environmental needs. These technologies provide a return on investment through reduced environmental, safety, and occupational health (ESOH) risks; cost savings; and improved efficiency. The new technologies typically have broad application to both the DoD community and industry.

The Joint Logistics Commanders (JLC) and Headquarters National Aeronautics and Space Administration (NASA) co-chartered the Joint Group on Pollution Prevention (JG-PP) to coordinate joint service/agency activities affecting pollution prevention issues identified during system and component acquisition and sustainment processes. The primary objectives of the JG-PP are to:

- Reduce or eliminate the use of Hazardous Materials (HazMats)
- Avoid duplication of effort in actions required to reduce or eliminate HazMats through joint service cooperation and technology sharing.

JG-PP projects typically involve an original equipment manufacturer (OEM) producing multiple defense systems for more than one of the Services, as well as at least one DoD depot maintaining one or more of the defense systems. JG-PP technical representatives for each project begin by identifying a target HazMat, related process, and affected substrates or parts that may cause environmental and/or worker health concerns. Project participants then identify alternative technologies or materials for evaluation.

ESTCP selected the Non-Chromate Aluminum Pretreatment (NCAP) project, led by the Naval Air Systems Command (NAVAIR) and coordinated with JG-PP, to assist in the mitigation of the significant ESOH risks that are associated with the use of chromate conversion coatings. Chromate conversion coatings contain hexavalent chromium, a known human carcinogen that is strictly regulated. The U. S. Environmental Protection Agency (EPA) limits air emissions and regulates solid waste disposal from operations using hexavalent chromium. The U. S. Occupational Safety and Health Administration (OSHA) regulates the amount of hexavalent chromium to which workers can be exposed, and has proposed reducing the Permissible Exposure Limit (PEL) for hexavalent chromium to a value in the range of $10 \mu g/m^3$ to possibly less than $1 \mu g/m^3$. Such limits, planned for implementation within the next two years, could increase costs of the pretreatment of aluminum and aluminum alloys; therefore, alternatives are being identified and evaluated. The project will achieve the goal of reducing or eliminating the use of hexavalent chromium in aluminum finishing by demonstrating and validating the performance of alternatives in accordance with the technical requirements and tests identified in the Joint Test Protocol (JTP).

The key benefit of the non-chromated pretreatment alternatives being demonstrated in this report is the elimination or absence of hexavalent chromium from the process chemicals and as-deposited coating. Eliminating chromates from the conversion coating or pretreatment operations will drastically reduce user liability and risk in the life cycle of the platform or parts being coated. The key challenge for the alternatives will be matching the technical performance of chromate conversion coatings in a cost-effective manner.

1.2 – PHASE I OBJECTIVE AND SCOPE OF WORK

The overall objective is to validate and implement multiple chromate-free aluminum pretreatment alternatives at a broad range of user facilities. The Phase I Report, dated 24 July 2003, presents an evaluation of laboratory coupon testing of non-chromate aluminum pretreatment alternatives through accelerated tests on flat coupons. Phase I of this effort focused on the laboratory evaluation of several possible non-chromate alternative technologies. The results of the analysis were used to support field testing in Phase II on components and in-service platforms where technical performance is highly dependant on service environment and overall platform design and use.

The NCAP Phase I Report from 2003 details the adhesion and accelerated corrosion performance of these alternatives. Phase I examined the behavior of several alloy, coating, and paint system combinations. The data was generated in accordance with the NCAP JTP, dated 13 December 2000, to determine the potential effectiveness of the alternatives as replacements for chromate conversion coatings. Both documents are available on the JG-PP website, at the following link: http://www.jgpp.com/projects/projects_index.html, under the project titled Non-Chromate Aluminum Pretreatments.

Table 1.1 – taken from the NCAP Phase I report – identifies the alternative non-chromated pretreatments that were evaluated in Phase I, and provides a summary of their chemistry, applications, advantages and disadvantages.

Product	**Chemistry (from MSDSs)**	**Processing**	**Application Methods**	**Classification***	**Advantages**	**Disadvantages**
Alodine™ 1200S	Chromic acid, complex fluorides, ferric compounds	One solution, room temperature	Immersion, spray, wipe	E, B, C	Easy to use, standard	Contains hexavalent chromium
Alodine™ 5200 and Alodine™ 5700	Organometallic zirconate complex	One solution, room temperature	Immersion, spray, wipe	C	Easy to use, room temperature, drop-in replacement for chromates	Minimal corrosion inhibition, impractical color change
Bi-K Aklimate™	Proprietary	Single solution, room temperature	Immersion, spray, wipe	C	Easy to use, room temperature solution replacement for chromates	Minimal bare corrosion resistance, clear and colorless (no color change)

AC-130/ 131™	Organosiloxanes, zirconates	One solution, room temperature	Immersion, spray, wipe	C	Easy to use, room temperature, drop-in replacement for chromates, dry in place	Minimal corrosion inhibition, dry in place, kitting and solution life, clear and colorless (no color change)
Brent Oxsilan™ AL-0500	Organosilane, ethanol, fluorotitanic acid	One solution, room temperature	Immersion, spray, wipe	C	Easy to use, room temperature solution replacement for chromates, dry in place	Minimal corrosion inhibition, dry in place, clear and colorless (no color change)
MacDermid Chemidize™ 727ND	Butyl cellosolve, other proprietary	One solution, room temperature	Spray, wipe	C	One solution, room temperature	Minimal corrosion inhibition, clear and colorless (no color change)
NAVAIR TCP	Chromium III sulfate basic, potassium hexafluoro-zirconate	One solution, room temperature, one to five minute dwell	Immersion, spray, wipe	E, B, C	Easy to use, drop-in replacement for chromates; corrosion inhibition present; toxicology study completed	Contains chromium, impractical color change
Sanchem Safegard™ 7000 (with Seal #2)	Potassium permanganate, seal: polyacrylic acid, poly propylene glycol, fatty acid esters	Two solution (coating and seal), elevated temp (200 °F) cure on sealer; pretreatment is ambient	Immersion, spray, wipe	C	Pleasing bronze-gold color to coating, easy to use	Minimal corrosion inhibition without sealer. Sealer requires elevated temperature cure and has poor adhesion characteristics.
Pantheon PreKote™	Diethylene glycol monobutyl ether, n-methyl pyrrolidone	One solution, wipe on by mechanical abrasion of substrate, room temperature	Wipe	C	Non-toxic coating left as a result of process	Minimal bare corrosion resistance, laborious manual application required, minimal color change

* E=electrical, B=bare, C=coated

Table 1.1: Summary of Non-Chromate Conversion Coating Alternatives

In the Phase I Report, Matzdorf, et al., reported that, "Each alternative tested shows acceptable performance in some selected cases that may be satisfactory for a given user, depending on operating environment and business cases involved. The only compositions that come close to matching the technical, process, cost, and flexibility of chromates are based on trivalent chromium. Although trivalent chromium is present in the solution and coating, toxicity studies, International Agency for Research on Cancer (IARC) regulations, and OSHA PELs suggest that the use of Trivalent Chromium Product (TCP) is acceptable, especially given its well-rounded performance. The next best product in testing was Alodine™ 5200/5700. Alodine™ 5200/5700 contains no chromium, is process flexible and can be applied like chromate conversion coatings. The remaining alternatives performed variably in the evaluation."

1.3 – PHASE II OBJECTIVE AND SCOPE

Out of the Phase I Laboratory testing, the potential alternative technologies were down-selected for field demonstration and validation testing by the respective services and program offices based upon their unique performance and operational environment requirements. The main advantage of any alternative is the elimination of hexavalent chromium. In most cases, the alternatives are trying to match the process and technical performance of the chromate solutions and coatings.

In Phase II of the ESTCP NCAP project, along with JG-PP and other leveraged funding, the focus was on validating the feasibility of applying and maintaining, i.e. utilizing and repairing, these conversion coatings in lieu of conventional chromate-based technologies. Testing was conducted with various organic coatings systems, according to the particular service and platform requirements. This variety in field testing helps assure that potential candidates to hexavalent chromium are applicable as alternatives in their own right, without the necessity of specifying the use of only one or two possible primers/paint systems. The field test phase of this project was constructed to cover the broadest range of aluminum alloys, processing methods and conditions, and the operational environments experienced by fielded platforms across DoD.

2.0 – SELECTED DEMOSTRATION / VALIDATION

The pretreatments being tested in Phase II are shown in Table 1.2.

Pretreatment	DoD Service	Platform(s)	Facilities
Alodine 5700 TCP - Color	US Army Ground Combat	Bradley Fighting Vehicle	Red River Army Depot United Defense - York
Alodine 5700 TCP	US Army Aviation	CH-47, H-60	Corpus Christi Ct AVCRAD
Alodine 5700 TCP	USMC Amphibious Assault	Expeditionary Fighting Vehicle	General Dynamics – Lima AVTB – Camp Pendleton
PreKote	US Air Force	F-16, C-130	Hill AFB
TCP	NAVAIR	CH-46, S-3, F-18	NADEP's CP, NI
TCP	NAVSEA	Landing Craft, Air Cushioned	NSWC – Little Creek, VA

Table 1.2: Selected Pretreatments for Dem/Val efforts

2.1 – NAVAIR TRIVALENT CHROMIUM PRETREATMENT (TCP)

TCP solutions generate pretreatment films on aluminum and aluminum alloys that improve corrosion inhibition and paint adhesion while maintaining electrical conductivity. The solution is used in a fashion similar to conventional chromate pretreatments. It can be applied by immersion, spray, and wipe application methods with a few minutes dwell time. Since the process chemistry is based on a surface reaction, rinsing stops the reaction and yields the final coating. TCP films have a very light color ranging from purple to blue to tan, depending on the alloy.

2.2 – HENKEL SURFACE TECHNOLOGIES ALODINE™ 5200® AND ALODINE™ 5700®

Alodine™ 5700 is the ready-to-use, or pre-mixed, version of Alodine™ 5200. The solution is used in a similar fashion to conventional chromate pretreatments. A major benefit is that it can be applied by immersion, spray, and wipe application methods with a few minutes dwell time similar to chromate conversion coatings. Coating can be applied using rinse or dried in place. Deposited coatings have a light color ranging from blue to tan depending on the alloy.

2.3 – PANTHEON CHEMICAL COMPANY PREKOTE™

PreKote™ is a non-chromated conversion coating used for metal surface pretreatment and pre-coating prior to painting. It is designed to promote paint bonding on aluminum, stainless steel, titanium, magnesium, and carbon steel. It is biodegradable, non-toxic, non-flammable, non-hazardous, non-corrosive, and free of phosphates and heavy metals. The solution is applied by a manual or automated scrubbing process, requiring multiple material application, scrubbing, drying, and rinsing steps. As a result, the product is not amenable to immersion or spray processing. PreKote™ has a slightly gray tint as applied.

2.4 – ADVANCED CHEMISTRY & TECHNOLOGY INC. AC-130/131™

AC-130/131™ conversion coating is a non-chromated solution that is designed to increase adhesion of organic coatings to aluminum, titanium, and corrosion resistant steel. The final coating solution is a product of mixing four components packaged in a "kit" that can be sized appropriately for a given application. The mixed solution has a "pot life" of 12-hours and is applied by spray, wipe, brush or dipping to leave a thin wet film on the parts. The coating is dried in place without rinsing and care must be taken to remove puddles and excess coating solution that may be retained in pockets or crevices that do not freely drain. These sol-gel coatings are clear and colorless and yield a slightly wet or glossy appearance.

2.5 – PHASE II EFFORTS SUMMARY

Field testing of the TCP was underway with NAVAIR when the ESTCP project began and the two efforts were leveraged together. In addition, Navy Sea Systems Command (NAVSEA) had begun an independent evaluation of the TCP for the Landing Craft, Air Cushioned (LCAC). As a result, the Navy supported its aircraft and LCAC demonstrations, and the Air Force (AF) took the lead on the PreKote™ demonstration with the F-16 and C-130 platforms. As a result of these initial, leveraged efforts, field testing opportunities outside the Navy were selected for the NCAP project to more broadly cover the potential applications and operational environments. ESTCP funded the Phase II efforts for the USMC Expeditionary Fighting Vehicle (EFV), the US Army Bradley Fighting Vehicle (BFV), and the US Army Aviation and Missile Command (AMCOM) platforms. NAVAIR, Boeing, and NASA have been demonstrating the AC-131™ for pre-paint and bonding applications.

Figure 2.1: US Marine Corps Expeditionary Fighting Vehicle (formerly Advanced Amphibious Assault Vehicle)

USMC Expeditionary Fighting Vehicle

The EFV demonstration/validation effort was conducted with General Dynamics Amphibious Systems (GDAMS), General Dynamics Land Systems (GDLS), and the Direct Reporting Program Manager (DRPM AAA) personnel. The prototype and System Design and Development Phase (SDD) vehicle hull and turret space frame structures are constructed from machined and welded aluminum alloys, and subsequently spray processed at the Lima Army Tank Plant (LATP), GDLS facility. The processing and painting were performed by LATP, GDLS contractor personnel, with on-site technical and chemical support provided by NAVAIR and GDAMS engineers. Additionally, since the aluminum alloy (AA) used to manufacture the hull and turret structures for the EFV was a new, untested alloy, AA2519-T87; NAVAIR and Army Research Laboratory (ARL) conducted numerous laboratory panel tests to optimize the process chemicals, time constraints, and subsequent primer/paint coating systems for use with the EFV. Prototype and SDD vehicles have been in field evaluation for over 2 years, and are still undergoing rigorous evaluations as part of the Test & Evaluation phase of SDD, from in-water amphibious testing at the Amphibious Vehicle Test Branch (AVTB), Camp Pendleton, CA and NAVAIR, Patuxent River, MD to desert/land testing at Marine Corps Base (MCB) 29 Palms, CA. On-site vehicle inspections were conducted periodically during testing, by GDAMS, NAVAIR, and USMC personnel.

US Army Bradley Fighting Vehicle

The BFV demo with United Defense (UDLP) and the office of the Program Manager Combat Systems (PMCS) used TCP-C, a modified TCP chemistry that imparts a dark purple-blue to brown color to the as-deposited conversion coating. The selection of TCP-C over the baseline TCP was made at the request of UDLP and PMCS engineering because UDLP desired the visual quality control assurance from a practical color change. The BFV demonstrations were component-only tests, as the OEM hull processing facilities did not have a spray-processing apparatus. A list of several components was compiled by NAVAIR, PMCS, and UDLP personnel, and then three sets of components, two new sets and one re-manufactured set, were procured. The components were immersion process conversion coated, primed, and top-coated at the NAVAIR Patuxent River, MD facility. The components were then transported to the field demonstration facilities to be installed on three M2A3 or M3A3 BFV variants as either test track or fielded training vehicles at various US Army sites. ARL is tracking and evaluating the 3 BFV vehicles in field testing; and reported on the performance of the vehicles at 6-months and 1-year.

Based on panel testing data generated at ARL, Aberdeen Proving Ground (APG), MD; the Red River Army Depot (RRAD) installed and currently maintains an Alodine™ 5700 immersion bath for conversion coating of aluminum road wheels for US Army ground combat vehicle platforms. RRAD obtained an approval letter for use of Alodine™ 5700 on aluminum road wheels, and is currently applying the coating on re-work vehicles via an immersion process.

Figure 2.2: US Army Bradley Fighting Vehicle

US Army Aviation Command

AMCOM engineers generated a large laboratory test matrix in October 2003 to down-select the best conversion coatings and non-chrome primers to examine in field testing. The test panels were processed and painted at NAVAIR Patuxent River (PAX), MD. Corrosion and adhesion evaluations were conducted by ARL. The panel matrix evaluated the several combinations of non-chromate coating systems, consisting of TCP, Alodine™ 5700, and PreKote™ on aluminum, with both water and solvent-reducible non-chrome primers. Alodine™ 1200S with high-solids, chromated epoxy primer was the control system. All coating systems were top-coated with Chemical Agent Resistant Coating (CARC) paint. Two non-chrome coating systems were identified for field testing, one with Alodine™ 5700 and the other using TCP as the conversion coating, based upon the results and recommendations of the laboratory evaluations at ARL. AMCOM personnel selected the Connecticut Aviation Classification Repair Activity Depot (AVCRAD) and Corpus Christi Army Depot (CCAD), TX as the two processing sites for this demo. Currently, six aircraft are planned for demonstration and validation efforts, with actual coating/painting operations to begin in FY05. Three aircraft will be coated at each demo site, with one airframe from each site being coated with a chromated conversion coating and MIL-PRF-23377 C2 chromated primer, as the control coating system. The platform for this demonstration will be either the CH-60 Blackhawk, the CH-47 Chinook, or some combination of the two. The Program Executive Office (PEO)

Aviation, along with the individual Program Management Activities (PMA's) from Army Aviation will determine if more aircraft or more various platforms are required for a full field test.

Figure 2.3: US Army H-60 Blackhawk

3.0 – ONGOING MARINE ATMOSPHERE EXPOSURE TESTING

3.1 – BACKGROUND

Phase I testing included outdoor, beachside exposure testing at the Corrosion Technology Testbed, Kennedy Space Center, FL. The testing is being completed by NASA and contractor personnel at the Kennedy Space Center (KSC), FL. 3"x5" aluminum coupons were pretreated with the alternative conversion coatings being examined, primed, top-coated, and shipped to KSC for testing in 2001.

The Phase I Report tabulated the performance data for the different pretreatment and primer combinations according to aluminum alloy. The rankings were from 1-year exposure data. The exposure testing was continued beyond 1 year, and 2-year ratings were taken in December 2003. As stated in the Phase I report, performance ratings are measured by ASTM D 1654 Procedure A; and any rating below "3" is considered failed and the panel removed from testing.

NASA's test facility is located 1.5 miles south of Launch Complex 39A. Figure 3.1 shows an aerial view of the site.

Figure 3.1: KSC Corrosion Testbed Beach-side Aerial View

Test stands are located 30 meters (100 feet) from the mean high-tide line and face the water. Test coupons are installed on yellow, painted steel test stands using porcelain insulator stand-offs. The rack angle of the coupons is 30 degrees from horizontal.

An "X" incision was scribed through the coating so that the smaller angle of the "X" was 30 to 45-degrees, making sure that the coating was scribed all the way to the substrate. The scribe had a 45-degree bevel, and each line of the "X" was approximately 4-inches long. The back and edges of the coupon were primed to prevent undercutting and corrosion products from contaminating the test stands.

The coupons were evaluated for surface corrosion and creepage from the scribe at 6-month intervals. Two-year ratings based on creepage from the scribe (ASTM D 1654A) are detailed here. Remaining coatings are being evaluated until failure, and will be rated on creepage from the scribe performance at yearly intervals, until completion of the 5 year test in December 2006.

3.2 – COATING PERFORMANCE AT TWO YEARS

Tables 3.1-3.5 detail corrosion performance for coating systems on each alloy after two years. An average rating "0.0" designation means that the coating system has failed and has been removed. However, if only some of the coatings from each set of 5 failed, the average rating is calculated from the remaining coupons, and the number of failed panels is given. The 1-year ratings are given first (left) for each coating/alloy combinations, to show any degradation relative to the other conversion coatings.

Pretreatment	AA2024		AA7075		AA5083		AA2219	
Alodine 1200S (control)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Alodine 5200/5700	10.0	10.0	9.2	8.2	10.0	10.0	10.0	10.0
Bi-K Aklimate	10.0	10.0	10.0	10.0	10.0	10.0	9.8	9.8
AC-131	10.0	10.0	10.0	10.0	10.0	10.0	9.3	9.3
Chemidize 727ND	10.0	9.8	10.0	10.0	10.0	10.0	7.6	6.4
Oxsilan Al-0500	9.6	9.6	10.0	10.0	10.0	10.0	9.8	9.8
Sanchem 7000	9.6	8.2	10.0	9.8	10.0	10.0	4.2	0.6 -4F
TCP	10.0	10.0	8.0	8.0	10.0	10.0	10.0	9.0
PreKote	10.0	10.0	10.0	10.0	10.0	10.0	10.0	7.2

Table 3.1: Average Surface Corrosion and Creepage from the scribe (5 panels) for Aluminum Alloys Coated with Mil-PRF-23377C Primer and Mil-C-85285 Topcoat

Pretreatment	AA2024		AA7075		AA5083		AA2219	
Alodine 1200S (control)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Alodine 5200/5700	10.0	10.0	8.8	8.8	10.0	10.0	10.0	10.0
Bi-K Aklimate	10.0	10.0	10.0	10.0	10.0	10.0	9.8	9.4
AC-131	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Chemidize 727ND	9.8	9.8	7.6	7.6	10.0	10.0	9.0	9.0
Oxsilan Al-0500	9.6	9.6	7.6	6.6	10.0	10.0	9.4	9.2
Sanchem 7000	0.0	0.0	3.2	2.4 -2F	10.0	9.4	6.4	6.4
TCP	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
PreKote	10.0	10.0	10.0	10.0	10.0	10.0	9.8	9.6

Table 3.2: Average Surface Corrosion and Creepage from the scribe (5 panels) for Aluminum Alloys Coated with Mil-PRF-85582 C2 Primer and Mil-C-85285 Topcoat

Pretreatment	AA2024		AA7075		AA5083		AA2219	
Alodine 1200S (control)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Alodine 5200/5700	10.0	9.8	8.8	8.0	10.0	10.0	9.4	9.4
Bi-K Aklimate	0.8	0.0	1.0	0.0	10.0	9.4	0.0	0.0
AC-131	5.3	5.0	7.3	4.7	10.0	10.0	0.0	0.0
Chemidize 727ND	0.8	0.0	1.2	0.0	10.0	9.4	0.0	0.0
Oxsilan Al-0500	7.6	7.2	9.2	9.0	10.0	9.8	2.8	0.0
Sanchem 7000	0.0	0.0	5.4	0.0	9.2	8.8	0.0	0.0
TCP	10.0	10.0	9.6	9.2	10.0	10.0	9.6	9.6
PreKote	3.8	0.0	1.4	0.0	9.0	8.6	0.0	0.0

Table 3.3: Average Surface Corrosion and Creepage from the scribe (5 panels) for Aluminum Alloys Coated with Mil-PRF-85582 NC Primer and Mil-C-85285 Topcoat

Pretreatment	AA2024		AA7075		AA5083		AA2219	
Alodine 1200S (control)	10.0	10.0	9.8	9.8	10.0	10.0	2.4	0.0
Alodine 5200/5700	10.0	7.8	8.6	8.6	10.0	10.0	3.4	4.0-4F
Bi-K Aklimate	0.8	0.0	9.4	0.0	9.8	9.4	0.0	0.0
AC-131	5.7	3.0	4.7	0.0	10.0	10.0	0.0	0.0
Chemidize 727ND	4.8	0.0	5.8	0.0	10.0	10.0	0.0	0.0
Oxsilan Al-0500	5.8	2.0-3F	9.2	1.8-4F	10.0	9.8	0.0	0.0
Sanchem 7000	9.8	0.0	0.2	0.0	10.0	9.8	0.0	0.0
TCP	10.0	10.0	10.0	10.0	10.0	10.0	3.6	1.4-4F
PreKote	4.2	0.0	6.0	0.0	10.0	10.0	0.0	0.0

Table 3.4: Average Surface Corrosion and Creepage from the scribe (5 panels) for Aluminum Alloys Coated with Mil-P-53030 Primer and Mil-C-53039 Topcoat

Pretreatment	AA2024		AA7075		AA5083		AA2219	
Alodine 1200S (control)	10.0	10.0	9.8	9.6	10.0	9.8	0.4	0.0
Alodine 5200/5700	10.0	10.0	8.8	8.8	10.0	9.8	2.4	0.0
Bi-K Aklimate	3.2	0.0	6.4	0.0	10.0	9.6	0.0	0.0
AC-131	9.5	9.0	1.3	0.0	10.0	10.0	1.0	0.0
Chemidize 727ND	6.0	0.0	2.2	0.0	9.2	8.4	0.0	0.0
Oxsilan Al-0500	9.4	2.8-2F	7.6	1.8-4F	10.0	10.0	0.8	0.0
Sanchem 7000	7.8	2.0-4F	6.6	0.0	10.0	9.6	0.0	0.0
TCP	10.0	9.8	10.0	10.0	10.0	10.0	1.4	0.0
PreKote	3.4	0.0	2.6	0.0	10.0	9.6	0.0	0.0

Table 3.5: Average Surface Corrosion and Creepage from the scribe (5 panels) for Aluminum Alloys Coated with Mil-P-53022 Primer and Mil-C-53039 Topcoat

Summary of Alternative Performance

Table 3.6 details the summary performance of each alternative pretreatment by primer system. It also shows an average rating for each primer across all pretreatments. These ratings provide a gauge of pretreatment robustness, showing how they perform across different alloys and primers, compared to the excellent all-around performance of the hexavalent chromium control.

	Primer											
Pretreatment	23377		85582 C2		85582 N		53022		53030		All Coatings	
Alodine 1200S (control)	10.0	10.0	10.0	10.0	10.0	10.0	7.6	7.4	8.1	7.5	9.1	8.9
Alodine 5200	9.8	9.6	9.7	9.7	9.6	9.3	7.8	7.2	8.0	6.8	9.0	8.5
Bi-K Aklimate	10.0	9.9	10.0	9.9	3.0	2.4	4.9	2.5	5.0	2.4	6.6	5.4
Boegel	9.8	9.8	10.0	10.0	5.7	4.9	5.5	4.8	5.1	3.2	7.2	6.5
Chemidize 727ND	9.4	9.1	9.1	8.7	3.0	2.5	4.4	2.1	5.2	2.6	6.2	5.0
Oxsilan Al-0500	9.9	9.8	9.2	8.6	7.4	6.9	7.0	3.9	6.3	3.4	7.9	6.5
Sanchem 7000	8.5	7.2	4.9	4.3	3.7	3.8	6.1	2.9	5.0	2.5	5.6	4.1
TCP	9.5	9.3	10.0	10.0	9.8	9.7	7.9	7.5	8.4	7.9	9.1	8.9
X-It PreKote	10.0	9.3	10.0	9.9	3.6	2.4	4.8	2.5	5.1	3.1	6.5	5.4
Overall Alternative Average	**9.7**	**9.3**	**9.2**	**9.0**	**6.2**	**5.8**	**6.1**	**4.5**	**6.2**	**4.4**	**7.5**	**6.6**

Table 3.6: Summary Ratings for Pretreatments and Primer Systems – 24-Months of Outdoor Exposure at Kennedy Space Center Beachfront Corrosion Test Site

The Alodine™ 5200/5700 and TCP alternatives perform comparably to the Alodine™ 1200S control regardless of the primer coating. Their superior performance is strongly evident in the non-chromate primer systems where no other alternative comes close. For the chromated primers, most of the alternatives show good performance, especially PreKote™, Bi-K Aklimate™, and AC-131™, all of which rate similar to the Alodine™ 5200 and TCP in the high 9's. Only the TCP and AC-130™ matched the perfect rating of the Alodine™ 1200S, and only when used in combination with the 85582C2 primer.

Like the previous corrosion tests, the chromate-based primer systems perform equally well and are the basis of the best coating systems. The non-chromate systems, on average, rank lower than the chromate systems especially with the poorer performing alternatives. There are two notable exceptions in this test.

The performance of the 85582 N primer with Alodine™ 1200S, TCP and Alodine™ 5200/5700 differs little from their performance with the sister chromate primers. The performance of the TCP and Alodine™ 5200/5700 with the non-chromate epoxy primers, 53022 and 53030 is equivalent or better than Alodine™ 1200S with the same primers. These non-chromate systems match the performance of the sister systems with chromate primers. No other non-chromate system competes as well.

4.0 – LEVERAGED EFFORTS

4.1 – AF F-16/C-130

4.1.1 – BACKGROUND

A multi-year effort at Hill Air Force Base (AFB) was under taken in 2000, with the oversight of the Air Force Corrosion Prevention and Control Office (AFCPCO), to reduce or eliminate the use of chromate compounds in the paint preparation process for aircraft.

Of the four products tested, three were eliminated early through laboratory testing. The fourth candidate, PreKote, was tested extensively against the current process. PreKote performed better than chromate conversion coating in adhesion/flexibility tests and performed equally well in other testing. In addition, it was found that PreKote could eliminate the solvent wipe down as well as the acid brightener used in conventional paint preparation procedures. The use of PreKote also reduced the need to sand anodized surfaces before repainting, but the limitations are that the application process is labor intensive.

The application process used in the Qualification Operational Test and Evaluation (QOT&E) process is called the "three-step" process. Step 1: the surface of the aircraft is scrubbed with PreKote and rinsed after scrubbing. Step 2: PreKote is applied to the surface again and agitated, and allowed to completely dry on the aircraft surface. Step 3, PreKote is applied to the surface again and agitated to remove the residue from Step 2.

4.1.2 – FIELD TESTING

Operational tests have been conducted on several aircraft and are ongoing. Air Education & Training Command (AETC) used PreKote on two aircraft in 1996. In March 1997, an F-16 was scuff sanded and repainted using PreKote in the prep for paint process. In November 1997, two fully stripped F-16 aircraft had their right wings treated with PreKote while the rest of the aircraft was treated with chromate conversion coating. These aircraft are in service at Eglin and at Homestead. Test aircraft, T-38, F-16, A-10, and C-130's, were prepared half with Alodine and half with PreKote.

AFCPCO is the responsible engineering authority for T.O. 1-1-8, "Application and Removal of Organic Coatings, Aerospace and Non-Aerospace Equipment." In 2000, they began evaluating PreKote for possible addition to T.O. 1-1-8 as an Air Force-wide approved alternative for chromated conversion coatings (as specified in MIL-C-5541/SAE AMS-C-5541 and MIL-DTL-81706). Based on extensive laboratory testing and limited field use (on F-16s, T-37s, and T-38s), AFCPCO determined there was not enough data on PreKote's operational performance on various AF aircraft substrates in severely corrosive environments.

For example, F-16s have anodized skin panels which increases their corrosion resistance, but many AF aircraft do not have anodized skins. Trainer aircraft typically do not experience extremely corrosive environments.

Therefore, the AF corrosion control office initiated a QOT&E of PreKote in conjunction with Ogden Air Logistics Center (OOALC), the Air Force Research Laboratory (AFRL) and the applicable operational Major Commands. The QOT&E is a six-year, full depot maintenance cycle evaluation in actual use, as part of a full coating system, that began in 2001 on four operational aircraft – two A-10s and 2 C-130s.

4.1.3 – FIELD TEST RESULTS

Hill AFB and the owning units have examined each of the test aircraft in 2002 and 2004. The results so far are very positive and no detrimental effects from the PreKote have been discovered. The half-and-half test aircraft prepared at Hill exhibited equal or better paint adhesion on the PreKote side when compared to the Alodine side.

The AFCPCO has completed a 24-month operational evaluation of PreKote on USAF aircraft. Results at the 24-month point of the QOT&E indicated paint adhesion performance is comparable between PreKote and Alodine 1200S chromated conversion coating. There was no evidence of decreased corrosion protection on the PreKote treated areas of the test aircraft, but corrosion performance cannot be fully evaluated until the coatings are stripped at the end of the testing.

The 24-month results are sufficient to allow AFCPCO to incorporate PreKote into T.O. 1-1-8, though they will continue the QOT&E for the full six years and evaluate the test aircraft when the paint is stripped in depot. Additionally, AFCPCO is also participating in other on-going PreKote operational evaluations.

Figure 4.1: Application of PreKote at Hill AFB

4.1.4 – STATUS

As of February 2004, AFCPCO has approved PreKote as a surface treatment alternative to chromate conversion coating prior to exterior painting of USAF aircraft. The approved process is being added to T.O. 1-1-8, "Application and Removal of Organic Coatings, Aerospace and Non-Aerospace Equipment," and includes specific process steps. The use of PreKote on AF aircraft requires System Program Office (SPO) approval, and the use of a chromated primer.

The F-16, T-37, T-38 and T-1 SPO's have now approved the use of PreKote, and Headquarters Air Education and Training Command (HQ AETC) has mandated its use on all AETC aircraft for which it's approved. If a base, MAJCOM, or ALC decides to pursue using PreKote in their paint processes on other systems, it must obtain approval from the appropriate SPOs. AFCPCO will provide existing test results upon request to assist SPOs with the engineering decision whether to approve PreKote.

However, the AFCPCO has noted some areas of consideration in the use of PreKote. Since application of PreKote is largely a manual process, the consistency of the process may be important to an overall satisfactory result. To achieve results equal to other weapon systems, they recommend adhering closely to application practices that have already been established. Also, they recommend the use of the current three-step application process, because it was used for the QOT&E. Variations of the process are being developed, but AFCPCO cannot recommend them until more testing is completed.

Note that all test results to date, current SPO approvals, and the assessment of low risk, are contingent on the use of a qualified chromated primer. When PreKote is used, corrosion inhibition comes only from the chromated primer. Past performance of non-chrome paint systems in AF use has been poor; the AFCPCO strongly recommends against the use of PreKote with non-chromated primers.

4.2 – NAVAIR S-3

4.2.1 – BACKGROUND

The US Navy's S-3 support aircraft are currently sprayed with a chromate conversion coating during de-paint/re-paint operations while undergoing Standard Depot Level Maintenance (SDLM) at the NADEP NORIS facility.

Four aircraft were sprayed with TCP for the S-3 demonstration; the first two were treated with TCP on the aft (tail) section only. The 3rd and 4th aircraft were completely treated with TCP.

4.2.2 – PROCESSING

Two tail sections of S-3A support aircraft were spray processed with TCP, in July and August of 1999. They were then finished with TT-P-2756, a non-chromated, self-priming polyurethane topcoat.

BUNO 160144 (AV-61) was processed on July 24, 1999 at NADEP NORIS. This aircraft was attached to VS-31, Jacksonville, FL. This was the first aircraft field application of the TCP.

BUNO 160589 (AO-62) was processed on August 2, 1999 at NADEP NORIS. This aircraft was attached to VS-41, North Island, CA.

Two full S-3B support aircraft were spray processed with TCP in April and June of 2000. They were then finished with TT-P-2756, a non-chromated, self-priming polyurethane topcoat.

BUNO 159770 (AO-75) was processed on April 30, 2000 at NADEP NORIS. This aircraft was attached to the Force Support Test Squadron, Patuxent River NAS, MD.

BUNO 106158 (AO-76) was processed on June 7, 2000 at NADEP NORIS. This aircraft was attached to VS-35 North Island, CA and then to VS-38 for a Western Pacific (WESTPAC) carrier deployment.

The spray processing for these aircraft was overseen by Mr. Tim Woods, 4.9.7, NORIS Materials Division.

The tail section of the S-3 was selected for the initial field testing because all of the common aluminum surfaces used on this aircraft, along with the various finishes (i.e. bare, clad, anodized, etc.), are represented over the aft section. The control coating for the chromated areas of the two tail-only demonstrations was Turco Accelagold™. All aircraft were deoxidized using Turco 3003 TWA™. All test aircraft were processed and painted in the same manner, with the same application procedures used for chromate processing at North Island.

TCP was spray applied over the horizontal and vertical tail surfaces, and aft fuselage. North Island's normal spray procedures were followed, whereby, the conversion coating materials were sprayed on wetted surfaces beginning at the bottom and working upward. The aircraft was rinsed with tap water at 50-70 psi following each process chemical application. A bluish iridescence was evidenced in the TCP application areas, but there was little color change relative to the chromated areas.

Figure 4.2: Fuselage Station 496-transition area

Figure 4.3: Close-up of TCP Treatment, Dry

The aircraft was then painted with the TT-P-2756 Self-Priming Topcoat (SPT), a non-chromated, polyurethane topcoat that is used without an underlying primer.

Figure 4.4. Finished BUNO 160144, North Island, July 1999

4.2.3 – FIELD TESTING RESULTS

BUNO 160589 was inspected at NORIS by Tim Woods on May 17, 2001. He reported that the corrosion control actions performed on the tail area of that aircraft were consistent to those performed in other areas of the aircraft.

BUNO 160144 was inspected at NAS Jacksonville by Jack Benfer, NADEP JAX Materials, on January 4, 2002. This aircraft, A/C S-3B, BUNO 160144 (700) is attached to VS-31. He reported that an interview with Maintenance Control indicated that this aircraft appeared to be performing equivalent to other S-3 aircraft within the squadron.

Man-hour and flight time data since February 2001 was presented to the inspection team. Additional data encompassing man-hours and flight time since receipt from depot would require a more thorough review of maintenance control log files and was not provided at the time of the inspection. Data presented is as follows:

S-3B AC 160144 (700) [Feb 2001 to Jan 2002]

Prevention	3299.3 man-hours
Treatment	1632.2 man-hours
Flight Time	419.2 hours

No differentiation of corrosion was discernable between port and starboard sides. In addition, no differentiation was discernable between forward and aft sections of the fuselage areas inspected.

BUNO 160158 was inspected at NORIS by Tim Woods and Ed Mullin on December 17, 2001, after returning from a 6+ month carrier deployment. It was reported by the maintenance personnel that this aircraft exhibited more corrosion than was normally observed. The aircraft showed signs of corrosion along some of the fastener rows, and in some surface areas away from fasteners or joints. The average thickness of the paint adjacent to an observed filiform corrosion area was 2 mils. This hits mid-range of the recommended thickness (1.7-2.3 mils) for SPT. Corrosion not necessarily adjacent to fasteners could be found in areas around the outer mold-line of the aircraft.

Figure 4.5. Open Area Corrosion

No control aircraft was available for this evaluation, as VS-38 did not have a chromated aircraft with a paint date close enough to 160158 for any correlation to be made. VS-35 had in its inventory S-3 BUNO 160567. SDLM was completed on this aircraft the week prior to 160158 being completed. BUNO 160567 (side #704) at VS-35 served as an operational control during the validation period of TCP on aircraft 160158. The fundamental difference in the finish systems of these aircraft is limited to the aluminum pretreatment; while 160158 had TCP applied, 160567 received chromate conversion coating (CCC). Both of these aircraft returned from a WESTPAC deployment within the same time period, SPT was applied to both, and both logged similar flight hours. Less active corrosion was evident on 160567, and, relative to 160158, fewer corrosion maintenance areas were evident. The paint thickness of 160567 measured closer to 3.0 mils in most areas inspected over the outer mold-line. One important difference to note is that 160158 was deployed on-board the USS Constellation, which is an oil-burning carrier, while 160567 was deployed on-board a nuclear-powered carrier.

Of the tail only aircraft, both have shown equivalent performance to the rest of the airframe over 2 years of service. Of the fully coated airframes, one has shown normal corrosion compared to similar controls. BUNO 160158 S-3B saw a full deployment in the South Pacific on the USS Constellation. This airframe showed more corrosion than comparable planes in the squadron.

A specific cause for the extra corrosion was not identified but two potential causes were identified: insufficient corrosion protection by the TCP/SPT coating system or inadequate rinsing during processing. Excessive TCP residue left during processing may cause corrosion in non-chromate coating systems. Since neither can be proven independently or acting together no conclusion can be reached other than more testing with this coating system is required before use in the field.

Figure 4.6: S-3A Viking – TCP on aft section – August 1999

4.2.4 – STATUS

As a result of the mixed field performance of the TCP with SPT, additional laboratory testing was conducted with panel specimens according to ASTM G-85 SO_2 acidified salt fog exposure. The initial 500-hour SO_2 salt fog test performed at NAVAIR on the TCP/SPT coating did not show a difference in performance between the TCP/SPT and Accelagold/SPT system that is currently used on the S-3. When the test was extended to 1000 hours, corrosion in the unscribed areas did appear on non-chromated systems but not on systems that had chromate in the pretreatment or primer. This discrepancy highlights the risk in evaluating new technologies by the minimum performance standards of the control coatings. NAVAIR does not recommend the use of TCP with the SPT, and will not pursue implementation of a non-chromate conversion coating on the S-3 platform at this time.

4.3 – NAVAIR F/A-18 C/D

4.3.1 – BACKGROUND

Naval Aviation experiences the harshest possible environment for aluminum corrosion, in that most fielded strike and support aircraft are deployed shipboard on aircraft carriers. Aluminum is the main metallic substrate used in production of military airframes and aircraft skins.

Current protection schemes are focused around the use of chromate materials, both for inorganic conversion coatings and secondary primer applications. Even with the current hexavalent chromium coating system, corrosion is a very large driver for operations and maintenance costs and severely impacts operational readiness.

As the US Navy's premier attack strike fighter aircraft, anything affecting the flight hours to maintenance down-time is a critical issue. For this reason, any possible alternatives must at the very least meet the performance of current, less environmentally friendly systems, even while we continue to strive for better than the current corrosion protection.

4.3.2 – PROCESSING

Two full F/A-18C fighter aircraft were spray processed with TCP10M2, a thickened version of the TCP, in November of 2000. They were then primed with MIL-PRF-85582 C1 and topcoated with MIL-P-85285 Gray.

BUNO 163757 (RF94) was processed on November 18, 2000 at NADEP NORIS. This aircraft, was assigned to COMSTRKFIGHTWINGPAC, VFA-146, at NAS Lemore, CA.

BUNO 163459 (RF96) was processed on November 21, 2000 at NADEP NORIS. This aircraft, was assigned to COMSTRKFIGHTWINGLANT, VFA-81, NAS Oceana, VA.

The spray processing for these aircraft was overseen by Mr. Tim Woods, 4.9.7, NORIS Materials Engineering Division.

A synopsys of his initial evaluation of BUNO 163757 processing is included below. Both aircraft were stripped, processed, and painted in the same manner, consistent with the chromate conversion coating processing.

The paint was removed using plastic media blasting (PMB). Subsequently, glass bead blasting was used to remove any corrosion products.

The aircraft was washed with Turco 5948R™ mildly alkaline cleaner, and then deoxidized with Turco 3003 TWA. During both of these cycles, white Scotch Bright™ pads were used to scrub the bare aluminum surfaces. The deoxidizer was left to dwell on the aircraft for 15 minutes.

Figure 4.7: TCP Application on BUNO 163757, North Island, November 2000

Following a thorough rinse after each of these steps the TCP was spray applied. Ten gallons was enough to sufficiently coat the metal surfaces of the aircraft twice. For both applications, the TCP was applied from the bottom of the aircraft and working upward. The TCP dwelled for 20+ minutes before rinsing at approximately 60 psi.

While the surface was still wet, black streaking was evident in some areas that were glass bead blasted the day before. Presumably aluminum clad or anodize was removed leaving a bare aluminum substrate (likely AA7075). These bare areas took on more color than areas not treated with glass bead blasting. The dark streaks persisted after the TCP was rinsed off and the surface had dried (Drying conditions: 75.3 degrees @ 25% RH).

Figure 4.8: Iridescent Blue Coloration of As-deposited TCP

The pretreatment was allowed to dry overnight. The airplane was then primed with Mil-PRF-85582, Type I, Class 1 at 0.8-1.8 mils, and top-coated with Mil-PRF-85285 polyurethane.

Figure 4.9: F/A-18C with TCP after Primer Application – November 2000, NORIS

4.3.3 – FIELD TESTING RESULTS

Both aircraft were subject to "pre-deployment" inspections by Tim Woods in 2001. These were done after only a few months at the squadron, where the aircraft had undergone at most a month or two shipboard. No issues or differences were noticed between the TCP aircraft and normal coating system aircraft. It was reported that the TCP aircraft were "invisible" to the squadrons, i.e. no one noticed that the TCP aircraft were in fact processed differently than the control system.

Following this, the two F-18's were deployed with their respective squadrons for full carrier deployments, i.e. several months. These aircraft are still in service with the TCP, and have each currently undergone three or more full carrier deployments.

BUNO 163459 was inspected at Marine Corps Air Station (MCAS) Beaufort, SC by Tim Woods and Craig Matzdorf in May 2002, after returning from a 6+ month carrier deployment. This aircraft had been in service for 13-months with TCP on all aluminum surfaces, including touch-up before final painting with MIL-PRF-85582 C and MIL-PRF-85285 Gray polyurethane topcoat. They reported that the coating system performance looked excellent, with no visible differences when compared to another squadron aircraft painted around the same time with the chromated control coating. The TCP F-18 was slightly better than average when compared to other aircraft being evaluated for the non-chromate primer demonstration.

Craig Matzdorf and Dr. Kevin Kovaleski, Materials Engineering Division, NAWCAD, Pax River, MD inspected BUNO 163459 after 3+ years in service with TCP, in May 2004 at MCAS Beaufort, SC.

Two other squadron jets were selected for comparison: BUNO 163487 (tail number 406) and BUNO 163433 (tail number 403). Both were finished with the standard MIL-C-5541 chromate conversion coating, MIL-PRF-85582 C primer, and MIL-PRF-85285 topcoat.

Figure 4.10: Chromate and TCP F/A-18 C's – May 2004, MCAS Beaufort

Maintenance personnel noted that 163459 was "one of the best jets with respect to corrosion". When asked about time or effort spent when repairing test aircraft, personnel did not feel they were paying any more or less attention to these aircraft than to others in the squadron.

Repaint occurred over scuff-sanded finish system and did not result in the removal of the pretreatment.

BUNO 163757 was inspected at NAS Lemoore, CA by Tim Woods in May 2004, after at least three full length carrier deployments. He reports that VFA-146 does an excellent job of inspecting and maintaining their planes.

The inspection showed the aircraft to be in great shape; with the overall condition with respect to corrosion being very good. The average paint thickness on this test aircraft was 5-mils, with nothing over 9-mils DFT. The squadron did not report any issues or concerns with the TCP aircraft; noting, "other jets require more diligence in maintaining the coating system."

Figure 4.11: BUNO 163757 F/A-18C w/ TCP – NAS Lemoore, May 2004

4.3.4 – STATUS

Overall, the TCP technology is performing at least as well as the standard chromate conversion coating in this demonstration. These aircraft had at least three carrier deployments and may have had a fourth. Maintenance personnel were enthusiastic about new technologies due to their environmental and health benefits. The TCP aircraft are performing on par with the best corrosion performance of the fully chromated system. The Planned Maintenance Interval (PMI) cycle for the F/A-18 is 60-months, meaning that these aircraft will be returning to the depot for re-work in approximately two years. This will mean the TCP aircraft will have been in service for 5 years or more.

As a result of these positive field test results, and combined with the H-46 demonstrations that are discussed in Section 4.4, NAVAIR Materials is planning to authorize the use of TCP under chromated primers, with the approval letter planned to issue in FY05. Additional FY05 efforts will focus on an extensive evaluation of new, non-chromate primer systems under qualification testing to MIL-PRF-23377 Class N; with field testing over TCP planned if applicable based on laboratory testing.

4.4 – NAVAIR CH-46

4.4.1 – BACKGROUND

NAVAIR's fleet of H-46 helicopters undergo depot-level rework at NADEP Cherry Point, NC. Due to severe environmental restrictions placed on the conventional spray-on/rinse-off chemical processing methods, NADEP CP, for the past several years, has utilized a hand application wipe-on/wipe-off method for chromate conversion coating their aircraft. This procedure is used for all pre-paint surface preparation of aluminum skins for the H-46 program. The hand application method generates very little waste, thereby significantly minimizing environmental wastewater issues experienced in spray operations with hexavalent chromium.

In 2000, the Environmental Affairs Office in Cherry Point determined that the NAVAIR TCP process does not fall under the environmental and health and safety regulations that govern the hexavalent chromium processes. This is due to trivalent chromium being non-carcinogenic, unlike hexavalent chromium.

Cherry Point decided to field test the TCP on the H-46 platform, on the basis of being able to spray apply TCP. A conventional spray application conversion coating process allows for faster turn around time for aircraft undergoing Standard Depot Level Maintenance (SDLM). The current hand application method requires between 4 and 6 man-hours of labor to conversion coat one CH-46 airframe. A spray application could reduce this process time by half, which affords a significant cost savings. At FY00 labor rates, it was estimated that annual costs savings by switching to a non-hazardous spray application would be approximately $30K for the sixty aircraft processed annually on average.

4.4.2 – PROCESSING

On October 23, 2000, NADEP Cherry Point completed its first trivalent chromium conversion coating (TCP) demonstration on specific areas of an H-46 helicopter, BUNO 165454. This helicopter was scheduled to go to HMM 774 in Norfolk, VA in November, 2000.

The three areas treated were the drive shaft tunnel, forward pylon, and aft pylon and cargo door.

Figure 4.12: H-46 Components with TCP – NADEP CP, October 2000

Following a thorough cleaning, the bare metal surfaces were deoxidized using MIL-C-10578 phosphoric acid. While the surface was still wet, a total of fifteen gallons of TCP was applied using a reciprocating drum pump. Artisans sprayed the material through a fan shaped nozzle, evenly spraying the drive shaft tunnel, forward and aft pylons, and the cargo door with one coat of TCP. The TCP remained on the surface for one minute, and then a second application was sprayed onto all surfaces again. After another minute this process was repeated for a third and final time. A very faint green tint began to show following the second application. After approximately 7 minutes the aircraft was rinsed thoroughly, evaluated for any remaining residue, and rinsed once again. The pretreatment was allowed to cure overnight, and the aircraft was painted the next morning.

On October 26, 2001, BUNO 154819 CH-46E was spray processed with TCP at NADEP Cherry Point. The aircraft was nearing completion of SDLM. The surface skin of the H-46 is primarily composed of clad AA2024-T3. James Whitfield, AIR 4.9.7 Materials Engineering, NADEP Cherry Point, NC oversaw the processing with TCP. His observations and comments on the processing are included below.

The exterior surfaces of the aircraft were stripped of old paint coatings by plastic media blasting. Landing gear and other surfaces sensitive to chemical processing were masked off prior to the start of spray operations. Cleaning was accomplished using a combination of steam cleaning and by scrubbing with MIL-PRF-85570 Type II Aircraft Cleaning Compound at 20% by volume. After cleaning, the aircraft was thoroughly rinsed with clean tap water. The cleaning step required approximately 2 hours.

While still wet from cleaning, the helicopter was deoxidized using MIL-C-10578 Type II Metal Cleaner and Conditioner at 20% by volume. The deoxidizer was allowed to dwell on the surface for 5-minutes before thorough rinsing with clean tap water. Surfaces were visually inspected to ensure a water-break free surface was obtained. The deoxidizing step took approximately 15 minutes and required 25 gallons of solution.

While still wet, surfaces were coated using TCP solution. The TCP was spray applied from the bottom working upward to ensure complete coverage. TCP was re-applied after 5-minutes to prevent drying. Total TCP dwell time was 10 minutes. Surfaces where then thoroughly rinsed with clean tap water and allowed to dry. Ambient temperature during application was 65 ^{0}F with 50% RH. The TCP application step took approximately 15 minutes and required 35 gallons of TCP.

Shop artisans indicated that the process went well and was less labor intensive than the hand application coating process used for the chromate conversion coatings. The entire cleaning, deoxidizing, and conversion coating pretreatment process took approximately 2.5 hours. They estimated that as much as 1 hour was saved on process throughput.

After a 12-hour pretreatment dry time, the helicopter was primed and painted with MIL-PRF-85582 C1 water-reducible, epoxy primer and MIL-PRF-85285 Type I polyurethane topcoat.

The shop artisans did note that the surface treatment color change is one of the few downsides to TCP. Conventional chromate conversion coatings provide a distinct color change on treated surfaces. TCP, however, does not provide a noticeable color change. For process consistency and quality control, a color change or other simple means of determining surface treatment is desired. For tracking and follow-up purposes, an aircraft logbook entry was made indicating TCP surface treatment.

4.4.3 – FIELD TESTING RESULTS

BUNO 154819 was fielded with HMM-264 squadron at MCAS New River, NC following final paint at Cherry Point. This aircraft was inspected by James Whitfield, NADEP CP, at HMM-264 on November 6, 2003, after 13-months in service.

This aircraft had recently returned from an 8-month deployment, most of which was shipboard on the USS Iwo Jima. This deployment included tours in Iraq, the horn of Africa, Albania, and Liberia. While deployed, aircraft in this squadron were subjected to the harsh corrosive environment typical for Navy and Marine operations.

The aircraft was examined to assess corrosion and coating system issues, and to compare finish system performance with other aircraft in the squadron (standard chromated coating system). Particular attention was given to fastener patterns, lap joints, butt joints, and other corrosion prone areas.

The paint system was found to be in good condition with only minor touch-up indications typical of aircraft in service for 2-years. No corrosion was noted during the inspection. Squadron maintenance records indicated that there were no notable differences between corrosion or paint repairs on this aircraft and other aircraft in the squadron that were finished with standard pretreatment materials. This was confirmed by inspection of other squadron aircraft that were refinished within a few months, before or after, of the date this aircraft was painted.

4.4.4 – STATUS

The inspection results for the CH-46's indicate that TCP is performing at least as well as standard pretreatment materials for aluminum alloys. NADEP Cherry Point has expressed the intention to implement spray processing of TCP upon issuance of the NAVAIR approval letter.

As a result of these positive field results, and combined with the F/A-18C demonstrations discussed in Section 4.3, NAVAIR Materials is planning to authorize the use of TCP under chromated primers, with the approval letter planned to issue in FY05. Additional FY05 efforts will focus on an extensive evaluation of new, non-chromate primer systems under qualification testing to MIL-PRF-23377 Class N; with field testing over TCP planned if applicable based on laboratory testing.

4.5 – NASA SOLID ROCKET BOOSTERS

4.5.1 – BACKGROUND

The Space Shuttle Solid Rocket Booster (SRB) had only one set of coatings and one type of pretreatment qualified for protection of aluminum hardware. All of the materials contained chromate compounds. A project was conducted to identify and qualify alternatives for the currently qualified coating system and pretreatment.

The coatings were evaluated for corrosion protection, bond strength, compatibility with other SRB materials, batch-to-batch consistency, and thermal environments stability. Two pretreatments and two coating systems met the SRB program criteria. The recommended products are Henkel Alodine 5700, MacDermid Chemidize 727 ND, and the coating systems submitted by Hentzen and by Lord Coatings. The coating systems were tested in both a primer only and a primer/topcoat configuration. Both were found to be acceptable for flight. There are significant processing advantages for each of the materials depending on how they are used. The Hentzen coatings are chromate free and have very good processing characteristics along with good overall properties and are recommended for first implementation as an alternate. Likewise, Alodine 5700 had very robust processing parameters and is recommended for first implementation as a pretreatment alternate.

4.5.2 – FIELD TESTING

NASA began treating SRB's with the non-chromate Alodine 5700/Hentzen primer system in 2002. The first hardware flew in the fall of 2002.

4.5.3 – STATUS

NASA implemented the Hentzen / Alodine 5700 system in June 2002. This change affected all structural aluminum (AA2219, AA6061, and AA7075) parts of the solid rocket boosters. No issues have been reported with this system.

4.6 – BOEING/AIR FORCE/NAVY

4.6.1 – BACKGROUND

The US Air Force and Boeing have been evaluating a Sol-gel-based conversion coating process for paint adhesion applications where chromate pretreatments are traditionally used. The surface treatment system being used is AC-131 from Advanced Chemistry and Technology in Garden Grove, CA. AC-131 is based on technology developed at Boeing as “Boe-gel” sol-gel chemistry-based conversion coating. AC-131 is intended for use as an adhesion promoter for pre-paint applications on a variety of metallic substrates.

The objective of the Advanced Aircraft Corrosion Protection (AACP) program, sponsored by the Aging Aircraft Division of the Aeronautical Enterprise Program Office, is to demonstrate and validate a coating system evolved from the AC-131/Boegel and to apply the coating system to aircraft for operational flight testing. This effort began in September 2002.

The project focused on two main evaluations to determine validity for field demonstration. The first significant milestone of the project was to investigate ways to make Boegel/AC-131 visibly inspectable. Several colored dyes were successfully added to the conversion coating promoting color definition. The second milestone was to validate the adhesion promoting characteristics of AC-131 on a variety of aluminum substrates and surface conditions. To accomplish this goal, the team worked to define the cleaning and deoxidizing requirements for aluminum surfaces required for good adhesion. Good adhesion was exhibited to aluminum alloys when either AC-131 or Alodine 1200S was applied, however, wet adhesion failures were observed when no conversion coating was applied. Similar adhesion performance was observed for both the AC-131 and the Alodine 1200S chromate control in wet tape and pull-off adhesion testing. The performance of coating systems with AC-131/Boegel in laboratory testing has been reported to be equivalent or sometimes better than the performance of coating systems with conventional chromate conversion coatings.

4.6.2 – STATUS

Advanced Chemistry and Technology, Inc. is currently evaluating a blue-dyed version of the AC-131 developed during the Boeing efforts to determine the adhesion performance of the colored coatings and to evaluate the effect of the dye on long term coating system performance.

The AF/Boeing plan is to field test the AC-131 versus a chromate conversion coating for prepaint operations beginning in FY05. An F-15, to be stationed at Eglin AFB, FL, and a KC-135 support aircraft, to be stationed at Hickam AFB, HI, will be painted at Warner Robbins ALC and The Boeing Aircraft Support Center (BASC), respectively, both in San Antonio, TX. Half of each aircraft will receive the conventional chromated coating, with the other half being processed with the AC-131 non-chromate sol-gel coating. The aircraft will then be primed with MIL-PRF-23377 C chromated, epoxy primer and top-coated with Advanced Performance Topcoat (APC).

5.0 – ESTCP NCAP EFFORTS

5.1 – US NAVY LANDING CRAFT, AIR CUSHIONED

5.1.1 – BACKGROUND

The current pre-paint procedure for the Landing Craft, Air Cushioned (LCAC) amphibious vehicle hulls, which are composed primarily of AA5456-H116, involves abrasive blasting with garnet until a surface profile of 3 mils is achieved. Selected compartments and voids are then coated with a solvent-reducible, non-chromated epoxy primer, MIL-DTL-24441B Type III, Formula 150, to a dry film thickness (DFT) of 3-4 mils and then coated with MIL-DTL-24441B Type III, Formula 151 for a final DFT of 6-8 mils. This is done for the recently created Craft Alterations CA-369K and CA-445K, which apply coatings to selected corrosion prone voids. Hexavalent chromium chemistry was suspended by NAVSEA in August 1991 and an alternative to abrasive blasting for surface preparation is desired.

Several issues have arisen with the current direct-to-metal process, one of which is adhesion loss due to undercutting and undercutting exacerbated by crevice corrosion between substrate and coating, and another being coating cracking due to craft flex and vibration.

Surface preparation is a key concern, as MIL-DTL-24441B exhibits poor adhesion when the nominal surface profile is less then 3-mils. This can be achieved by grit-blasting, but not by other mechanical surface preparation methods, such as shot-peening or grit-impregnated sanders. AA5456-H116 has a tendency to polish after approximately 2 mils of profile have been achieved by mechanical methods. Additionally, both Assault Craft Unit Four (ACU-4) and ACU-5 are prohibited by NAVSEA from sailors performing abrasive blasting due to dust generation. This adversely affects the coatings performance of any maintenance and repair efforts conducted at the unit level. With respect to CRAFTALT installation as performed by contractors, production schedule analysis has indicated that implementation of TCP in place of the current abrasive blast process could reduce production time by 23 man-days and hangar time by 8 days.

These tests were initiated and overseen by Mr. Paul Dobias, NSWC Carderock Division, Materials Process and Engineering Branch. The LCAC program began testing TCP as a potential surface preparation method, allowing a substitution for abrasive blasting as a pre-paint process. The TCP was chosen for demonstration because of the potential for realizing both a time/cost savings, as well as improved adhesion and corrosion performance when compared to a direct-to-metal process.

5.1.2 – FIELD TESTING

The US Navy LCAC program has been field-testing TCP for the last 3-4 years, in both beach-side outdoor exposure testing and vehicle applications. This work was conducted at ACU-4 in Little Creek, VA. The LCAC is a NAVSEA program, and initiated this field test using ARCOVA-supplied TCP.

The exposure testing was conducted on panels composed from AA5083-H111, AA5086-H116, and AA5456-H116 (AA5456-H116 is the primary alloy used for construction of LCAC hull structures).

Al alloy	**Surface Prep**	**Primer/Topcoat**	**Test**
5456H116 5086H116 5083H111	None, Garnet-blast to 3 mil, 120-grit abrade w/ TCP	None	Bare, Beachside Outdoor Exposure
5456H116 5086H116 5083H111	None, Garnet-blast to 3 mil, 120-grit abrade w/ TCP	MIL-DTL-24441B TyIII F150/151 DFT – 8-10 mil	Scribed, Painted Beachside Outdoor Exposure

Table 5.1: Beach-side Exposure Testing – begun March 2001, ACU-4 Little Creek, VA

Two test components were treated on LCAC-26 in August 2000, to examine the TCP as an adhesion promoter for surface preparation, and to evaluate TCP for surface corrosion protection. The components were painted with MIL-DTL-24441B TyIII.

The first test area was the deck of the oily waste tank, which can contain MIL-H-23699 hydraulic fluid, seawater, and engine cleaning detergents. This is an area where adhesion loss is observed due to breakdown of the organic coating.

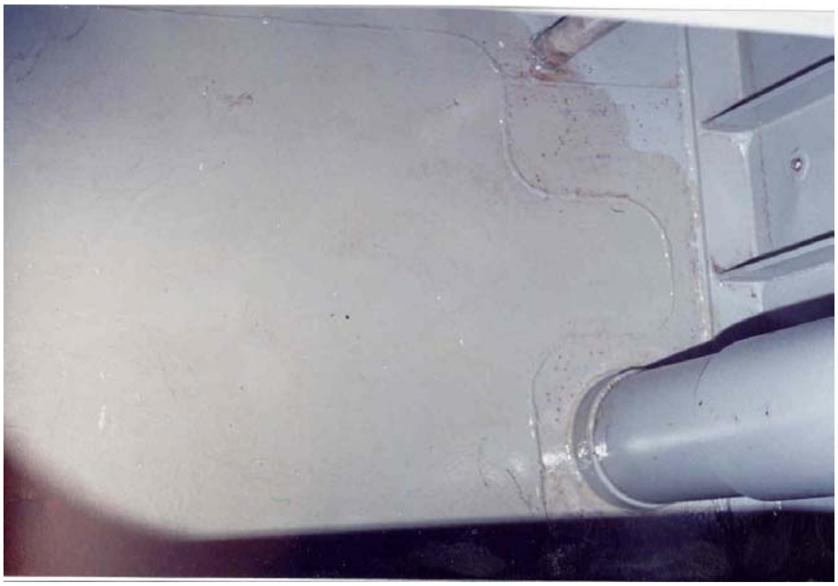


Figure 5.1: LCAC-26 Oily Waste Tank with TCP Test Patch

The second test area was on the deck where there is a void observed to suffer periodic seawater penetration. The TCP for this effort was obtained from the American Research Corporation of Virginia (ARCOVA).

5.1.3 – RESULTS

Beach-side testing coupons were exposed on 30 degree racks at the Little Creek, VA site for 4 years. Within 6 months of exposure, the scribed painted coupons with no surface preparation exhibited undercutting from the scribe. The garnet-blasted coupons developed undercutting around 3.5 years, the TCP coupons are still in testing, no undercutting is evident.

Figure 5.2: Beach-side Exposure Racks, Little Creek, VA

Untreated Blasted TCP

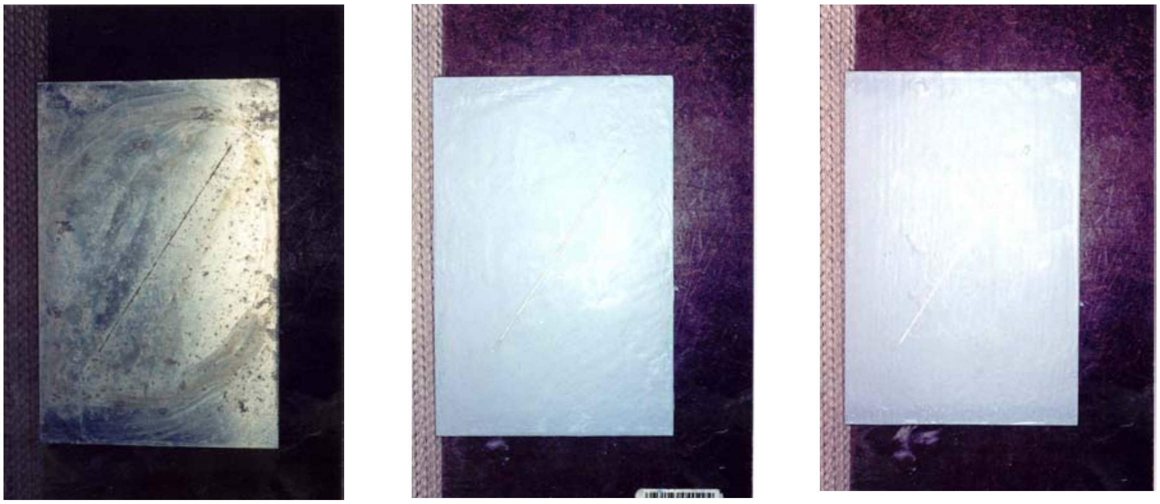


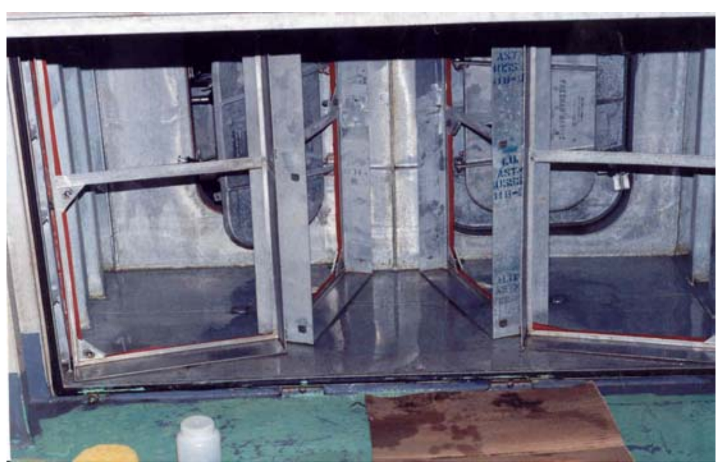
Figure 5.3: AA5456-H116 Coupons (Bare, Blasted, or TCP) coated with MIL-DTL-24441B F150/151 – 1.5+ years Beach-side Exposure

In December 2002, the test coupons were evaluated for surface pitting and general corrosion. Both the garnet blasted coupons and the coupons treated with TCP performed better than those with no surface preparation, which were now bare due to all of the coating having lost adhesion. The overall evaluation was that TCP reduced the incidence of pitting corrosion comparative to other surface preparation methods.

The two painted TCP components were evaluated after 4 years of service on LCAC #26: no corrosion, undercutting, or adhesion failures were noted. This demonstrated the adhesion performance when subjected to both corrosive and vibrational/flexing environments.

The field test for bare corrosion resistance was deemed inconclusive due to prior pitting damage that was not fully removed.

Figure 5.4: TCP Applied to Air Intake Plenum Deck, LCAC-26



5.1.4 – STATUS

NAVSEA PEO SHIPS, PMS 377 has indicated that they will authorize TCP for pretreatment of aluminum alloys of LCAC as soon as commercial products are qualified to MIL-DTL-81706B and concurrence from the Technical Warrant Holder (TWH) are obtained.

5.2 – USMC EXPEDITIONARY FIGHTING VEHICLE

5.2.1 – BACKGROUND

The Marine Corps' current Amphibious Assault capability currently relies on the use of the legacy platform USMC Amphibious Assault Vehicle (AAV); a lightly armored aluminum troop carrier capable of transporting a full squad of Marines from an off-shore transport ship onto dry land. This platform is from a 20+ old design, and the USMC realized the need to update their capability in this critical area.

The Expeditionary Fighting Vehicle (EFV) program was originally designated the AAAV – Armored Amphibious Assault Vehicle. The contractor and designer, GDAMS, has been manufacturing and testing prototype and SDD vehicles for the past few years. The SDD phase is still underway, with all ten of the planned vehicles either in testing or in the final stages of manufacture; with the planned production of one more training vehicle. For reasons of weight limit concerns, and because of improved ballistics properties; the EFV program decided to move away from the AA5083-H131 alloy used for the AAV, and chose a new alloy AA2519-T87.

While the ballistics and strength/weight ratio improved with the use of this alloy, the problem of corrosion was greatly magnified. AA2519 is a high copper alloy very susceptible to pitting and exfoliation corrosion. Due to the use of a corrosion-prone alloy, in conjunction with the extremely harsh operating environment experienced by the EFV; the corrosion control coatings and materials must be as robust at possible.

At the outset of this new acquisition program, the PM made the executive decision to comply with the strictures of an environmentally "green" program. Included in this is the full prohibition of the use of hexavalent chromium containing coatings.

The OEM is GDLS; and the EFV's are being produced at the Lima Army Tank Plant (LATP) facility, in Lima, OH. The LATP site is where the US Army's M1A2 Abrams battle tank is manufactured.

Originally, the EFV prototype vehicles were prepared and coated using a grit-blast/wash primer process that had shown good performance characteristics on high-strength and armor steel alloys (like the Abrams). During initial field and in-water testing with P1, the first prototype vehicle, serious problems arose with the coating system and its corrosion performance. These corrosion and adhesion issues needed to be addressed for the unique performance and operational requirements of AA2519-T87.

The corrosion coating system issues that needed to be addressed were serious coating/substrate adhesion loss on the P1 hull, turret, and other components, as well as rapid exfoliation corrosion of the aluminum substrate.

The initial coating procedure was wash with a standard alkaline steel cleaner, abrasive blast with alumina to a 1.5-2.0 mil surface profile, wash prime with a water-reducible non-chrome primer, prime with a solvent-reducible, epoxy CARC, and finally topcoat with a water-reducible, polyurethane CARC.

It was suggested that the program look into a chemical process and conversion coat surface preparation in lieu of the mechanical surface preparation/wash primer process.

5.2.2 – P1 - TCP PERFORMANCE VALIDATION

General Dynamics and the EFV Program requested that the Inorganic Coatings Team (ICT) refurbish deflectors, part number AV1060625, commonly called "steering buckets" and two seal plates, numbers AV106015-1P (port side) and AV106015-1A (starboard side) from EFV P1.

Two deflectors were refurbished and an evaluation was done to validate the performance of NAVAIR's TCP using a standard "wet" surface preparation process. These parts were grit blasted with alumina on August 14, 2001 to remove the paint system and corrosion products. Later that morning the four components were processed in the Inorganic Coatings Lab, Patuxent River, MD using the following process:

1. Cleaned using a warm mildly-alkaline, non-silicated, non-etching aluminum cleaner. (Turco 4215 NC LT™ – 120 F) Solution was scrubbed lightly onto the components with Scotch-Brite pads. Figure 5.5 shows the cleaning of a steering bucket.
2. Rinsed thoroughly with warm tap water followed by deionized (DI) water.
3. While still wet, Turco 3003 TWA cleaner/deoxidizer was hand-applied with Scotch-Brite pads, scrubbing gently to ensure contact of the chemical with all surfaces.
4. Allowed 3003 TWA to dwell on the substrate for 15 minutes.
5. Rinsed thoroughly with cold tap water followed by DI water.
6. While still wet, spray-applied TCP10P solution using a two-liter, hand-pumped solution sprayer. Figure 5.6 shows the application of TCP.
7. Allowed TCP to dwell on the surface for 5 minutes, keeping the surface wet. This required the additional misting of the surface twice due to the low humidity and high airflow in the lab.
8. Rinsed thoroughly with cold tap water followed by DI water.
9. Allowed components to air-dry for one hour. Figure 5.7 shows a component with a dried TCP film.

Figure 5.5: Cleaning Steering Bucket

Figure 5.6: Application of TCP

Figure 5.7: TCP Coating after Drying

Later in the afternoon of August 14, 2001, the components were painted using MIL-PRF-85582-NC Type II primer from PRC-DeSoto. This primer is flat black in color. On the morning of August 15, 2001, the components were painted with a MIL-C-53039 gray CARC topcoat from Hentzen. Components were allowed to cure until late in the afternoon when they were picked up by a member of the GDAMS team and taken back to the test building. It is important to note that the tight schedule for reworking the components led to only a 6-hour cure for the topcoat. Ideally, the topcoat would be allowed to cure for 24 hours before handling and exposure to a corrosive environment. Painted components are detailed in Figures 5.8, 5.9, and 5.10. All four components were reinstalled on the P1 that evening and painted black for aesthetic purposes.

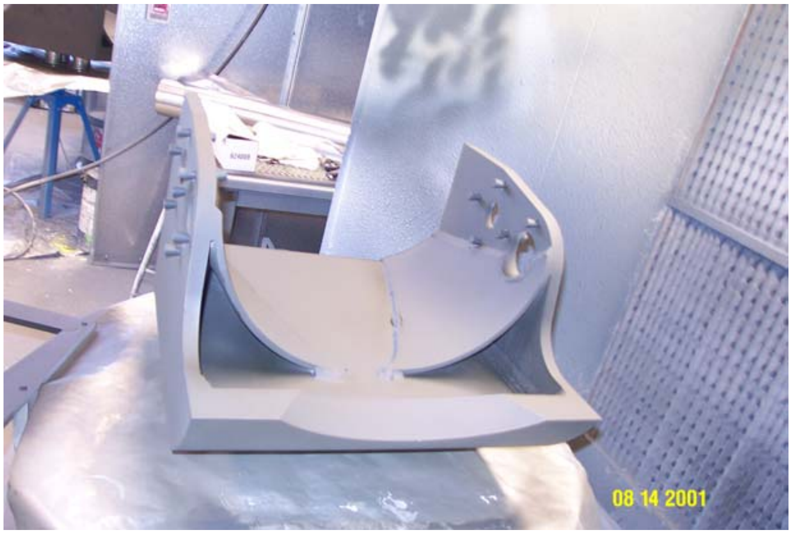


Figure 5.8: Steering Bucket after Priming with MIL-PRF-85582 NC

Figure 5.9: Steering Bucket after Topcoat Application with MIL-C-53039

Figure 5.10: Seal Plate after Topcoat Application with MIL-C-53039

While the components were being painted on the afternoon of August 14, members of the Inorganic Coatings Team (ICT) applied a TCP coating to the mating surfaces of the seal plates on the port and starboard sides where corrosion and adhesion damage had occurred. In addition, the P1 team requested that TCP coating be applied to the port and starboard water jet thrust plates. These areas were cleaned and mechanically prepped by the P1 team. Immediately after being wiped clean with an alcohol wipe, the surfaces were treated with TCP. The TCP was wiped onto the surfaces using a clean cotton rag and allowed to dwell for 10 minutes. Repeat applications of TCP were made after approximately three to seven minutes. No TCP solution ran onto adjoining surfaces. After the dwell, un-reacted solution was wiped from the treated surfaces using a second clean rag saturated with clean DI water. The surfaces were then allowed to air-dry with help from a large fan. That evening, the P1 crew primed these surfaces using MIL-PRF-85582 NC material applied from Sem-pen™ touch-up paint applicators. Figures 5.11 and 5.12 depict the TCP touch-up process.

Figure 5.10: Seal Plate Mating Surface after Corrosion Removal

Figure 5.11: Application of TCP Coating on Seal Plate Mating Surface

5.2.3 – LABORATORY TESTING

Concurrently with the limited initial field testing on the P1, a large laboratory panel test matrix was started at NAVAIR Pax River to determine the optimum surface preparation and pre-paint coating system for processing of later prototype and SDD vehicles at LATP.

This matrix looked at the possible process combinations resulting from using grit-blasted and as-machined surfaces, with and without an alkaline chemical cleaner, and with and without a chemical deoxidation step. Two wash primers at specified thicknesses were evaluated by dry/wet tape adhesion and neutral salt fog (ASTM B117) compared to two non-chromate chemical conversion coating alternatives and a chromate control.

All coating permutations were subsequently coated with either MIL-PRF-85582 N or MIL-P-53022, with MIL-PRF-85582C1 as the chromated control primer.

Mechanical Surface Prep	**Dwell**	**Alkaline Clean**	**Chemical Deoxidize**	**Pretreatment or Wash Primer**	**Primer**	**Test**
Grit Blast	2 hours or 24 hours	None, Turco 4215, or MEK solvent wipe	none or Turco 3003/SmutGo	Aqua Zen (1.0, 2.5, & 4.0 mils)	85582 NC or 53022	Dry, 1,4,7 Day Wet Adhesion or ASTM B117 NSF
Grit Blast	2 hours or 24 hours	None, Turco 4215, or MEK solvent wipe	none or Turco 3003/SmutGo	Kem Aqua (1.0, 2.5, & 4.0 mils)	85582 NC or 53022	Dry, 1,4,7 Day Wet Adhesion or ASTM B117 NSF
Grit Blast	2 hours or 24 hours	None, Turco 4215, or MEK solvent wipe	none or Turco 3003/SmutGo	Slikote (1.0, 2.5, & 4.0 mils)	85582 NC or 53022	Dry, 1,4,7 Day Wet Adhesion or ASTM B117 NSF
As-Machined	N/A	None, Turco 4215, or MEK solvent wipe	none or Turco 3003/SmutGo	Aqua Zen (1.0, 2.5, & 4.0 mils)	85582 NC or 53022	Dry, 1,4,7 Day Wet Adhesion or ASTM B117 NSF
As-Machined	N/A	None, Turco 4215, or MEK solvent wipe	none or Turco 3003/SmutGo	Kem Aqua (1.0, 2.5, & 4.0 mils)	85582 NC or 53022	Dry, 1,4,7 Day Wet Adhesion or ASTM B117 NSF
As-Machined	N/A	None, Turco 4215, or MEK solvent wipe	none or Turco 3003/SmutGo	Slikote (1.0, 2.5, & 4.0 mils)	85582 NC or 53022	Dry, 1,4,7 Day Wet Adhesion or ASTM B117 NSF
Grit Blast	2 hours or 24 hours	None, Turco 4215, or MEK solvent wipe	none or Turco 3003/SmutGo	Alodine 5200	85582 NC or 53022	Dry, 1,4,7 Day Wet Adhesion or ASTM B117 NSF
As-Machined	N/A	None, Turco 4215, or MEK solvent wipe	none or Turco 3003/SmutGo	Alodine 5200	85582 NC or 53022	Dry, 1,4,7 Day Wet Adhesion or ASTM B117 NSF
Grit Blast	2 hours or 24 hours	None, Turco 4215, or MEK solvent wipe	none or Turco 3003/SmutGo	TCP	85582 NC or 53022	Dry, 1,4,7 Day Wet Adhesion or ASTM B117 NSF
As-Machined	N/A	None, Turco 4215, or MEK solvent wipe	none or Turco 3003/SmutGo	TCP	85582 NC or 53022	Dry, 1,4,7 Day Wet Adhesion or ASTM B117 NSF
Grit Blast	2 hours or 24 hours	None, Turco 4215, or MEK solvent wipe	none or Turco 3003/SmutGo	Turco Accelagold (chromate control)	85582 NC or 53022	Dry, 1,4,7 Day Wet Adhesion or ASTM B117 NSF
As-Machined	N/A	None, Turco 4215, or MEK solvent wipe	none or Turco 3003/SmutGo	Turco Accelagold (chromate control)	85582 NC or 53022	Dry, 1,4,7 Day Wet Adhesion or ASTM B117 NSF
Grit Blast	N/A	Turco 4215	Turco 3003/SmutGo	Accelagold, TCP, Alodine 5200	85582 C1	Dry, 1,4,7 Day Wet Adhesion or ASTM B117 NSF

Table 5.2: Coating System Test Variables

The last coating system variable was the control, a fully chromated coating system – using a chromate control primer, MIL-PRF-85582C1 evaluated over the chromate control, as well as a chromated primer control over non-chromate pretreatments Alodine 5200 and TCP.

The process protocols are outlined below.

1. Alkaline Cleaner – Turco 4215 NC LT, 15-minute immersion at 120 ^{0}F
2. Deoxidizer – Turco 3003 TWA 25% by volume, 15-minute contact by spray application at ambient temperature with a Scotch-Brite scrub
3. Desmutter – Turco Smut-Go NC, 30 to 60-second contact by spray application at ambient temperature
4. Primer – Mil-PRF-85582 C and N & Mil-P-53022 were applied at a DFT of 0.9-1.5 mils
5. Topcoat – MIL-DTL-64159 Type II CARC 383 Green for ASTM B117 Neutral Salt Fog
6. Process – Coupons were rinsed thoroughly between each step with ambient DI water
7. Coupons were not allowed to dry out between process steps. This mitigates re-oxidation or contamination of the surface
8. Pretreated surfaces were allowed to dry overnight before primer applications or per technical process instruction for the wash primer products
9. Coupons were top-coated 24 to 48-hours after primer application
10. Grit-Blast with alumina (aluminum oxide) to a 1.0-1.5-mil surface profile
11. Wash Primers were applied at wet film thicknesses of 1.0, 2.5, and 4.0-mils – corresponds to a DFT of 1.0, 1.5, and 2.0-mils

5.2.4 – P1 AND LABORATORY TESTING RESULTS

5.2.4.1 – LABORATORY TESTING

The chemical conversion coatings, Alodine 1200S, TCP, and Alodine 5700 outperformed the wash primers in corrosion and adhesion testing, regardless of primer. Both of the non-chromate conversion coatings averaged better than a “4A” rating in dry and wet adhesion testing by ASTM D 3359, regardless of surface preparation method or subsequent primer coating.

Based on the delamination and blistering issues noticed with the wash primer coating system on the P1, NAVAIR made the recommendation that for this aluminum alloy and operational environment, the EFV program should use a chemical conversion coating as the preferred surface preparation process.

In the laboratory testing, no difference was observed in the corrosion and adhesion performance of the conversion coatings when applied over an as-machined surface compared to a grit-blasted surface. The EFV program decided to pursue a chemical clean and deoxidation process, which is less costly and less time/labor intensive than an abrasive blast process. The performance of the wet processed TCP/MIL-PRF-85582 NC coating system merited additional investigation and validation of the process and coating system for potential implementation by GD for the EFV program. Early performance feedback led to discussions of potentially using a wet process for new hulls as well as evaluating TCP in other EFV applications including the track cover door, sprocket carriers, idler wheels and hull touch-up.

5.2.4.2 – PERFORMANCE OF INITIAL COMPONENTS WITH TCP ON EFV P1

NAVAIR personnel visually inspected the performance of the new coatings after one, two, four and six week intervals. Feedback was also garnered from the P1 crew. At each interval there was no evidence of corrosion, paint blistering or other coating problems. Figures 5.13 and 5.14 show the starboard steering bucket and seal plate on EFV P1 after 2 weeks in service on the platform. The performance of the pretreated components on the P1 was significantly better than the original coating system, and the vehicle was re-worked with a full conversion coating system. Since the re-coat chemicals were hand applied, one half of the vehicle was coated with a chromate control system and the other half was a non-chromate test system.

Figure 5.13: Starboard Steering Bucket and Seal Plate after 2 Weeks in Service

Figure 5.14: Inside of Starboard Steering Bucket after 2 Weeks in Service

5.2.5 – SDD VEHICLE HULL AND TURRET PROCESSING

5.2.5.1 – BACKGROUND

The SDD phase of this new acquisition program began in 2000, with the production and processing of E1 at LATP. Ten vehicles were planned for the SDD phase, nine “E” variants – standard model squad amphibious vehicle, and 1 “C” variant – a commander’s vehicle, lacking the 25mm gun on the turret but with an upgraded communications and electronics package. Based on the outcome of the early laboratory testing and the initial field test data on the P1 components, Alodine 5700 and TCP were selected as the non-chromate conversion coating alternatives. One SDD vehicle was planned for a fully chromated coating system.

5.2.5.2 – INITIAL PROCESSING

A representative from NAVAIR was present at LATP for the processing of the first SDD EFV – E1. GDAMS and Henkel Surface Technologies (HSTNA) – maker of the Alodine™ product line and main chemical supplier for LATP – were also present for on-site technical support. The E1 process used an alkaline cleaner already stocked at LATP for cleaning of painted steel surfaces, and an aerospace standard phosphoric acid deoxidizer with a mild, nitric-acid desmutter for surface preparation. The E1 vehicle was sprayed with Alodine 5700 using 2-gallon plastic garden sprayers. Several spray processing recommendations were made by NAVAIR and HSTNA, and these changes were incorporated into the process for the next vehicle.

5.2.5.3 – PROCESSING

When initial prototype and SDD manufacture began for this program, LATP did not have any experience with aluminum finishing. The original prototype vehicles were mechanically prepared and wash primed with the same process as that employed for steel substrates. Additionally, the use of a newly designed aluminum alloy, AA2519-T87, meant that there was a large learning curve to overcome in the pretreatment of these vehicles. The first few vehicles in SDD exhibited cohesive adhesion failures occurring at the primer metal interface. This indicated a possible problem with the conversion coating process. The original chemical process needed improvements in chemical selection, application temperatures, and greater attention to detail in chemical dwell times and rinsing parameters.

The first issue, resolved after the processing of E1, was the use of the 2-step deoxidation/de-smutting process originally suggested by NAVAIR. While this process worked well in the laboratory tests, it was found to be too time and labor intensive for a manual spray process application. By the time the chemicals were finished being applied, the first area would be dry, allowing for the deposition of chemical contaminants and/or re-oxidation of the aluminum substrate. Laboratory testing was conducted at NAVAIR to look at milder, slower acting single-step deoxidizers that would not cause extensive smutting of the surface, even at longer dwell times. Ridoline™ 4450, a citric/dilute hydro-acetic acid mix was selected as the giving the best clean, oxide free surface without smutting. E2 was processed using the Ridoline 4450.

The next issue was the use of the K-56™ cleaner, where it was observed that even after several cleanings, the aluminum did not exhibit a uniformly water-break free surface. A water-break free surface indicates the high-surface tension of the metal when it is free of organic contaminants such as machining oils, dirt, and fingerprints. HSTNA suggested the use of a cleaner, Aerowash™, specifically designed for cleaning aluminum alloys. The transition was made to the use of Aerowash before E4; however, it was noted that the Aerowash's cleaning capability was greatly diminished when not used at an elevated temperature.

Figure 5.15: EFV E3 Spray Processsing – LATP

For quality control, several adhesion tests were conducted for each vehicle, in accordance with ASTM D 3359 Procedure B, to ascertain the consistency of the processing and the quality of the conversion coating. Adhesion issues were seen up to SDD vehicle E4, as the process parameters were gradually optimized. It was noted that the third SDD vehicle, C1, had the best overall adhesion (though still not in keeping with performance levels suggested by laboratory testing). This vehicle experienced the shortest dwell times and most consistent rinsing of the early demonstrations. This suggested that with proper process control and optimization, high performance could be achieved with the selected non-chromate pretreatments. Between E4 and E7, several significant changes were made to the process chemicals and controls. E6 was the chromate control vehicle, and no adhesion or processing issues were experienced. E7 was processed with the non-chromate system, TCP and MIL-P-53022.

5.2.5.4 – E7 PAINT ADHESION RESULTS

There were no adhesion issues observed with E7. The processing dwell times were exactly within the optimum range and the TCP solution was diluted to 30% by volume instead of the usual 50% by volume. This may have lowered the solution activity, making the conversion coating reaction less restrictive on dwell time.

5.2.6 – PROCESSING – CURRENT PROCESS

5.2.6.1 – E8

Processing for the E-08 began on 15 March 2004. Table 5.3 outlines the pretreatment steps for the EFV E8 including alkaline cleaning, deoxidizing and application of TCP. A four-man crew was used. All adhesion test results were ratings of 4A or better.

Time	Notes
0845	Rinsed pumps, hoses and vacuum tubes. Filled rinse barrel. Retrieved a degrease can on top of the vehicle. K-56 wash only at de-burr station. Very little filings. Spray cleaned with hot Aerowash™.
0853	Begin Aerowash™.
0909	Finish Aerowash™. Good foamy coverage.
0930	Finish rinse. Stress high volume, low pressure for rinsing vehicles.
0935	Vacuum out water. Three new drain holes on this vehicle resulted in less water being trapped after rinsing. Will do a double rinse after deoxidizing – first quick rinse to dilute the chemical and a second longer rinse to focus better on coverage and inserts.
0945	Break.
0950	Chips and shavings appear to have collected at the two rear central floor panels. Vacuumed prior to deoxidizing.
1015	Begin deoxidization using Ridoline 4450™. Start from bottom of vehicle and work up.
1029	Begin first rinse.
1032	Begin second rinse focusing on inserts.
1050	Vacuum out all water.
1102	Begin TCP application. Start from the bottom and work up the vehicle. Apply on outside of vehicle, then inside of vehicle and finally a quick second coat on the outside.
1125	Begin Rinse.
1145	Final DI water rinse.

Table 5.3: Outline of E8 Processing

5.2.6.2 – E9

Time	Notes
0834	Started Aerowash. Began in front, then below hull, up the sides to the top and then inside.
1005	Completed Aerowash. Total Aerowash time – 45 minutes
1010	Rinsing started.
1035	Rinsing finished. Nice water break-free surface.
1040	Excess water vacuumed out of hull from areas where it had collected. Set-up Ridoline 4450 spray wands and pump hoses. Two 2.5 gal/min. pumps were to be used.
1048	Vacuuming complete.
1216	Began spraying Ridoline 4450. 4450 application approximately 25 minutes.
1241	Began rinse. Rinse overlapped approximately one minute more of 4450 application.
1302	Finished rinsing. Total rinse time ~ 20 minutes.
1309	Begin TCP-cc2 spray.
1331	Completed TCP-cc2 application.
1332	Began fire hose rinse.
1347	Finished fire hose rinse.
1349	Began DI water rinse.
1404	Finished DI water rinse.

Table 5.4: Outline of E9 Processing

This was the first vehicle to receive a spray application of TCP-color. TCP-color is a pH-stabilized formulation of the TCP used on the previous vehicles. TCP-color also incorporates additional chemistry that enables a color change upon the treated areas for an easier visual confirmation of the application. Previous laboratory studies showed a dark purple/brown color on treated areas when using an immersion application process. High-pressure spray application could not be suitably tested within the laboratory environment prior to use on the vehicle.

After TCP-color application, a visible color change was not observed. A darker brown/gray coloring was visible in areas where TCP streaked/ran off from inserts. See Figure 5.16. This same coloring could also be seen where TCP pooled in pocketed areas of the vehicle. An overall very slight smoky appearance could be seen on the vehicle. The iridescent appearance from the non-color change TCP was more evident than the observed color change from the TCP-C application. The dark colored streaking and well areas were examined the following morning and a powdery coating was not present in those areas. Regardless of film coloration, no adhesion failures were seen with this vehicle.

Figure 5.16: Minimal TCP Color Change Observed Near Inserts

No adhesion performance differences were noted between the chromate control vehicle, E6, and the latter SDD vehicles. Several process iterations were used in this demonstration with various results, until the optimum chemicals and parameters were found. This indicates the importance of repeatability and quality control in the validation of these non-chromate alternatives. Table 5.5 outlines the chemicals, pretreatments, and paint systems used in the SDD phase of the EFV program and shows the gradual optimization of the coating system.

Paint Plan as of 02/03/03

SDD Vehicle	Cleaner	Deox	Pretreatment	Primer	Exterior Top Coat	Interior Top Coat	Build Order
E1	K-56	Turco 3000/Turco Smut-go	Alodine 5700	MIL-PRF-85582 - NC	MIL-PRF- 64159 TyII CARC	MIL-PRF-22750	1
E2	K-56	Ridoline 4450	Alodine 5700	MIL-PRF-85582 - NC	MIL-PRF- 64159 TyII CARC	MIL-PRF-22750	2
C1	K-56	Ridoline 4450	NAVAIR - TCP	MIL-P-53022	MIL-PRF- 64159 TyII CARC	MIL-PRF-22750	3
E3	Aerowash	Ridoline 4450	NAVAIR - TCP	MIL-PRF-85582 - NC	MIL-PRF- 64159 TyII CARC	MIL-PRF-22750	4
E4	Aerowash	Ridoline 4450	Alodine 5700	MIL-P-53022	MIL-PRF- 64159 TyII CARC	MIL-PRF-22750	5
E5	Aerowash	Ridoline 4450	NAVAIR - TCP	MIL-P-53022	MIL-PRF- 64159 TyII CARC	MIL-PRF-22750	6
E6	Aerowash	Ridoline 4450	Alodine 1200S - Hex Cr	MIL-P-23377 - C	MIL-PRF- 64159 TyII CARC	MIL-PRF-22750	7
E7	Aerowash	Ridoline 4450	NAVAIR - TCP	MIL-P-53022	MIL-PRF- 64159 TyII CARC	MIL-PRF-22750	8
E8	Aerowash	Ridoline 4450	NAVAIR - TCP	MIL-P-53022	MIL-PRF- 64159 TyII CARC	MIL-PRF-22750	9
E9	Aerowash	Ridoline 4450	NAVAIR - TCP	MIL-P-53022	MIL-PRF- 64159 TyII CARC	MIL-PRF-22750	10

Alodine 5700 and TCP are Non-hexavalent chromium conversion coatings
MIL-P-53022, and MIL-PRF-85582 N are Non-hexavalent chromium primers.
E6 is a fully chromated system - this is the control vehicle

Table 5.5: SDD PAINT PLAN

5.2.7 – CURRENT PROCESS – LRIP

The chemical process will be as finalized in the SDD phase: standard aluminum process, spray clean – 100+ ^{0}F, mildly-alkaline, non-etching, non-silicated cleaner; spray deoxidize – ambient, non-smutting citric/acetic acid solution; spray conversion coating – ambient TCP or Alodine 5700.

The current manual spray process – 3-4 man team, 6 hours start to finish is planned to be replaced in Low Rate Initial Production (LRIP) with an automated, car-wash style spray processing line for clean, prep, and conversion coating application.

Alkaline Cleaner	Aerowash 10% vol. 100 F
Deoxidizer	Ridoline 4450 10-15 minute dwell
Pretreatment	TCP 30-50% vol. 10-15 minute dwell
Primer	MIL-P-53022 CARC white
Topcoat (Interior)	MIL-C-22750 seafoam green
Topcoat (Exterior)	MIL-DTL-64159 TyII CARC 383 Green or Tan

Table 5.5: Target coating system for EFV LRIP

5.2.8 – PROTOTYPE AND SDD VEHICLES FIELD TESTS

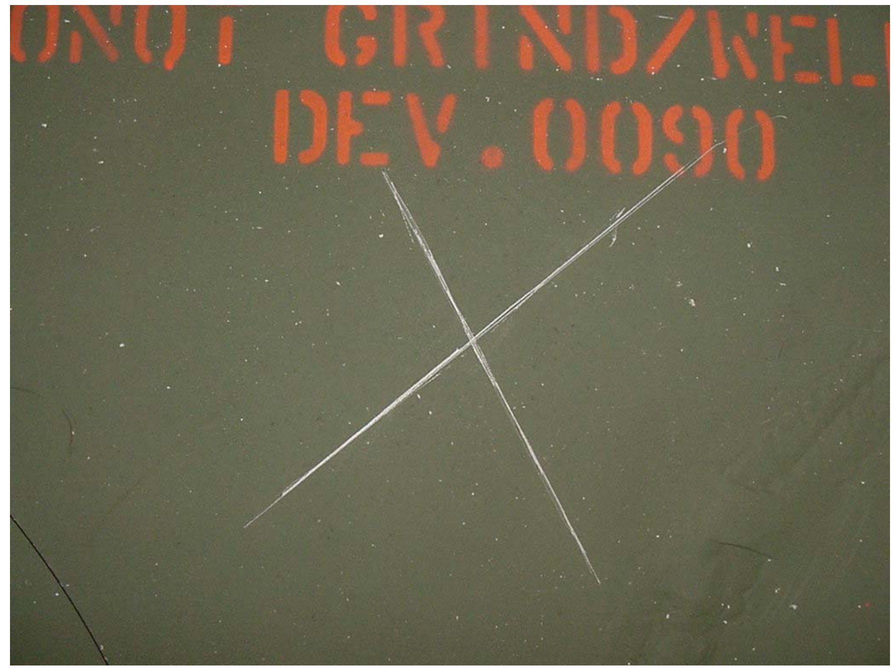
5.2.8.1 – P1 - PERFORMANCE OF CHROMATED AND NON-CHROMATED SYSTEMS ON USMC-EFV P1

P1 and P3 were stripped and repainted by a third-party, industrial painter using chemical conversion coating as the surface preparation before field testing, because of the corrosion and paint adhesion issues experienced with the prototype vehicles. Both vehicles had a fully chromated test coating on the starboard side that was compared to a non-chromated coating system, using TCP as the pretreatment, on the port side.

Before the P1 vehicle was fielded at the USMC Amphibious Vehicle Test Branch (AVTB) at Camp Pendleton, the paint system was scribed through in an “X” pattern at several locations on the hull. The main scribe location was forward on the lower side-wall of each vehicle. This area is subject to scrapes and dings during land movement, and is fully submerged when the vehicle is in the water. The initial inspection of P1 was conducted at 4 months, at AVTB. Preliminary results indicated that the non-chromate system was keeping pace with the chromated products. The next inspection was conducted at roughly 1 year of testing, in August 2003.

P1 Non-chromate vs. chromate Testing Results

Non-Chromate



Chromate

Figure 5.17: P1 – 4 Months In-Water Testing

Craig Matzdorf, NAVAIR, visited the AVTB on the morning of August 6, 2003 and observed corrosion issues on the forward scribed areas on each side of the P3 hull. A field observation was conducted and photos were taken of interior and exterior examples of corrosion.

The forward scribed area on each side of the hull of the USMC-EFV P1 was observed. The chromated coating showed no corrosion whatsoever, with the scribes remaining bright and shiny. The non-chromated coating showed some white corrosion product in the scribe and one or two small corrosion pits. No undercutting or damage was noted away from the scribes. The other general areas that were visible showed no difference in performance on either side.

Of note is that the vehicle was parked facing north and the port side (with the non-chromate system) was very wet under the flaps. The starboard side (with the chromate system) was dry. This may be due to the washing schedule and how much sun the EFV gets after rinsing. If the port side is typically wet longer, the corrosion potential is far higher than for the starboard side. This must be taken into account when comparing the coating systems. It was suggested that AVTB personnel be questioned regarding the rinsing protocol and whether the port side does typically stay wet longer, before or after rinsing.

It was noted that the steering buckets and brackets around them on both sides were different than previously and had large unpainted areas that were beginning to surface corrode and pit. It was recommended that these surfaces be cleaned of corrosion, treated with TCP, primed and top-coated as soon as possible to prevent further degradation.

Figure 5.18: P1 Inspection – C. Matzdorf at AVTB, Camp Pendleton – August 2003

P1 was inspected by Bill Nickerson of NAVAIR and Kevin Clark of GDAMS at the GDAMS Woodbridge, VA facility on February 19, 2004. Again, similar surface corrosion and paint adhesion performance was observed between the fully chromated and fully non-chromate coating systems.

One area of concern was noted in the performance difference with respect to galvanic corrosion. The non-chromate system exhibited significantly more corrosion around dissimilar metal interfaces than did the chromated coating system. It was noted that the non-chromate system was MIL-PRF-85582 N primer, a water-reducible non-chrome epoxy primer; while the chromated side was MIL-PRF-23377 C2 primer, a solvent-reducible chromated epoxy primer.

Subsequent laboratory testing confirmed that the large discrepancy in galvanic protection was a property of the primer system. The MIL-P-53022 solvent-reducible non-chrome epoxy primer performed very similarly to the MIL-23377 C2 primer; leading to the conclusion that a solvent-based primer, regardless of chromate content, was preferable for galvanic corrosion protection due to increased barrier protection against moisture ingress compared to water-based primers for use on the EFV platform.

5.2.8.2 – E2 AND E7 – IN WATER TESTING, AVTB, CAMP PENDLETON, CA

EFV SDD Vehicles E2 and E7 were inspected by Bill Nickerson, NAVAIR, and Kevin Clark, GDAMS, along with Subra Bettadapur, DRPM AAA, at AVTB, Camp Pendleton on May 24, 2004. These vehicles have been undergoing in-water testing and evaluation at the Amphibious Vehicle Test Branch, Camp Pendleton, CA for almost 2 years.

Both of these vehicles were spray processed at the LATP facility with a non-chromate alternative conversion coating, and painted with a non-chromate primer and CARC topcoat.

E2 was processed as follows:

1. Clean with K-56 alkaline cleaner
2. Deoxidize with Ridoline 4450
3. Pretreat with Alodine 5700
4. Prime with MIL-PRF-85582 N
5. Topcoat with MIL-DTL-64159 TyII

E7 was processed as follows:

1. Clean with Aerowash
2. Deoxidize with Ridoline 4450
3. Pretreat with TCP
4. Prime with MIL-P-53022
5. Topcoat with MIL-DTL-64159 TyII

It was observed that both vehicles had areas of paint loss due to scraping and gouging caused by rocks and debris around track areas, and on the lower anterior-hull from abrasion during water-to-land movements. Figure 5.19 shows severe scraping damage on the lower anterior-hull of E7 – no additional undercutting from the damaged areas is evident.

Figure 5.20: E7 Lower Anterior Hull

Figure 5.21 shows a cross-hatch scribe area on E7 from the initial QC paint adhesion inspection at LATP – no undercutting or peeling of the paint system from the scribe was observed. No corrosion product was evident in the scribed area.

Figure 5.21: E7 Cross-hatch Scribe

E2 exhibited significantly more corrosion, additional undercutting, paint adhesion problems from damaged areas than did E7. Figure 5.22 shows paint chipping on E2's top, port side, in front of the driver's hatch. This area sees a high volume of traffic, but similar damage was not evident on the E7.

Figure 5.22: E2 Driver's Hatch

It is important to note that E2 was processed much earlier in the SDD cycle than was E7, and some paint adhesion issues in QC testing after processing were noted even before field testing. E7 had perfect paint adhesion test results after processing. The biggest factor was the processing differences, as E2 was still cleaned using the K-56 product, which is not designed for aluminum substrates. After the processing of E2, it was agreed by consensus that a water-break-free surface must be achieved before continuing with the chemical processing.

The field tests bear out the absolute criticality of applying the chemical conversion coating with the proper process controls and parameters. Once the proper chemicals and process checks were in place, such as wetting the surface after cleaning to ensure water-break free surface and good attention to chemical dwell times during processing, no paint adhesion issues have been reported. E7, E8, and E9 vehicles all passed the QC paint adhesion inspection at LATP and the non-chromate coating system is performing very well on E7 in field testing.

5.2.8.3 – STATUS

The EFV program is scheduled to begin LRIP in early FY06. TCP has been selected as the pretreatment for the processing of the hulls and turrets. Both TCP and Alodine 5200/5700 have been approved for use on components by GDAMS and their vendors. The USMC AVTB is currently using Alodine 5700 pre-saturated wipes for coating system maintenance and repair touch-up applications on the SDD vehicles fielded there.

5.3 –US ARMY BRADLEY FIGHTING VEHICLE

5.3.1 – INTRODUCTION

The US Army's M2 Bradley Fighting Vehicle entered production by United Defense in 1980. Originally, this program utilized a chromate conversion coating applied by immersion process to enhance corrosion resistance and paint adhesion on aluminum hull, turret, and armor components.

The United Defense facility possesses an automated hoist and immersion system, whereby an entire hull can be lifted and dipped through the 32,000-gallon process tank line in 2.5 – 3 hours. The process line utilized Chemetall-Oakite™ brand chemicals, and consisted of a mildly alkaline non-silicated cleaner, a hot phosphoric acid etch, a ferric sulfate/nitric acid based de-smut, and finally the chromate conversion coating. Each step in the process was followed by a halo-spray, clear water rinse. This line is not currently in use.

UDLP-York, the OEM, is still upgrading and retrofitting BFV's to the new M2A3, M3A3 variations. In depot maintenance and rework efforts, it was noticed that the aluminum armor alloy, AA7039, evidenced severe intrametallic delamination probably caused by environmentally assisted stress corrosion cracking (SCC). The decision was made to move to a manual surface prep method, as it was thought that the immersion process trapped moisture in small cracks and tight areas on the vehicles, thereby accelerating the delamination. The PM CS Environmental Management Team (EMT) has suggested an SCC evaluation of AA7039 with the current process versus an immersion process using both chromate control and TCP to ascertain the differences, if any, between the chemical immersion or manual surface preparation methods.

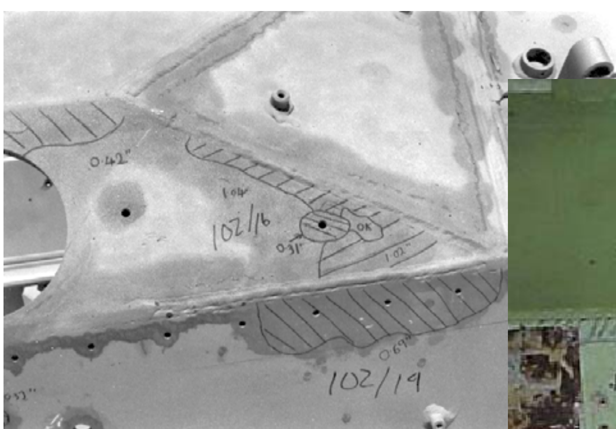


Figure 5.23:
Delaminations on BFV Hull
Components – AA7039

The current repair procedure for SCC damaged parts on re-man BFV's is as follows: abrasive media blast, weld repair visible surface cracking, leave existing delaminations as is, perform weld and machining modifications, steam clean/pressure wash, bake/dry hulls at 180-200 ^{0}F, abrasive blast, prime, and topcoat.

The manual surface preparation, direct-to-metal (DTM), involved grit-blasting the hulls and turrets to a 1.5-3.0 mil surface profile to enhance paint adhesion. The DTM process increases the corrosion performance through adding surface area with the roughened profile thereby increasing adhesion of primer/paint systems to the substrate; however, the mechanical surface modification offers no active corrosion inhibition beyond that supplied by the primer inhibitors. Mechanical bonding helps protect from undercutting at damaged areas, but offers no protection from surface corrosion where paint is removed at damaged areas. Additionally, the same delamination SCC issues have been observed with AA7039 as were observed with the original chemically processed vehicles.

The current DTM process affords reduced corrosion protection versus a chemically conversion coated surface and has not been seen to eliminate or reduce the SCC of the armor components. A chemical coating process also gives the extra benefit of being a faster, and much less labor-intensive process. This allows for uniform surface preparation, even in corners, bolt-holes, and other areas inaccessible to grit-blasting. The DTM process is also more costly and time-consuming than the chemical process – which cleans, etches, and prepares the surface at the same time. The chemical process could save roughly 4-hours of labor costs per vehicle.

Direct-to-Metal	**Chemical Processing**
Abrasive blast – Paint removal	Abrasive blast
Weld repair cracks	Weld repair cracks
Perform weld and machining modifications	Perform weld and machining modifications
X Steam clean/pressure wash	
X Bake hulls prior to paint at 180-200F	
X Abrasive blast – Surface Prep	→ Immersion application of MIL-C-5541 TCP
Prime	Prime
Topcoat	Topcoat

Table 5.7: DTM vs. chemical processing

UDLP would like to re-instate the old conversion coating process, but a return to the chromate-based chemistry is now prohibited by environmental and health & safety regulations. The BFV program office, along with the OEM, is seeking a viable, non-chromate aluminum pretreatment for implementation on re-manufactured Bradley Fighting Vehicles. Being able to return to a chemical surface preparation method will yield a performance increase and a cost savings to the program. An added bonus to the OEM would be to conserve an uncommon resource in having a high volume process line capable of treating entire hull structures by immersion. As a result, the BFV was added to the NCAP project as a high-value demonstration platform; with a very high likelihood of implementing a non-chromate pretreatment.

5.3.2 – COMPONENT SELECTION

PM Combat Systems (PMCS) and NAVAIR generated a list of selection criteria for the demonstration/validation components. A group of ten BFV parts were selected for NCAP Phase II testing. NAVAIR's TCP conversion coating was selected by the PMCS Environmental Management Team (EMT) as the demonstration technology for these field evaluations.

The test components met the following criteria:

- Common to M2A3, M3A3, and M3A3 BFIST vehicles
- Material: AA5083 or AA5086
- Pretreatment: DTM (no conversion coating) or with MIL-C-5541 Class 1a or 3
- Modular - easily removed and replaced (bolt-on)
- Not a safety critical item
- Sized to fit within a 2 cubic foot space

To ensure the greatest possible range of performance evaluation, the parts were selected to expose the alternative pretreatment to a wide stress environment; including sun/weathering, abrasion, flexing, non-skid, electrical bonding, cemented cushion/seal material, heat, water.

Both interior and exterior parts were selected, allowing for evaluation of the pretreatment with both coatings systems in use on BFV's. Table 5.8 lists the primer/paint systems for interior and exterior applications.

COMPONENT	CURRENT PRETREATMENT	PRIMER	TOPCOAT
Exterior	None	MIL-P-53022 Solvent Reducible, Epoxy CARC, White	MIL-C-53039A Solvent-based, 1K, Moisture-cured, 1.5lbs VOC, Polyurethane CARC, 686 Green or 686 Tan*
Interior	None or Class 1A chromate	MIL-P-22750 Solvent Reducible, Single-coat, Epoxy CARC, Sea-foam Green	

*Note: for this field evaluation, all exterior parts were top-coated with 686 Tan

Table 5.8: BFV Paint Systems

The ten components selected are listed in Table 5.9 by part number and description. For this demonstration, all exterior components are currently DTM processed.

NO.	PART NO.	DESCRIPTION	LOCATION	SURFACE TREATMENT	CARC PAINT
1.	12369237	Guard, headlight right	Hull exterior - front glacis	None	Exterior
2.	12369239	Guard, headlight left	Hull exterior - front glacis	None	Exterior
3.	12297423	Floor Plate, Bilge Pump *	Hull interior - driver's station	Class 1A MIL-SPEC-5541	Interior
4.	12297676	Door, Stowage Box, Right * ****	Hull exterior - on right rear	None	Exterior
5.	12297915	Door Assembly, Stowage Box. Left Side * ****	Hull exterior - on left rear	None	Exterior
6.	12307386	Steering Wheel (yoke)	Hull interior - driver's station	None	Interior
7.	12307324	Plate, Floor, Left Hand **	Turret interior - basket floor	Class 1A MIL-SPEC-5541	Interior
8.	12307255	Holder, Flagstaff	Turret exterior - atop primary sight "dog house"	None	Exterior
9.	12976354	Antenna Bracket	Turret exterior - atop bustle	None	Exterior
10.	12469917	Bracket, Mounting, vehicle motion sensor	Hull interior, inside power plant compartment	None	Interior

* Cushion/gasket material cemented to part after painting
** Nonskid applied to part before painting.
*** Requires insert p/n 12307422
**** Stowage box and door used for re-man parts to avoid fit-up problems
Due to time and availability constraints the re-man component set did not contain Part No.s 3, 9, or 10

Table 5.9: Selected BFV Non-chromate Pretreatment Field Test Components

Figure 5.24: Headlight Guards

Figure 5.25: Stowage Box Doors

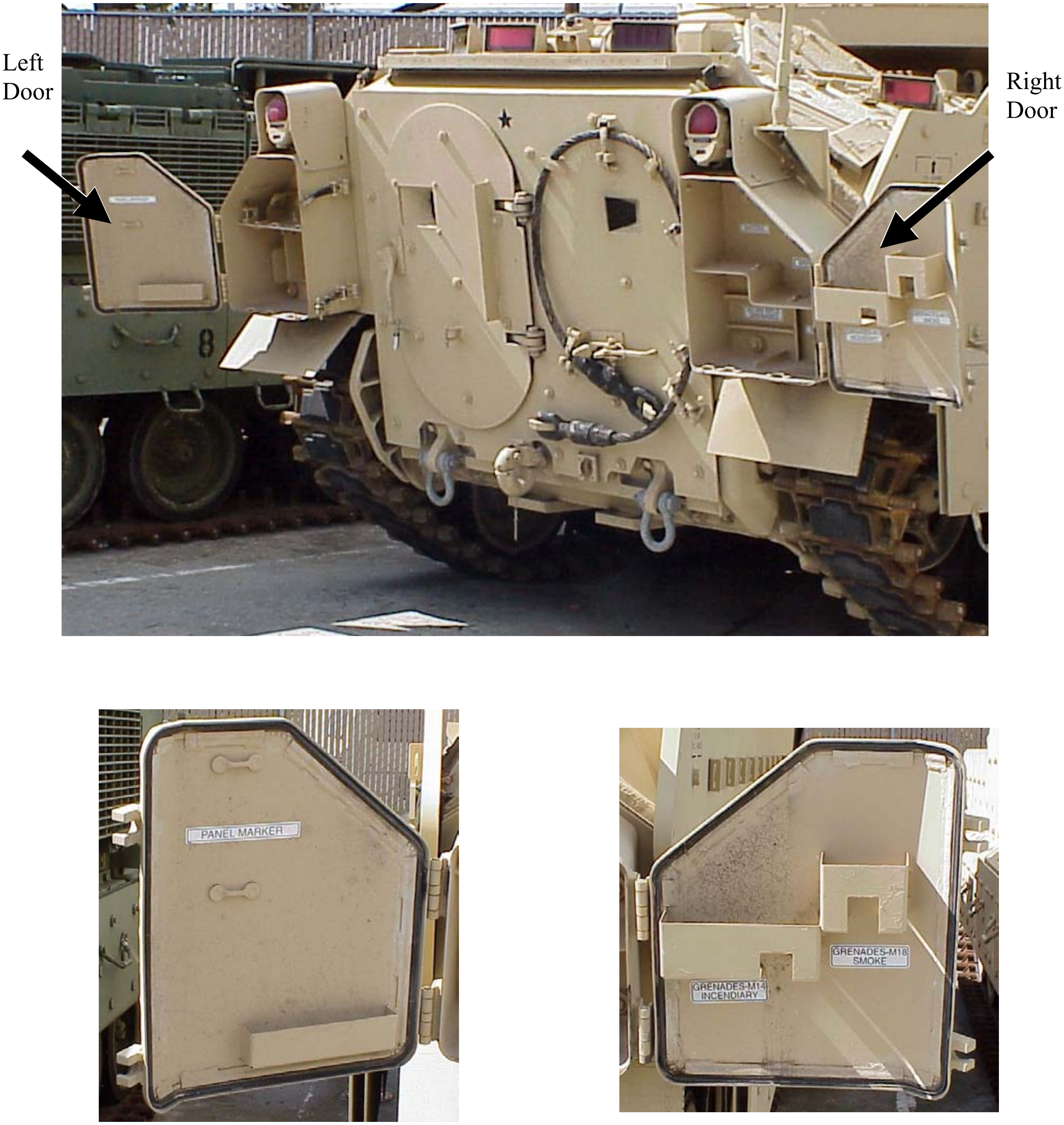


Figure 5.26: Floor Plate, Bilge Pump

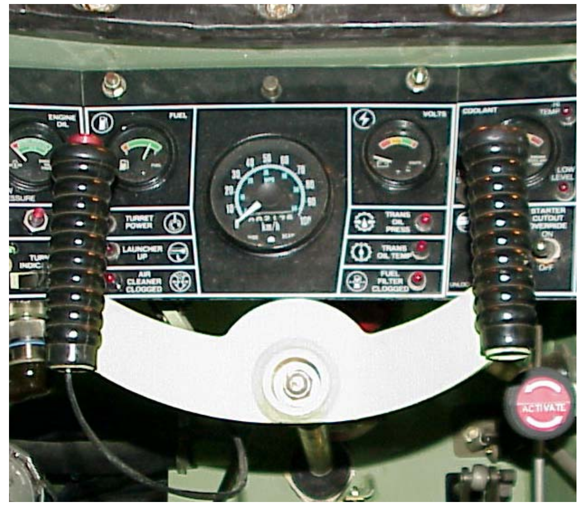


Figure 5.27: Driver's Steering Yoke

Figure 5.28: Turret Left Floor Plate

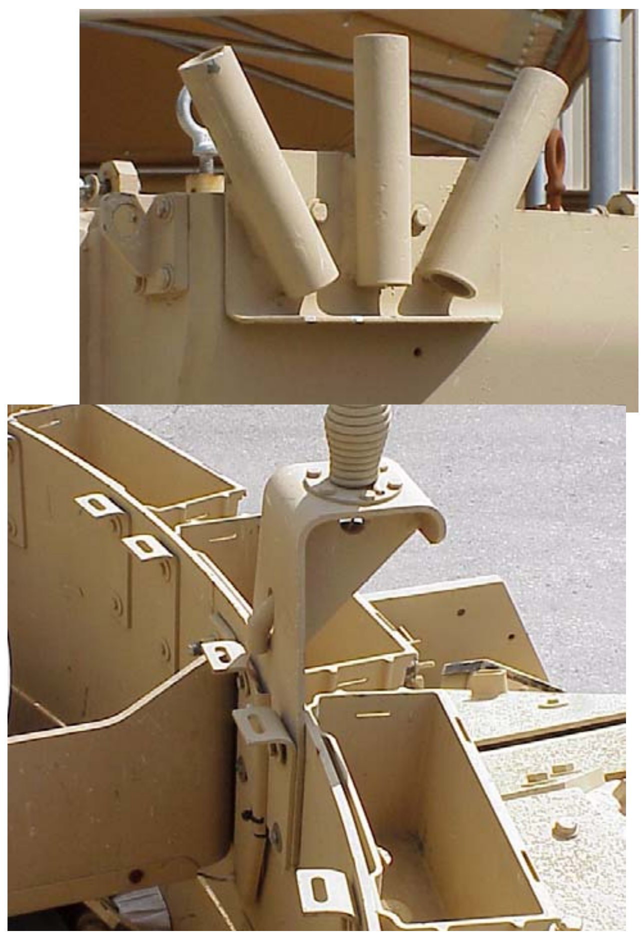


Figure 5.29: Flagstaff Holder (Top R) and GPS Antenna Bracket (Lower R)

5.3.3 – PROCESSING

5.3.3.1 – COMPONENTS

Two sets of new components were procured and shipped to Patuxent River, MD in August 2003. One of the identified components in the sets was not treated at that time, as the component was plated steel that had been chromated by the vendor before procurement by the program office. This component, Part No. 12469917, Bracket, Mounting, Vehicle Motion Sensor, was subsequently dropped from the test matrix, and was not evaluated during field testing.

NAVAIR pretreated the components by an immersion process, using the same chemical products as used in the processing line at the York, PA facility. Heather McNabnay, Environmental Coordinator, PM Ground Combat Systems, and Tom Braswell, Floor Support Engineering, UDLP-York were on hand to observe and assist in the pretreatment. Table 5.10 outlines the pretreatment process.

PRODUCT NAME	CHEMICAL DESCRIPTION	PROCESS TEMPERATURE	IMMERSION TIME
Oakite NST 10%	Mild alkaline, non-etching, non-silicated cleaner	120-130 F	6 minutes
Oakite 33 12.5%	Phosphoric acid etch	117-120 F	6-12 minutes
Oakite LNC 10%	Dilute acid/ferric based desmutter/brightener	Ambient	30 seconds –2 minutes
TCP-CC	Non-chromate conversion coating with color change	Ambient (80 F)	5-15 minutes

TABLE 5.10: BFV Components Process Parameters

Mr. Braswell primed the components within 24-hours of conversion coating, and top-coated the exterior components within 48-hours of priming. The interior components were sprayed with a single-coat, solvent-reducible, epoxy CARC. The exterior components were primed with a solvent-reducible, epoxy CARC primer and top-coated with a single-component, moisture-cured, polyurethane CARC.

At the PMCS EMT meeting October 2003, a concern was raised about the validity of only testing new components, when in fact the majority of BFV's and BFV parts are re-manufactured. Re-man parts will be blasted or ground to remove old paint, corrosion, or other surface damage before re-work and painting operations take place. This distressed surface is much rougher and less uniform than the neat, machined surface of a new part.

As a result, a third set of components was procured; these being removed from fielded vehicles recently arrived at UDLP-York for re-manufacturing. This set of components included a right and left storage box in lieu of the right and left storage box doors in the two sets of new components. The parts were shipped to Patuxent River, MD in November 2003. Several areas on each part were ground down to bare aluminum using a typical grinder and 120-180 grit grinding wheel. The re-man parts were then pretreated in accordance with the procedures in Table 5.10, by NAVAIR and UDLP personnel.

The re-worked components from set three were then primed over the newly conversion coated areas, and the entire part was then top-coated; the paint system was the same as in the first two sets.

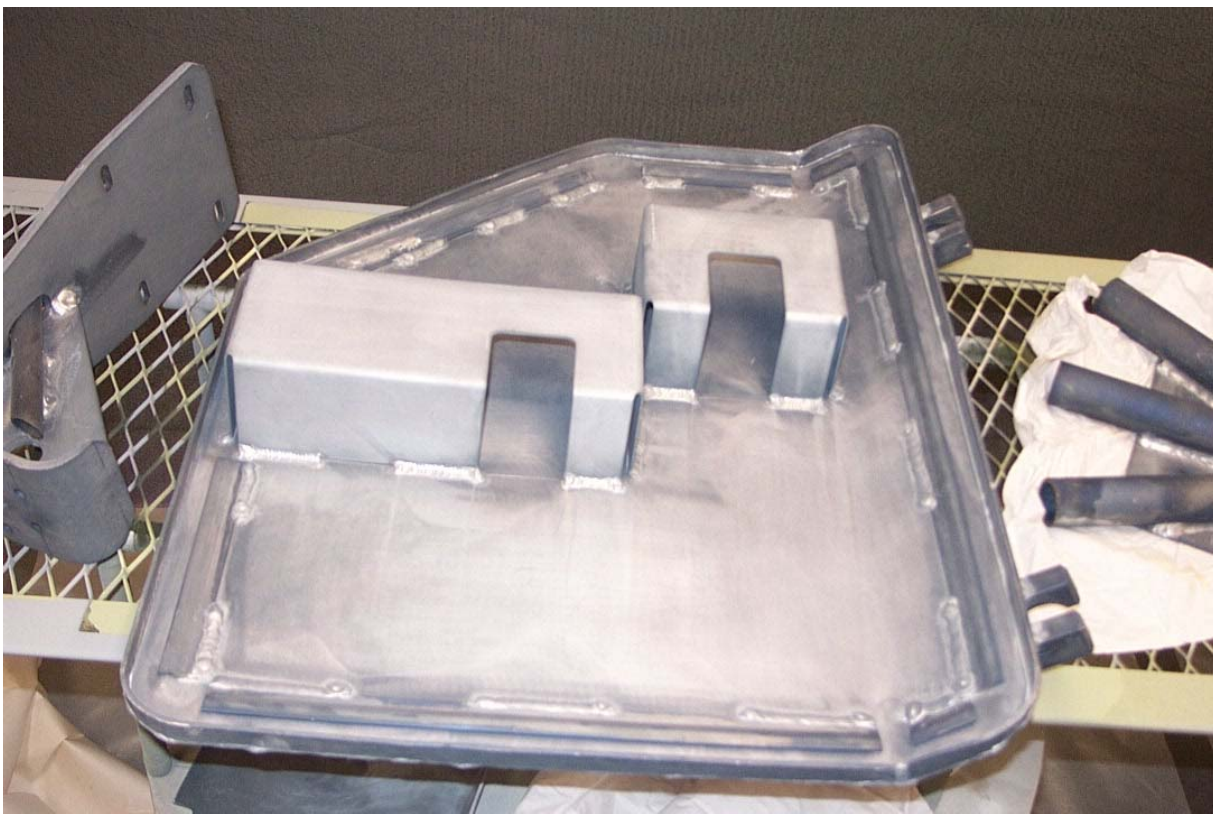


Figure 5.30: TCP-C BFV Components Awaiting Primer Application – August 2003

Figure 5.31: Primer Application – Left Headlight Guard – August 2003

Figure 5.32: Interior Components after Application of Single-Coat, Sea-Foam Green Epoxy CARC – August 2003

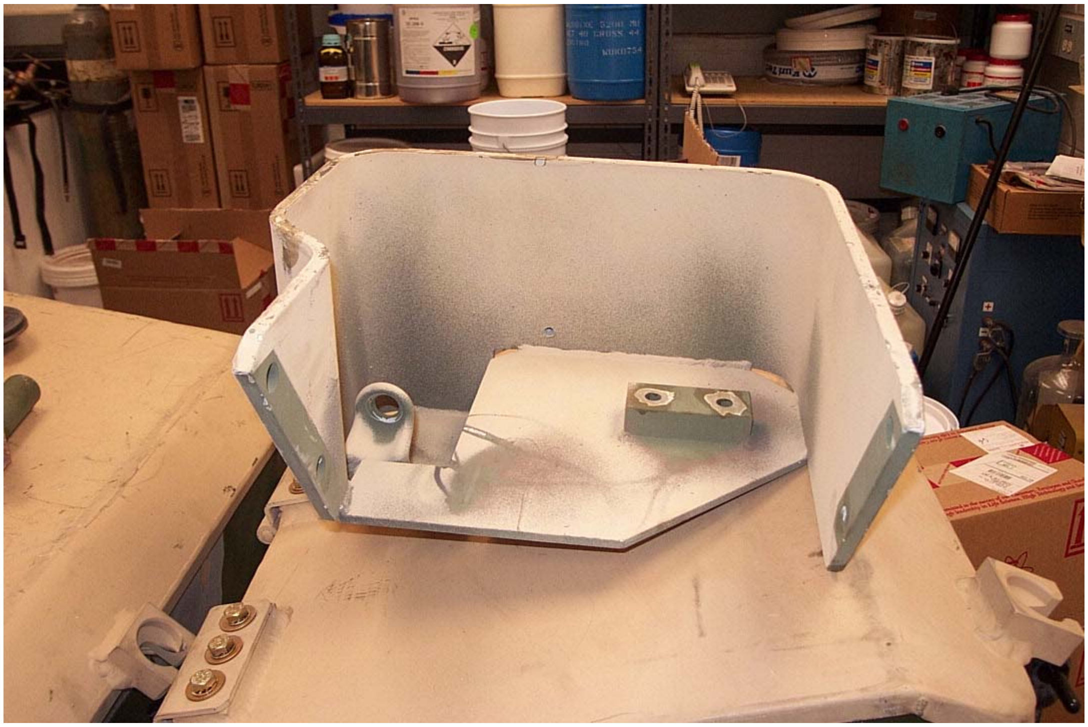
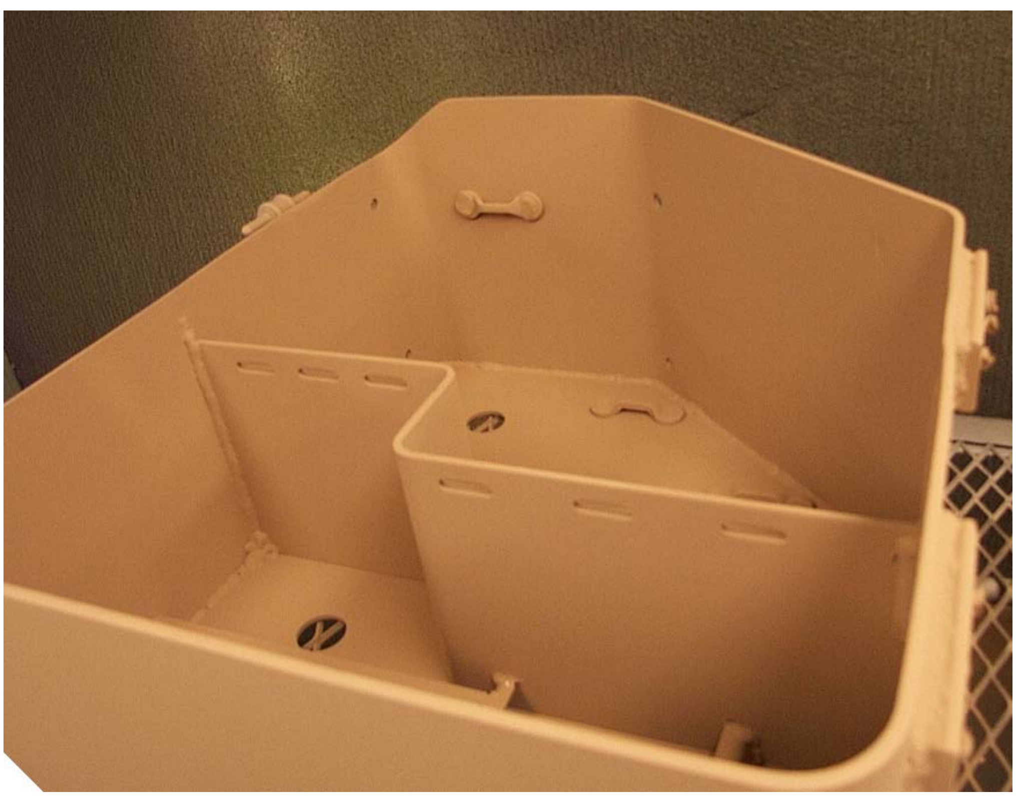


Figure 5.33: Re-Man Components – As received – November 2003 (Top)
And after Grinding/Preparation of Selected Re-Work Areas (Bottom)

Figure 5.34: Re-Man Parts after Pretreatment of Selected Test Areas (Top)
And after Primer and Top-Coat Application (Bottom)



5.3.4 – QC PANEL TESTING/LAB VALIDATION

To ensure that the coatings were not damaged or contaminated during the component processing, two sets of quality control panels were coated and painted at the same time. Each set consisted of 10-each of 4"x12" aluminum panels, one set of AA5083-H131 and the other of AA6061-T6. The panels were then primed and painted at the NAVAIR Pax River, MD facility at the same time as the field test components. These QC panels were then shipped to UDLP-York for accelerated corrosion testing in ASTM B117 neutral salt fog and GM9540P cyclic testing.

Another set of panels, 20-each of 4"x12" AA5083-H131 and AA6061-T6 were processed with the original TCP, two variations of the TCP-C, and Oakite 163™ chromate control to determine the optimum conversion coating formulation for this effort. These panels were then packaged and shipped to UDLP-York, for primer and topcoat application in the York small parts production paint line. These panels were also put into accelerated corrosion testing in accordance with ASTM B117 and GM9540P.

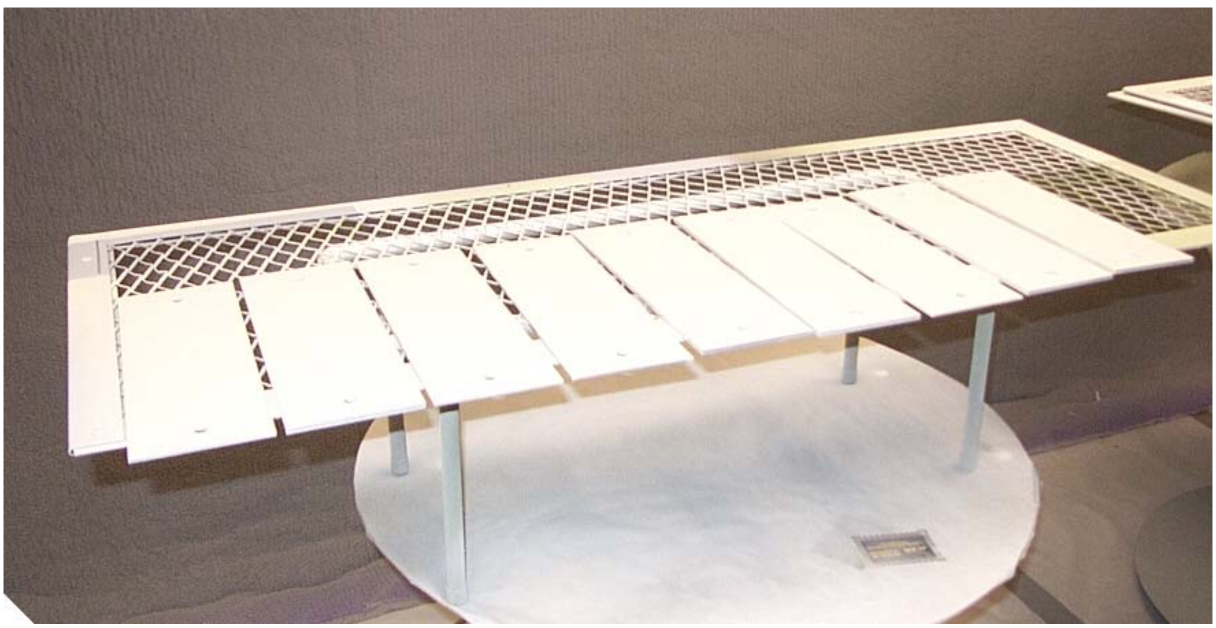


Figure 5.35: QC panels after MIL-P-53022 Primer Application

All panels were processed in accordance with the parameters contained in Table 5.10. Laboratory accelerated corrosion testing and evaluation was conducted by Doug Russo, CTC at the United Defense, York, PA facility. Table 5.11 outlines the test parameters and results for the QC test matrix. All testing and evaluation was performed by CTC York, with testing oversight provided by York FSE, NAVAIR, ARL, and the BFV EMT.

All panels were given a numerical rating by distance of undercutting from the scribed area, according to ASTM D610.

	ASTM B117- 3,000 HRS.		
PANEL ID	**DFT IN MILS**	**ASTM D610**	**UNDERCUTTING**
TCP5083 #1	3.2	10	<0.01 IN.
TCP5083 #2	3.9	10	<0.01 IN.
TCP5083 #3	3.2	10	<0.01 IN.
TCP5083 #4	3.1	10	<0.01 IN.
TCP5083 #8	3.6	10	<0.01 IN.
TCP6061 #5	2.9	10	<0.01 IN.
TCP6061 #6	3	10	<0.01 IN.
TCP6061 #7	3.4	10	<0.01 IN.
CONTROL 6061 #9	4	10	<0.01 IN.
CONTROL 6061 #10	3.2	10	<0.01 IN.
	GM9540P-120CYCLES		
TCP5083 #11	3.1	10	<0.01 IN.
TCP5083 #12	3.3	10	<0.01 IN.
TCP5083 #13	3.8	10	<0.01 IN.
TCP5083 #14	3.8	10	<0.01 IN.
TCP6061 #15	3.1	10	<0.01 IN.
TCP6061 #16	3.4	10	<0.01 IN.
TCP6061 #17	3.2	10	<0.01 IN.
CONTROL 5083 #18	3.8	10	<0.01 IN.
CONTROL 5083 #19	3.1	10	<0.01 IN.
CONTROL 5083 #20	3.4	10	<0.01 IN.

Table 5.11: Accelerated Corrosion Testing of QC Panels Pretreated and Painted at the time of the Field Test Components.

All panels passed regardless of alloy or pretreatment, and no performance difference was identified between the chromate controls and the TCP panels. This validates that the TCP conversion coating applied to the BFV test components was done properly; thereby supporting the field test results as valid data.

The secondary set of corrosion panels for TCP process optimization were run out to 3,020-hours of ASTM B117 and 120-cycles (3000-hours) of GM9540P with same results as the first set of coupons.

The average DFT was 4.92-mils for the TCP panels and 4.93-mils for the chromate control panels.

5.3.5 – FIELD TESTS

5.3.5.1 – RESULTS

M2A3 Bradley Fighting Vehicle #258 – Parts were installed at APG, MD on August 30, 2003. This vehicle was scheduled for testing at APG Test Track facility. After testing at APG, this test vehicle was shipped to Huntsville, AL for modification, then returned to APG.

Brian Placzankis, Coatings and Corrosion Branch, Army Research Lab, APG, MD and Bill Nickerson, Inorganic Coatings, Naval Air Warfare Center, Aircraft Division, Patuxent River, MD inspected the vehicle at 6 months in January 2004 at the APG Test Track. Heather McNabnay, PMCS, and Tom Braswell, UDLP-York were also present for the inspection. No corrosion or adhesion loss was observed on any of the components at this time. Additionally, no undercutting or propagating paint loss was observed at damaged or dinged areas. This vehicle was again inspected at 12 months of service by Brian Placzankis, when it was returned to APG after installation of the Chassis Modernization/Embedded Diagnostics upgrade at Huntsville, AL. This mod kit is an upgrade to the hull electronics for the BFV's, and requires the removal of the legacy steering yoke component. All other TCP components remain in service on the vehicle. While the vehicle evidenced much use, and was quite dirty and scuffed from testing, no corrosion or adhesion problems were reported, and no undercutting or additional paint adhesion loss was noted at damaged or dinged areas.

Figure 5.36: BFV M2A3 258 – APG, MD August 2004

M2A3 Bradley Fighting Vehicle #031 – Parts were installed at Ft. Benning, GA on October 16, 2003. This vehicle is a training vehicle for soldiers, and is frequently in the field. This vehicle is still fielded and used for training at Ft. Benning, GA.

Brian Placzankis, ARL, and Bill Nickerson, NAVAIR, inspected the vehicle at 9 months in May 2004 at the Ft. Benning Motor Pool. The vehicle had approximately 6500 kM put on it in training operations since fielding in October 2003. No corrosion or adhesion loss was observed on any of the components at this time. Additionally, no undercutting or propagating paint loss was observed at damaged or dinged areas. All TCP test components, including the legacy steering yoke, remain in service on the vehicle.

Figure 5.37: BFV M2A3 031 – Ft. Benning, GA May 2004

M3A3 Bradley Fighting Vehicle #086Y – Re-man parts were installed at Yuma Proving Ground (YPG) on February 18, 2004. This vehicle was scheduled for desert testing at the YPG vehicle test track; this terrain is very hard and rocky, leading to a lot of damage from dings and scrapes. This vehicle was transferred to APG, MD for the Chassis Modernization/Embedded Diagnostics modification kit installation on July 27, 2004.

Brian Placzankis, ARL, inspected the vehicle after almost 6 months in service with the test components, in July 2004 at APG. This vehicle had more dings, scrapes, and overall dirt and damage to the coating system than the other two test platforms. In several areas, the paint removal was down to exposure of the underlying TCP. See figure 5.38. This is again attributable to the extremely rocky terrain at YPG. No corrosion or adhesion loss was observed on any of the components at this time. Additionally, no undercutting or propagating paint loss was observed at damaged or dinged areas. All TCP test components, with the exception of the legacy steering yoke, remain in service on the vehicle.

Figure 5.38: BFV M3A3 086Y – APG, MD

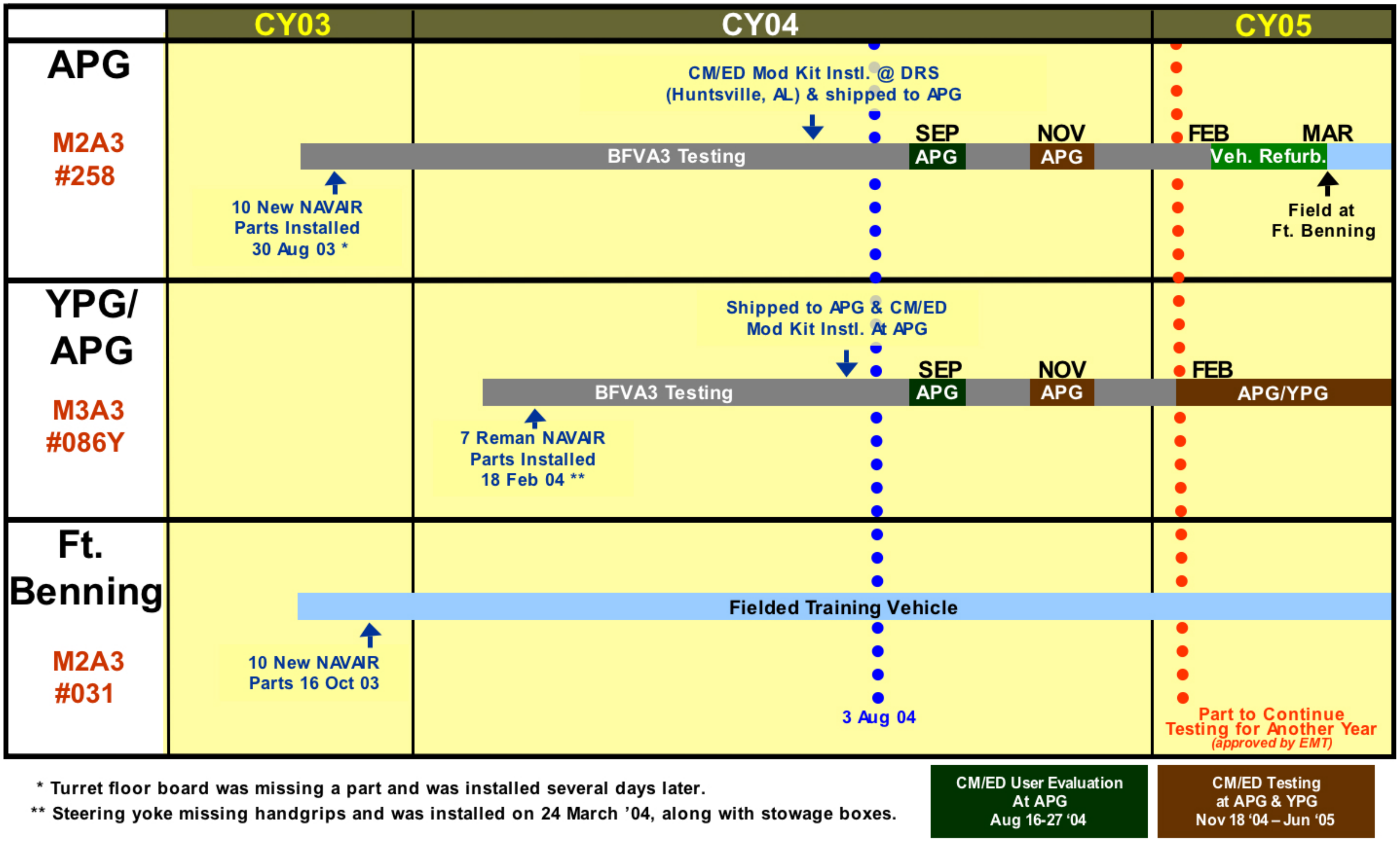


Table 5.12: Vehicle Test Schedule – 28 July 2004

NAVAIR test parts remain on all three vehicles except for the steering yokes on 2AGR0258 and 3AGR00086Y at APG. Chassis Modernization/Embedded Diagnostics mod kits were installed and revised yokes replaced the NAVAIR steering yokes. There are no reported problems with NAVAIR test parts.

5.3.6 – STATUS

No adhesion or corrosion issues have been reported with the test components. Testing will be continued for another 12 months, and possibly longer, to extract as much test data as possible. Currently, UDLP-York has expressed the intention to implement TCP as soon as a commercial source is qualified to MIL-DTL-81706B. PMCS has approved its use for spray applications only at this time. Approval for full immersion processing of the hull and turret structure is pending the results of the stress-corrosion-cracking test being conducted by United Defense CTC Santa Clara, CA.

5.3.6.1 – STRESS CORROSION CRACKING EVALUATION

The SCC testing will be conducted by CTC Santa Clara, with testing oversight by the PMCS EMT. The purpose of this evaluation is to determine effect of hexavalent chrome, trivalent chrome, and the current steam cleaning process on SCC in AA7039 armor plating. The same 7039 plate, i.e. same heat lot, will be used to produce all samples. The samples will be modified to create short transverse cracks. The following variables will be examined, hexavalent chromium conversion coating, TCP conversion coating, pressure wash, and steam clean; with and without subsequent drying bake. This test will use fasteners and Belleville washers to create a controlled stress.

The sample size will be 8 inches wide, 12 inches long, and 1 inch thick. The selected proportional fastener torque will create 5-ksi tensile stress.

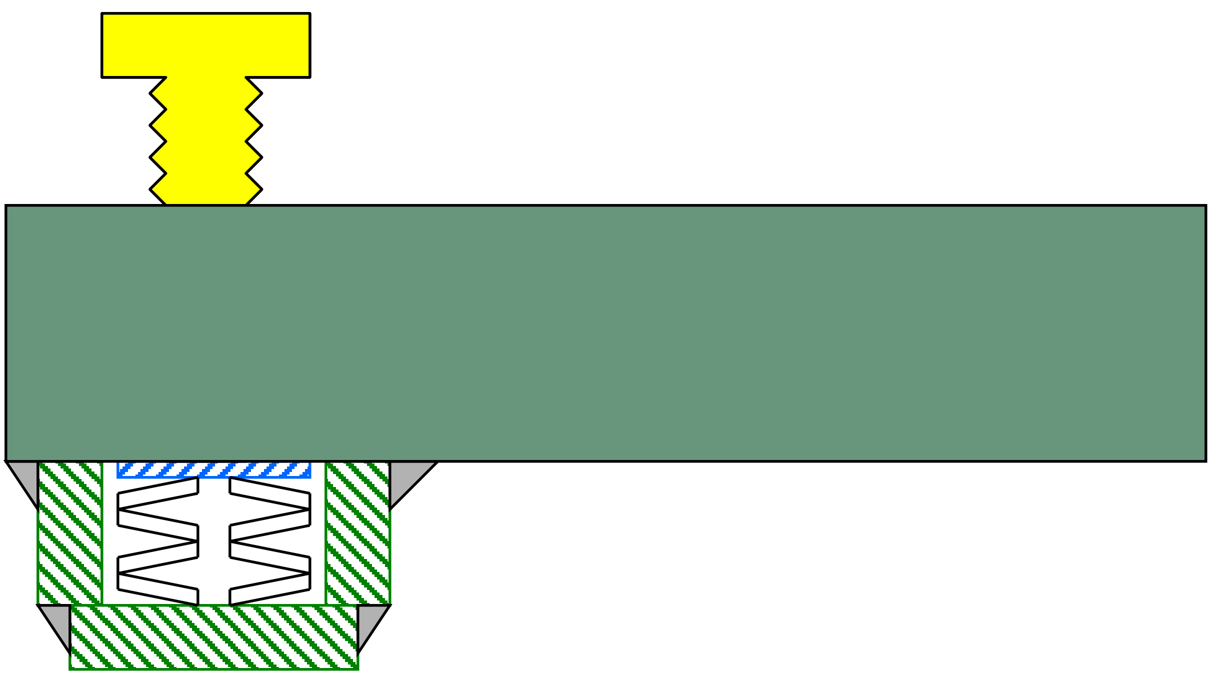


Figure 5.39: SCC test specimen schematic

The test plan is as follows: create cracked samples from untreated AA7039, torque fasteners to the predetermined value, expose the samples to a salt spray environment, examine the samples daily for cracks using ultrasonic imaging in an attempt to grow a 2-inch crack.

The test samples, two replicates each (16 total), will then be processed with the following pretreatments, and re-exposed to a salt spray environment to monitor propagation of the crack. The pretreatments will be – none, MIL-C-5541 (chromate control), NAVAIR TCP, pressure wash, bake, and no bake.

The results from this test will be presented to the PM Combat Systems EMT at the next quarterly meeting, with final status on chemical conversion coating by immersion processing to be determined at that time.

5.4 – US ARMY AVIATION

5.4.1 – BACKGROUND

In August of 2003, the Environmental, Engineering, and Logistics Oversight (EELO) office at AMCOM in Huntsville, AL put together a comprehensive panel test matrix to identify a non-chromate system for demonstration as a potential replacement coating system for their current chromate-based pretreatment and primer process. Currently, Army Aviation Depots spray chromate conversion coating, and paint with MIL-PRF-23377 C primer and MIL-C-46168 Type IV CARC, a 2-component, polyurethane topcoat.

Panel preparation and coating was conducted by NAVAIR, Patuxent River, with AMCOM EELO, and ARL present from October 14-17, 2003. Panels were then shipped to ARL for corrosion and adhesion testing. All testing and evaluation was conducted under the oversight of PEO Aviation, AMCOM Materials, EELO, ARL, and NAVAIR.

The three alternative pretreatments selected for aluminum alloy testing were Alodine 5700, NAVAIR TCP, and PreKote. These pretreatments were evaluated over AA2024-T351 and AA7075-T651 alloys. The non-chrome primer alternative evaluated was MIL-PRF-85582 N since no qualified version of MIL-PRF-23377 N was available at the start of testing. All three pretreatments were evaluated under chromated primers (MIL-PRF-23377 C and MIL-PRF-85582 C) and the non-chromate MIL-PRF-85582 N. The potential replacement primers, MIL-PRF-85582 C and N were coated with the latest generation CARC topcoats, MIL-C-53039A Low VOC and MIL-DTL-64159 Type II to evaluate the coating "system" performance.

5.4.2 – LABORATORY TESTING

Testing was conducted by ARL at APG, MD by the Coatings and Corrosion Branch. Corrosion testing was conducted according to ASTM B117 neutral salt fog and GM9540P cyclic corrosion. All corrosion tests were run out to 3,000 hours, with regular evaluations by ARL and AMCOM. Adhesion testing was conducted according to ASTM D4541-95 pull-off and ASTM D3359 wet tape testing. Adhesion Testing was completed in early 2004 and corrosion testing was completed in July 2004. Table 5.13 shows the full aluminum coating system test matrix.

PNL ID		ALUMINUM AL2024-T3												ALUMINUM AL7075-T6						
		4 Control	5	6	7	8	9	10	11	12	13	14	15	13 Control	14	15	16	17	18	19
	Panel Type	2024T3	2024T3	2024T3	2024T3	2024T3	2024T3	2024T3	2024T3	2024T3	2024T3	2024T3	2024T3	7075T6	7075T6	7075T6	7075T6	7075T6	7075T6	7075T6
	Panel Pre-Treatment	MIL-C-5541	MIL-C-5541	MIL-C-5541	MIL-C-5541	TCP	TCP	TCP	Alodine 5200	Alodine 5200	Alodine 5200	X-IT Precoat	X-IT Precoat	MIL-C-5541	MIL-C-5541	MIL-C-5541	TCP	TCP	TCP	MIL-C-5541
	Primer	23377C	85582N	85582N	85582N	85582C	85582N	85582N	85582C	85582N	85582N	85582C	85582N	23377C	85582N	85582N	85582C	85582N	85582N	85582C
	Topcoat	46168IV	53039	64159II	64159IILSL	64159II	53039	64159II	64159II	53039	64159II	64159II	64159II	46168IV	53039	64159II	53039	53039	64159II	64159II
A	Wet Adhesion - ASTM D 3359	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
B	Salt Spray - ASTM B 117	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
C	Pull-Off ASTM D 4541-95	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
D	GM 9540B - Method B	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
E	Outdoor Exposure - FL	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
F	QTRAC	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
G	Electrochemical Impedance Spectroscopy	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Control Set	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	TOTAL PANELS RQD PER SET	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
					ALUMINUM - AL2024-T3						**192**				**ALUMINUM - AL7075-T6**				**112**	

Table 5.13: AMCOM – NAVAIR PANEL TEST MATRIX OCTOBER 2003

5.4.2.1 – PULL-OFF ADHESION TESTING – ASTM D 4541-95

AA2024-T3

Pretreatment	**Primer**	**Topcoat**	**Adhesion (30 measurement Avg. – psi)**
Alodine 1200S	MIL-PRF – 23377 C	MIL-C-46168 Ty IV	3205.67 ±261.15
Alodine 1200S	MIL-PRF – 85582 N	MIL-C-53039A	2913 ±213.79
Alodine 1200S	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	2609 ±246.89
TCP	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	2739 ±177.91
TCP	MIL-PRF – 85582 N	MIL-C-53039A	3064.33 ±194.35
TCP	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	2579.33 ±204.21
Alodine 5700	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	2601.33 ±304.37
Alodine 5700	MIL-PRF – 85582 N	MIL-C-53039A	2563.67 ±423.28
Alodine 5700	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	1644 ±275.91
PreKote	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	2388 ±114.09
PreKote	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	2861 ±272.94

Table 5.14: Pull-Off Adhesion Data – AA2024T3

AA7075-T6

Pretreatment	**Primer**	**Topcoat**	**Adhesion (30 measurement Avg. – psi)**
Alodine 1200S	MIL-PRF – 23377 C	MIL-C-46168 Ty IV	3229 ±317.41
Alodine 1200S	MIL-PRF – 85582 N	MIL-C-53039A	2993 ±233.90
Alodine 1200S	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	2310 ±173.90
TCP	MIL-PRF – 85582 C	MIL-C-53039A	2994.33 ±427.70
TCP	MIL-PRF – 85582 N	MIL-C-53039A	2931 ±201.93
TCP	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	2509.67 ±149.05
Alodine 1200S	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	2712 ±195.95

Table 5.15: Pull-Off Adhesion Data – AA7075T6

5.4.2.2 – WET TAPE ADHESION TESTING – ASTM D 3359

AA2024-T3

Pretreatment	**Primer**	**Topcoat**	**Panel 1 – 2 meas. Avg**	**Panel 2 – 2 meas. Avg**
Alodine 1200S	MIL-PRF – 23377 C	MIL-C-46168 Ty IV	5	5
Alodine 1200S	MIL-PRF – 85582 N	MIL-C-53039A	5	5
Alodine 1200S	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	4	4
TCP	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	4	5
TCP	MIL-PRF – 85582 N	MIL-C-53039A	5	5
TCP	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	5	4.5
Alodine 5700	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	4.5	4 Blisters
Alodine 5700	MIL-PRF – 85582 N	MIL-C-53039A	4	4.5 Blisters
Alodine 5700	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	3.5	3.5
PreKote	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	3.5	3 Blisters
PreKote	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	4.5	4

Table 5.16: Wet Tape Adhesion Data – AA2024T3

AA7075-T6

Pretreatment	**Primer**	**Topcoat**	**Panel 1 – 2 meas. Avg**	**Panel 2 – 2 meas. Avg**
Alodine 1200S	MIL-PRF – 23377 C	MIL-C-46168 Ty IV	4.5	5
Alodine 1200S	MIL-PRF – 85582 N	MIL-C-53039A	5	5
Alodine 1200S	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	4.5	4.5
TCP	MIL-PRF – 85582 C	MIL-C-53039A	5	5
TCP	MIL-PRF – 85582 N	MIL-C-53039A	5	5
TCP	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	4.5	4.5
Alodine 1200S	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	5	4

Table 5.17: Wet Tape Adhesion Data – AA7075T6

5.4.2.3 – NEUTRAL SALT FOG TESTING – ASTM B 117

AA2024-T3 – Ratings According to ASTM D 1654 Procedure A

Pretreatment	**Primer**	**Topcoat**	**Corrosion Results (5 panel Avg.)**
Alodine 1200S	MIL-PRF – 23377 C	MIL-C-46168 Ty IV	8.6±0.89
Alodine 1200S	MIL-PRF – 85582 N	MIL-C-53039A	7.2±0.44
Alodine 1200S	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	7.4±0.55
TCP	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	9.0±0.00
TCP	MIL-PRF – 85582 N	MIL-C-53039A	5.8±0.84
TCP	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	5.0±0.71
Alodine 5700	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	8.6±0.55
Alodine 5700	MIL-PRF – 85582 N	MIL-C-53039A	6.4±1.34
Alodine 5700	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	4.4±0.55
PreKote	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	7.4±0.55
PreKote	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	2.4±1.52

Table 5.18: Neutral Salt Fog Corrosion Data – AA2024T3

AA7075-T6 – Ratings According to ASTM D 1654 Procedure A

Pretreatment	**Primer**	**Topcoat**	**Corrosion Results (5 panel Avg.)**
Alodine 1200S	MIL-PRF – 23377 C	MIL-C-46168 Ty IV	9.0±0.0
Alodine 1200S	MIL-PRF – 85582 N	MIL-C-53039A	7.4±0.55
Alodine 1200S	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	7.8±0.45
TCP	MIL-PRF – 85582 C	MIL-C-53039A	8.8±0.45
TCP	MIL-PRF – 85582 N	MIL-C-53039A	7.2±0.45
TCP	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	7.2±0.45
Alodine 1200S	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	9.0±0.0

Table 5.19: Neutral Salt Fog Corrosion Data – AA7075T6

5.4.2.3 – CYCLIC SALT FOG TESTING – GM9540P

AA2024-T3 – Ratings According to ASTM D 1654 Procedure A

Pretreatment	**Primer**	**Topcoat**	**Corrosion Results (5 panel Avg.)**
Alodine 1200S	MIL-PRF – 23377 C	MIL-C-46168 Ty IV	9.0±0.0
Alodine 1200S	MIL-PRF – 85582 N	MIL-C-53039A	6.2±0.45
Alodine 1200S	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	6.4±0.45
TCP	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	8.4±0.89
TCP	MIL-PRF – 85582 N	MIL-C-53039A	5.4±0.55
TCP	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	5.0±0.0
Alodine 5700	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	8.6±0.55
Alodine 5700	MIL-PRF – 85582 N	MIL-C-53039A	5.0±0.0
Alodine 5700	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	4.2±0.84
PreKote	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	8.6±0.89
PreKote	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	3.6±0.89

Table 5.20: Cyclic Salt Fog Corrosion Data – AA2024T3

AA7075-T6 – Ratings According to ASTM D 1654 Procedure A

Pretreatment	**Primer**	**Topcoat**	**Corrosion Results (5 panel Avg.)**
Alodine 1200S	MIL-PRF – 23377 C	MIL-C-46168 Ty IV	9.4±0.55
Alodine 1200S	MIL-PRF – 85582 N	MIL-C-53039A	7.6±0.89
Alodine 1200S	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	7.2±0.45
TCP	MIL-PRF – 85582 C	MIL-C-53039A	9.2±0.45
TCP	MIL-PRF – 85582 N	MIL-C-53039A	7.0±1.41
TCP	MIL-PRF – 85582 N	MIL-DTL-64159 Ty II	8.6±0.55
Alodine 1200S	MIL-PRF – 85582 C	MIL-DTL-64159 Ty II	8.8±0.45

Table 5.21: Cyclic Salt Fog Corrosion Data – AA7075T6

5.4.3 – FIELD TEST SYTEMS SELECTION

The current demonstration selection is to evaluate two non-chromate coating systems in field application on Army helicopters. Subject to approval from the PMA's, the plan is to process six full CH-47 aircraft at two separate depots. Three aircraft will be processed at CCAD and three aircraft will be processed at the CT AVCRAD facility. Each site will process one control aircraft, to be primed with MIL-PRF-23377 C1 or C2, chromated epoxy primer. Table 5.18 outlines the planned demonstration coating systems.

Aircraft	Pretreatment	Primer	Topcoat
CH-47	TCP	MIL-PRF-23377 C	MIL-C-53039A 1.5VOC
CH-47	TCP	MIL-PRF-85582 N	MIL-C-53039A 1.5VOC
CH-47	TCP	MIL-PRF-23377 N	MIL-C-53039A 1.5VOC
CH-47	Alodine 5700	MIL-PRF-23377 C	MIL-DTL-64159 TyII
CH-47	Alodine 5700	MIL-PRF-85582 N	MIL-DTL-64159 TyII
CH-47	Alodine 5700	MIL-PRF-23377 N	MIL-DTL-64159 TyII

Table 5.22: AMCOM Coating System Demonstrations

5.4.3.1 – GENERAL GUIDELINES – AIRCRAFT CLEANING, SURFACE TREATMENT AND COATING

Aircraft will be inspected to identify coating problems and recorded in the aircraft coating test log (provided). Obvious corrosion, missing rivets, loose/flaking paint, etc. should all be noted. Aircraft shall be cleaned per normal operations at the facility and required maintenance accomplished prior to preparation for de-painting/painting operations.

Components normally removed prior to de-painting shall be removed and de-painted in accordance with normal procedures. Any aluminum substrate components removed for hand de-painting and processing shall follow the guidelines below for surface preparation and conversion coating of the aluminum substrate. Other non-aluminum components shall be prepared per normal procedures.

Once stripped, the aircraft shall be inspected for corrosion, and localized corrosion removed by hand abrasion (bristle disk, sander or hand sanding) no steel or iron abrasive should be used for removing corrosion on aluminum substrates, products like steel wool, stainless steel shot or grinding/abrading wheels, etc. should be avoided. Other identified flaws shall be repaired per normal procedures.

Cleaning of the aircraft is one of the most critical aspects of the TCP application and each step shall be closely followed to ensure a properly prepared surface prior to TCP application. All surfaces to be treated with TCP shall be cleaned to a water-break-free surface with a mild alkaline (pH 8-9, nothing over 9.5) cleaner conforming to MIL-PRF-85570 Type II or MIL-PRF-87937 Type II. Cleaners shall be diluted to the proper strength using deionized (DI) water to eliminate potential ion deposition on the cleaned substrate. If obvious signs of surface contamination remain, the cleaning process shall be repeated until a water-break-free surface is obtained. If there are signs of “acrylic smear” from Type V PMB an appropriate cleaner shall be substituted that will remove the contamination or the contaminants should be removed using medium grit Scotchbrite pads and an aqueous cleaner. Any alternate cleaner selection must be coordinated with the Research, Development Engineering Center, Materials Branch prior to use. Personnel shall avoid the use of high pH, strong alkaline cleaners to prevent damage to the aluminum substrates. Rinse water shall be deionized to eliminate conductive ions being trapped on the bare substrate creating potential corrosion initiation sites or sites where the TCP will not properly adhere. A deoxidation step may follow substrate cleaning for final surface preparation prior to TCP application. If a deoxidation process is used, the final rinse will also use DI water.

Following cleaning (and deoxidation, if used) the surface shall be treated with TCP. TCP shall be applied by hand sprayer ensuring the entire surface to be treated is completely coated with the TCP solution. The nominal dwell time prior to rinsing the TCP from the surface shall be 10-15 minutes. (Note: There is no obvious color change to the treated surface like Alodine 1200 series chromate conversion coatings. However, experienced personnel will be able to tell when the rinse should be performed. Properly applied, TCP leaves the treated surface with a subtle, iridescent blue-lavender color.) DI water shall be used for the TCP rinse step.

Following TCP treatment, the substrate shall be allowed to dehydrate for 16-24 hours. This is the proper “cure” time for the pretreatment. If scheduling is tight, a 4-hour dry time after processing can be implemented. Following dehydration, the aircraft shall be masked and coated with the proper primer and top-coating as required.

5.4.4 – STATUS

EELO personnel briefed the cognizant PMA’s and AMCOM Materials in Fall 2004 to obtain approval for the CH-47 as the demonstration platform. If the PMA’s do not want to accept the results of the demo without a broader platform base, i.e. CH-60’s, AH-64E’s, etc., the planned number of aircraft will have to be increased. No changes to the processing sites should be necessary, regardless of the outcome of the PMA’s decision.

All processing will be done under the oversight of AMCOM Materials, and EELO. Bill Nickerson, NAVAIR will be present for technical processing support. William Alvarez, AMCOM EELO and Paul Robinson, (Titan Systems) EELO will evaluate the in-service performance of the test systems. Final approval for implementation must come from AMCOM Materials and Engineering.

Spray processing is planned to begin in the early 2005 timeframe, with the first 6 month in-service evaluation in FY05.

6.0 – IMPLEMENTATION OF ALTERNATIVES IN DoD AND NASA

6.1 – MILITARY AND INDUSTRIAL PRETREATMENT SPECIFICATIONS

NAVAIR is currently in the process of revising the MIL-DTL-81706 qualification specification and the MIL-C-5541 quality control specification governing aluminum conversion coatings.

The proposed revisions are circulated through DoD and government contractors for comments and review, the inputs collated and organized, and a final revision written. Both revisions will allow the qualification and use of any non-chromate aluminum pretreatment that can pass the performance requirements for qualification. No changes have been made to the corrosion and adhesion testing requirements for aluminum conversion coatings.

Additionally, NAVAIR Materials will be working with the SAE-AMS Committee B toward the revision of the industrial aluminum conversion coating specification, also to include provisions for non-chromate coatings that meet the corrosion and adhesion performance requirements.

6.2 – ALODINE™ 5700

6.2.1 – NASA

NASA has implemented a non-chromate coating system for use on their aluminum alloy Solid Rocket Boosters (SRB). The Space Shuttle SRB conducted a project to identify and qualify alternatives for the traditional, qualified chromate coating system and pretreatment. Testing gathered information on corrosion protection, bond strength, compatibility with other SRB materials, batch-to-batch consistency, and thermal environments data. Two pretreatments and two coating systems met the SRB program criteria. The recommended pretreatments were Henkel Alodine 5200/5700 and MacDermid Chemidize 727 ND. Alodine 5700 had very robust processing parameters and was recommended for first implementation as a pretreatment alternate.

NASA implemented a Hentzen non-chromate primer / Alodine 5700 pretreatment system in June 2002. This change affected all structural aluminum (2219, 6061, and 7075) parts of the solid rocket boosters. The first hardware flew in the fall of 2002.

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6.2.2 – US Army TACOM

The US Army TACOM has implemented Alodine 5200/5700 conversion coating on AA2024-T4 and AA2014-T6 road wheels for the Bradley Fighting Vehicle, the M113, and the MLRS. TACOM has also implemented Alodine 5200/5700 on Aluminum tracks for the M1A1 Abrams Tank. This technology has been implemented in the US Army Red River Army Depot's (RRAD) Rubber Products Operations since early 2003.

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6.3 – PREKOTE™

As of Feb. 2004, the F-16, T-37, T-38 and T-1 SPOs have approved the use of PreKote, and HQ Air Education and Training Command (AETC) has mandated its use on all AETC aircraft for which it's approved. If a base, MAJCOM, or ALC decides to pursue using PreKote in their paint processes on other systems, it must obtain approval from the appropriate SPOs. AFCPCO will provide existing test results upon request to assist SPOs with the engineering decision whether to approve PreKote.

AFCPCO continues to recommend chromated conversion coatings for optimum corrosion protection. Multiple laboratory tests, by various organizations, indicate PreKote is one of the best performing non-chromated surface treatments, but its corrosion protection is still less than that of chromated Alodine 1200S. Several other candidate materials are also being tested as possible alternatives to Alodine. It is likely that more than one material will meet AF needs. In cases where chromate cannot be used due to environmental restrictions, PreKote provides a low risk alternative. Note that all test results to date, current SPO approvals, and the assessment of low risk, are contingent on the use of a qualified chromated primer. When PreKote is used, corrosion inhibition comes only from the chromated primer. Past performance of non-chrome paint systems in AF use has been poor; and AFCPCO strongly recommends against the use of PreKote with non-chromated primers. Since application of PreKote is largely a manual process, the consistency of the process may be important to an overall satisfactory result. To achieve results equal to other weapon systems, we recommend adhering closely to application practices that have already been established.

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6.3 – TCP

6.3.1 – NAVSEA

Based on the results of the outdoor exposure panel testing and the multi-year field demonstration at ACU-4, NSWCCD Materials has indicated that they will implement the TCP for pretreatment of aluminum alloys on the LCAC as soon as a commercial product is qualified to MIL-DTL-81706B. NAVSEA Materials is awaiting the issuance of the NAVAIR TCP approval letter for implementation.

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6.3.2 – USMC

The Expeditionary Fighting Vehicle is approaching the end of the SDD phase. Environmental, safety and health restrictions have led the program office to mandate the use of chromate and cadmium free coating systems. The program is scheduled to begin LRIP in FY06.

TCP has been selected as the pretreatment for the processing of the AA2519 hull and turret structures. Both the TCP and Alodine 5200/5700 have been approved by the PM for use on aluminum components by GDAMS and their vendors. The Marines' AVTB is currently using Alodine 5700 pre-saturated wipes for coating system maintenance and repair touch-up applications on the SDD vehicles fielded there.

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6.3.3 – NAVAIR

Overall, the TCP technology is performing at least as well as the standard chromate conversion coating in the demonstrations with the F/A-18's and CH-46's.

NAVAIR Materials is planning to authorize the use of TCP under chromated primers, with the approval letter planned to issue FY05. Addtitional FY05 efforts will focus on an extensive evaluation of new, non-chromate primer systems under qualification testing to MIL-PRF-23377 Class N; with field testing over TCP planned if applicable based on laboratory testing.

As a result of the mixed field performance of the TCP with SPT, NAVAIR does not recommend the use of TCP with the SPT, and will not pursue implementation of a non-chromate conversion coating on the S-3 platform at this time.

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6.4 – AC-130/131

6.4.1 – BOEING/AF

Boeing Commercial Airplanes is using AC-131 on chromated aluminum rivets for B737 aircraft to improve paint adhesion to the rivets. The chromate plus AC-131 coating is applied to the rivets at the rivet manufacturer. Boeing Commercial Airplanes traditionally utilized Alodine 1000™ clear, chromate conversion coating for pretreatment of aluminum rivets on commercial aircraft. They were experiencing paint loss due to adhesion failure at the rivets. B737 aircraft produced since the spring of 2004 have had the chromate/AC-131 coated rivets used in the fuselage. The incidence of paint adhesion failures to the rivets has been significantly decreased with the new coating system.

Boeing Commercial Airplanes is also performing scale-up and producibility trials of AC-131 with the goal of replacing the colorless chromated Alodine 1000 that is currently applied to new production commercial aircraft. Negotiations with customers to identify an operational evaluation are underway with application to production aircraft anticipated in mid 2005.

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6.4.2 – NAVAIR/AF

Although not part of the scope of the ESTCP Non-Chromate Aluminum Pretreatments project, which focuses on pre-paint conversion coating applications for increased paint adhesion, corrosion protection, and electrical properties of aluminum alloys, a closely related use of hexavalent chromium coatings is as a pre-adhesive treatment on aluminum alloys prior to structural bonding applications. Traditionally, adhesive bonding is done with chromated aluminum surfaces.

This Joint Service program (PP-0204) is also being funded by the support of the ESTCP office. This project is using repair demonstrations to validate the use of sol-gel based surface preparations for adhesive bonding that were developed under SERDP programs PP-130 and PP-1113. This work has focused on the implementation of repair practices developed for a commercial, epoxy functional sol-gel – AC-130 from AC Tech – in applications where the sol-gel could be used to replace a hazardous surface preparation method with no reduction in expected adhesive bond performance. Furthermore, the use of the AC-130 system has the added benefits of simplicity and process robustness, especially when compared to difficult and dangerous surface preparation methods that use strong acids and hexavalent chromium. These two factors have been combined to guide the use of sol-gel in DoD repair applications to both replace hazardous surface preparation methods and to supplant obsolescent repair methods with inferior structural performance. The use of this sol-gel is coupled with a zero-VOC primer material in most applications to provide a surface protection scheme for steel, aluminum, or titanium that is suitable for structural bonding. In laboratory testing, this combination has been used to demonstrate bonded strength and durability performance that exceeds the best existing treatments for the alloys evaluated. Through the demonstration process, this is being translated into a robust repair process that allows repair artisans to restore components to near pristine condition. To this end, demonstration of process utility has occurred with repair development on a number of weapon systems for the tri-service partners, and off-program transitions have been deployed with success in the field. Current work in this program has targeted high-impact transitions that will provide the most benefit per dollar spent, and will enable the services to move sol-gel technology through their logistics and repair systems as quickly as possible.

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7.0 – CONCLUSIONS AND RECOMMENDATIONS

All the alternatives being demonstrated are aqueous solutions designed to deposit a conversion coating on aluminum alloy substrates to enhance paint adhesion and painted corrosion performance. Alternatives face the challenge of the low cost and ease of application of the chromate conversion coatings while providing a coating that provides acceptable technical performance. Along with technical performance, processing and toxicity issues are important to consider in capturing the overall impact of an alternative.

There are currently four non-chromate alternatives in various stages of validation or implementation. Alodine 5200/5700, PreKote, and AC-130/131 provide paint adhesion and painted corrosion protection, and are all non-chromium chemistries. The TCP provides both painted and unpainted corrosion protection as well as electrical conductivity in corrosive environments. However, TCP does contain trivalent chromium, and users will need to balance total chromium waste-water requirements with technical performance requirements when deciding on implementation of TCP. TCP and Alodine 5200/5700 provide the most process flexibility, as they can be applied like a chromate conversion coating, by immersion, spray, or wipe-on methods. AC-130/131 can be used in spray applications. PreKote must be manually applied for proper coating performance.

All of the demonstration coatings have shown good paint adhesion and corrosion performance when used under chromated primers. The PreKote and the AC-130/131 have not yet been demonstrated in high corrosion environments. The TCP and Alodine 5200/5700 have shown good paint adhesion and painted corrosion performance when used under both chromated and non-chromated primers. TCP and Alodine 5200/5700 have performed well in high corrosion environment testing. The exception to this is the performance of the TCP on one of the four NAVAIR S-3 demonstrations using non-chromated Self-Priming Topcoat. A positive outcome of the S-3 testing was the finding that 500-hour SO_2 salt-fog was not enough to discriminate between the chromated and non-chromate coating systems. By extending the test to 1000-hours, additional corrosion and blistering were observed with fully non-chromated coating systems. This is a clear example of a test designed to evaluate the performance of chromate-based materials, which are not typically tested to failure, but to minimum performance standards.

It is therefore critical with any new non-chromate material that it be tested to failure against the chromated control. Additionally, any new coating application should be demonstrated and validated by field-testing for each operational environment where implementation is being considered. Only then can the complete technical performance of a coating or coating system be determined.

Implementation of any alternative must take into consideration the costs, process, health and safety, laboratory and field testing performance, and the specific coating system application and operational environment.

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APPENDIX C – PHASE I LABORATORY REPORT

ESTCP

Environmental Security Technology Certification Program

Non-Chromate Aluminum Pretreatments
Phase I Report
Project #PP0025

August 2003

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ACRONYMS AND ABBREVIATIONS

ACU-4	Assault Craft Unit Four
AAAV	Advanced Amphibious Assault Vehicle
AETC	Air Education & Training Command
AFB	Air Force Base
ARL	Army Research Laboratory
ASTM	American Society for Testing and Materials
CARC	Chemical Agent Resistant Coating
CCTC	Cyclic Corrosion Test Chambers
CTC	Concurrent Technologies Corporation
DoD	Department of Defense
Dpi	Dots Per Inch
DUSD-ES	Deputy Undersecretary of Defense for Environmental Security
ESOH	Environmental, Safety, and Occupational Health
ESTCP	Environmental Security Technology Certification Program
FED	Federal
FOD	Foreign Object and Debris
GM	General Motors
HazMats	Hazardous Materials
HCl	Hydrochloric Acid
JG-PP	Joint Group on Pollution Prevention
JLC	The Joint Logistics Commanders
JTP	Joint Test Protocol
LC_{50}	Median Lethal Concentration
LCAC	Landing Craft, Air Cushion
LD_{50}	Lethal Dose
MEK	Methyl Ethyl Ketone
MIL	Military
MSDS	Material Safety Data Sheet
NASA	National Aeronautics and Space Administration
NAVAIR	Naval Air Systems Command
NCAP	Non-Chromate Aluminum Pretreatment Project
NCMS	National Center for Manufacturing Sciences
NDCEE	National Defense Center for Environmental Excellence
OEM	Original Equipment Manufacturer
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
RH	Relative Humidity
RRAD	Red River Army Depot
RT	Room Temperature

SPO	System Program Office
SPT	Self Priming Topcoat
SRB	Solid Rocket Booster
STD	Standard
TCP	Trivalent Chromium Pretreatment
TO	Technical Order
UDRI	University of Dayton Research Institute
USMC	United States Marine Corps
VOC	Volatile Organic Compounds

EXECUTIVE SUMMARY

Aerospace and Department of Defense (DoD) users presently enhance the corrosion resistance and paint adhesion performance of aluminum alloys with hexavalent chromium-based products that deposit a conversion coating on the surface of the metal. These coatings are very thin, inexpensive to produce, extremely process flexible, and can be applied by immersion, spray and wipe techniques.

Although chrome conversion coatings offer many advantages, the downside is that they contain hexavalent chromium, or chromate, species that are known carcinogens. The risk of worker exposure to these chemicals, the potential liabilities due to accidental leaks to the environment, and waste disposal issues are making the use of chromate-based conversion coatings unaffordable.

This report examines accelerated corrosion exposure of aluminum alloys 2024, 2219, 5083, and 7075 specimens treated with the candidate hexavalent chromium free pretreatments as well as one hexavalent chromium based pretreatment (Alodine 1200S) used as a control. The data from the Nonchromated Aluminum Pretreatment Project (NCAP) Joint Test Protocol (JTP) tests are considered together to form an accurate evaluation of the potential effectiveness of the selected alternatives as replacements for chromate conversion coatings. This data is solely intended to provide support for additional product validation and field-testing at user facilities. The performance requirements are documented in the JTP for Validation of Non-Chromate Aluminum Pretreatments dated 13 December 2000.

Eight potential nonchromated pretreatment alternatives are identified and discussed in this Phase I Report. They are Henkel Surface Technologies Alodine® 5200/5700, Fortune Chemical Company X-It PreKote™, MacDermid Chemidize® 727ND, Brent OXSiLAN® AL-0500, NAVAIR Trivalent Chromium Pretreatment (TCP), Boeing Boegel Sol-gel (now available from Advanced Chemistry & Technology Inc. as AC-131), Bi-K Aklimate, and Sanchem Safegard7000.

Each alternative tested shows acceptable performance in some selected cases that may be satisfactory for a given user, depending on operating environment and business cases involved. The only compositions that come close to matching the technical, process, cost, and flexibility of chromates are based on trivalent chromium. Although trivalent chromium is present in the solution and coating, toxicity studies and OSHA PELs suggest that the use of TCP is acceptable, especially given its well-rounded performance. The next best product in testing was Alodine 5200/5700. Alodine 5200/5700 contains no chromium, is process flexible and can be applied like chromate conversion coatings. The remaining alternatives performed variably in the evaluation.

ACKNOWLEDGEMENTS

This report was prepared by the generous support of the Environmental Security Technology Certification Program (ESTCP) and the Office of the Deputy Undersecretary of Defense for Environmental Security (DUSD-ES). The effort was led by the Naval Aviation Systems Command (NAVAIR) Materials Division Patuxent River and coordinated with Joint Group on Pollution Prevention (JG-PP). The principal investigator for the NCAP project is Craig Matzdorf, Code 4.3.4, NAVAIR Materials Division Patuxent River.

The authors of the report wish to acknowledge the leadership and support of the many Navy managers, engineers, and Fleet support personnel who contributed to this effort. A special thanks to NAVAIR Patuxent River, Army Research Laboratory (ARL), University of Dayton Research Institute (URDI), National Aeronautics and Space Administration (NASA) and contractor personnel at Kennedy Space Center in Florida, National Defense Center for Environmental Excellence (NDCEE) and Concurrent Technologies Corporation (CTC) for their support in material testing and demonstration; Assault Craft Unit Four (ACU-4), Naval Amphibious Base, Little Creek, Virginia for their support in the evaluation of test patches on Landing Craft, Air Cushions (LCACs); S-3B, F/A-18, and H-46 support personnel for their help in material flight-tests; principal investigators from the Navy, Army, Air Force, and Marine Corp for providing project summaries and testing results; and, Science Applications International Corporation for their support in the preparation of this report.

1.0 INTRODUCTION

1.1 Project Background

The Environmental Security Technology Certification Program (ESTCP) was established as a program of the DoD in December 1993. The ESTCP is managed by the Office of the Deputy Undersecretary of Defense for Environmental Security (DUSD-ES). The ESTCP demonstrates and validates laboratory-proven technologies that target the DoD's most urgent environmental needs. These technologies provide a return on investment through reduced environmental, safety, and occupational health (ESOH) risks; cost savings; and improved efficiency. The new technologies typically have broad application to both the DoD sustainment community and industry.

The Joint Logistics Commanders (JLC) and Headquarters National Aeronautics and Space Administration (NASA) co-chartered the Joint Group on Pollution Prevention (JG-PP) to coordinate joint service/agency activities affecting pollution prevention issues identified during system and component acquisition and sustainment processes. The primary objectives of the JG-PP are to:

- Reduce or eliminate the use of Hazardous Materials (HazMats)
- Avoid duplication of effort in actions required to reduce or eliminate HazMats through joint service cooperation and technology sharing.

JG-PP projects typically involve an original equipment manufacturer (OEM) producing multiple defense systems for more than one of the Services, as well as at least one DoD depot maintaining one or more of the defense systems. JG-PP technical representatives for each project begin by identifying a target HazMat, related process, and affected substrates or parts that may cause environmental and/or worker health concerns. Project participants then identify alternative technologies or materials for evaluation.

ESTCP selected the NCAP project, led by Naval Air Systems Command (NAVAIR) and coordinated with JG-PP, to assist in the mitigation of the significant ESOH risks that are associated with the use of chromate conversion coatings. Chromate conversion coatings contain hexavalent chromium, a known human carcinogen that is strictly regulated. The U. S. Environmental Protection Agency (EPA) limits air emissions and regulates solid waste disposal from operations using hexavalent chromium. The U. S. Occupational Safety and Health Administration (OSHA) regulates the amount of hexavalent chromium to which workers can be exposed, and has proposed reducing the Permissible Exposure Limit (PEL) for hexavalent chromium from the current 50 micrograms per cubic meter ($\mu g/m^3$) to less than 1 $\mu g/m^3$. Such limits could increase costs of the pretreatment of aluminum and aluminum alloys; therefore, alternatives are being identified and evaluated. The project will achieve the goal of reducing or eliminating the use of hexavalent chromium in aluminum finishing by demonstrating and validating the performance of alternatives in accordance with the technical requirements and tests identified in the JTP.

The key benefit of the nonchromated pretreatment alternatives being demonstrated in this report is the elimination or absence of hexavalent chromium from the process chemicals and as-deposited coating. Eliminating chromates from the conversion coating or pretreatment operations will drastically reduce user liability and risk in the life cycle of the platform or parts being coated. The key challenge for the alternatives will be matching the technical performance of chromate conversion coatings in a cost-effective manner.

1.2 Objective and Scope of Work

The overall objective is to validate and implement multiple chromate-free aluminum pretreatment alternatives at a broad range of user facilities. This report presents an evaluation of laboratory coupon testing of non-chromate aluminum pretreatment alternatives through accelerated tests on flat coupons. Section 2 of this document discusses the testing requirements for alternative aluminum pretreatments, which were prepared for tests called out in the NCAP JTP. Section 3 provides an overview of the alternative aluminum pretreatments. In Section 4, initial surface preparation and initial paint applications are described. Section 5 presents the results of the tests conducted on various aluminum alloys for nonchromate aluminum pretreatment alternatives. Section 6 provides an overview of uncertainty associated with nonchromated systems, and Section 7 presents the implementation status of alternative aluminum pretreatments in other organizations. The results of the analysis will be used to support and justify field testing on components or in-service platforms where technical performance is highly dependant on service environment and overall platform design and use.

2.0 TEST PROTOCOL DESCRIPTION

Eight non-chromate aluminum pretreatments were prepared for tests called out in the NCAP JTP. Table 2.1 lists all engineering and testing requirements, and acceptance criteria identified in the NCAP JTP for validating alternatives to chromate conversion coatings.

Table 2.1: Engineering and Testing Requirements

Engineering Requirement	Test	JTP Section	Acceptance Criteria
Corrosion Resistance	Neutral Salt Fog on Unpainted Substrate with Pretreatment	3.1	• Class E: 7 days with no visible sign of corrosion whatsoever; spots and discoloration are acceptable; lightening of coating is acceptable. • Class B1: 7 days with no visible sign of corrosion; lightening of coating is acceptable. • Class B2: 14 days with no visible sign of corrosion; lightening of coating is acceptable.
Corrosion Resistance	Neutral Salt Fog on Scribed, Painted Substrate	3.2	• Class C: 3,000 hours with no evidence of corrosion (minor surface corrosion in scribe permissible).
Corrosion Resistance	SO_2 Salt Fog on Scribed, Painted Substrates	3.3	• Class C: 500 hours with no evidence of corrosion (minor surface corrosion in scribe permissible).
Corrosion Resistance	Cyclic Corrosion Test on Scribed, Painted Substrates	3.4	• Class C: Equivalent or improved performance compared to controls.
Corrosion Resistance	Filiform Corrosion Resistance	3.5	All filaments ≤ 1/4"; Majority < 1/8".
Corrosion Resistance	Marine Atmospheric Test (Beach Test) Exposure on Scribed, Painted Substrates	3.6	Class C: Equivalent or improved performance compared to chromate controls.
Adhesion	Wet Tape Adhesion and Water Resistance of Painted Substrates	3.8	Method A: Rating of ≤ 4A.
Adhesion	Dry Tape Adhesion of Painted Substrates	3.9	Method B: Loss of two or more complete primer squares shall constitute failure (≤ 4B).
Electrical Resistance	Electrical Conductivity of Unpainted, Pretreated Substrates	3.11	• <5 milliohms/square-inch as coated. • <10 milliohms/square-inch after 168 hours neutral salt fog exposure
Environmental, Safety and Occupational Health (ESOH)	Toxicology	3.12	Less toxic than MIL-C-81706 chromate conversion coating control per EPA Toxicity Categories (40 CFR 156.10).
Reparability	Reparability	3.13	Corrosion resistance, paint adhesion, and electrical contact resistance equal to or better than controls.

Paint adhesion, bare corrosion, and electrical contact resistance tests were completed first. After achieving acceptable paint adhesion results, painted corrosion tests were then completed. For all testing, alternatives were applied and tested by DoD or contractor personnel and not at vendor sites. Alternatives not available for "in-service" testing were considered immature for this project. Alternatives must reach maturity before depots and OEMs will consider them for implementation.

Alternatives were also rated on process flexibility. Parameters such as number of solutions or steps in the process, heating requirements, and curing requirements were detailed. Processes that require elevated temperatures for pretreatment solutions or curing may be appropriate for immersion application, but may not be applicable for spray or wipe application to already-assembled platforms.

Coating usage was divided into the following three categories:

> B - Unpainted (bare) substrates requiring maximum corrosion resistance.
> C - Painted surfaces requiring maximum paint adhesion and corrosion resistance.
> E - Unpainted (bare) surfaces for electrical applications requiring corrosion resistance and low resistivity.

Test results for each coating system lead to a rating based on overall performance. Table 2.2 lists the rating classes for these coating systems.

Table 2.2: Rating Classes for Coating Systems

Rating Class	Requirement
B1	Bare corrosion resistance for 7 days.
B2	Bare corrosion resistance for 14 days.
C1	Painted corrosion resistance and paint adhesion using MIL-P-23377G primer.
C2	Painted corrosion resistance and paint adhesion using MIL-PRF-85582B Class C2 primer.
C3	Painted corrosion resistance and paint adhesion using MIL-PRF-85582B Class N primer.
C4	Painted corrosion resistance and paint adhesion using MIL-P-53022B primer.
C5	Painted corrosion resistance and paint adhesion using MIL-P-53030A primer.
E	Bare corrosion resistance for 7 days and acceptable electrical conductivity.

Substrate Descriptions: Table 2.3 lists alloy name, composition, and typical use for each of the 5 substrates selected for testing. These substrates represent a cross section of aluminum alloys used in the joint community.

Table 2.3: Substrate Descriptions

Alloy Name	Composition	Typical Use/ Field Test Platforms
2024-T3 (clad used for Filiform Corrosion Test)	4.5% Cu, 1.5% Mg, 0.6% Mn	Aircraft structures, rivets, hardware, truck wheels.
2219-T87	6.3% Cu, 0.3% Mn	Structural uses at high temperatures, high strength weldments.
5083	4.5% Mg, 0.7% Mn	Applications requiring a weldable, moderate-strength alloy having good corrosion resistance. Marine and welded structural applications.
7075-T6	5.5% Zn, 2.5% Mg, 1.5% Cu, 0.3% Cr	Applications where very good strength and good resistance to corrosion are required. Aircraft structural parts.
6061-T6	1.0% Mg, 0.6% Si, 0.25% Cu, 0.25% Cr	Applications where good strength, formability, weldability, and very good resistance to corrosion are required.

Experimental Procedure: All coupons for the entire NCAP JTP were procured and prepared at the same time at NAVAIR's facilities at Patuxent River, MD. Coupons used were nominally 3.0 inches by 5.0 inches for paint adhesion and painted corrosion testing and 3.0 inches by 10.0 inches for bare corrosion and electrical contact resistance testing. Coupons varied in thickness depending on the alloy. All nine pretreatments, including the chromate conversion coating control Alodine 1200S, were applied over a two-week period for all painted coupon tests. Pretreatments were applied by manufacturer's recommendations using the same alkaline cleaning and deoxidizing chemicals for all processes: Turco 4215 alkaline cleaner and Turco Smut-GO NC, respectively. The coatings were then allowed to stand overnight with subsequent primer and topcoat application. The coating system's respective primer coats were applied within 24 hours after the pretreatment application for each pretreatment for each alloy, and the topcoats were applied after 24-hour primer cure. The full coating system was then cured at ambient conditions for 14 days before testing. The coupons were then sorted for each JTP test, respectively, which are discussed in Section 5.0.

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3.0 NON-CHROMATE CONVERSION COATING ALTERNATIVES

The main advantage of any alternative is the elimination of hexavalent chromium. In most cases the alternatives are trying to match the process and technical performance of the chromate solutions and coatings. Section 3.0 describes the alternatives being evaluated in this report.

3.1 Alodine 1200S

Alodine 1200S is the control process and coating used for this evaluation. The solution is mixed from powdered chemicals and yields a solution that can be used by immersion, spray, or wipe processes. This product is qualified to MIL-OTL-81706A. Final coatings are light tan to iridescent gold depending on alloy.

3.2 Bi-K Aklimate

Bi-K solutions are proprietary aqueous mixtures designed to produce an adhesion-promoting coating on aluminum alloys. The solution is used in a similar fashion to conventional chromate pretreatments. Rinsing yields the final coating. Although not processed by spray or wipe methods in this project, these appear feasible. Aklimate coatings are clear and colorless.

3.3 Boeing Boegel Sol-gel (Now Available From Advanced Chemistry & Technology Inc. as AC-131)

Boegel EP-II conversion coating is a non-chromated solution that is designed to increase adhesion of organic coatings to aluminum, titanium, and corrosion resistant steel. The final coating solution is a product of mixing four components packaged in a “kit” that can be sized appropriately for a given application. The mixed solution has a “pot life” of 12 hours and is applied by spray, wipe, brush or dipping to leave a thin wet film on the parts. The coating is dried in place without rinsing and care must be taken to remove puddles and excess coating solution that may be retained in pockets or crevices that do not freely drain. Boegel coatings are clear and colorless and yield a slightly wet or glossy appearance.

3.4 Brent OXSiLAN® AL-0500

OXSiLAN® AL-0500 is a silane based multi-purpose, two-part liquid treatment for aluminum that is designed to improve the performance of paint systems and inhibit corrosion on non-painted surfaces. It does not contain any regulated heavy metals, phosphates, nitrites, or molybdates. The solution is used in a similar fashion to conventional chromate pretreatments and can be applied via immersion, spray or wipe methods. Coatings are not rinsed and allowed to dry in place. Chemetall Oakite purchased Brent in 2001. The OXSiLAN coating is clear and colorless and yields a surface with slightly wet or glossy appearance.

3.5 Fortune Chemical Company X-It PreKote™

X-It PreKote is a non-chromated conversion coating used for metal surface pretreatment and pre-coating prior to painting. It is designed to promote paint bonding on aluminum, stainless steel, titanium, magnesium, and carbon steel. It is biodegradable, non-toxic, non-flammable, non-hazardous, non-corrosive, and free of phosphates and heavy metals. The solution is applied by a manual or automated scrubbing process, requiring multiple material application, scrubbing, drying, and rinsing steps. As a result, the product is not amenable to immersion or spray processing. PreKote has a slightly gray tint as applied.

3.6 Henkel Surface Technologies Alodine 5200® and Alodine® 5700

Alodine 5700 is the ready-to-use, or pre-mixed, version of Alodine 5200. The solution is used in a similar fashion to conventional chromate pretreatments. A major benefit is that it can be applied by immersion, spray, and wipe application methods with a few minutes dwell time similar to chromate conversion coatings. Coating can be applied using rinse or dried in place. Deposited coatings have a light color ranging from blue to tan depending on the alloy.

3.7 MacDermid Chemidize® 727ND

Chemidize® 727ND is a non-chromated product that is designed to clean and treat an aluminum surface in a single operation. The solution is pre-thickened paste-like material designed to be brush applied to surface during processing. Material rinsing from coupon surface required water impingement or mechanical action to remove. Once disturbed the material was easy to rinse. As formulated, the material is not amenable to immersion processing and difficult to spray. The 727ND leaves aluminum surfaces a bright metallic color with no visible evidence of coating.

3.8 NAVAIR Trivalent Chromium Pretreatment (TCP)

TCP solutions generate pretreatment films on aluminum and aluminum alloys that improve corrosion inhibition and paint adhesion while maintaining electrical conductivity. The solution is used in a similar fashion to conventional chromate pretreatments. It can be applied by immersion, spray, and wipe application methods with a few minute dwell time. Since the process chemistry is based on a surface reaction, rinsing stops the reaction and yields the final coating. TCP films have a very light color ranging from purple to blue to tan, depending on the alloy.

3.9 Sanchem Safegard7000

The solution is used in a similar fashion to conventional chromate pretreatments. It is deep purple in color and was spray-applied for this project. Immersion and wipe application methods appear feasible. Sanchem 7000 with the sealer has historically demonstrated unacceptable paint adhesion. As a result, painted systems in this testing were used with the Sanchem 7000 without sealer to maximize paint adhesion. Since prior evaluations noted unacceptable paint adhesion with Seal #2, it was only used to evaluate bare (unpainted) corrosion resistance. Sanchem 7000 coatings were an attractive bronze-gold color, similar to chromate conversion coatings.

Table 3.1 provides the summary of non-chromate pretreatment alternatives being evaluated in Phase I: Lab Validation of this project. Alternative chemistry, applications, advantages and disadvantages are all detailed.

Table 3.1: Summary of Non-Chromate Conversion Coating Alternatives

Product	Chemistry (from MSDSs)	Processing	Application Methods	Classification*	Advantages	Disadvantages
Alodine 1200S	Chromic acid, complex fluorides, accelerators	One solution, room temperature	Immersion, spray, wipe	E, B, C	Easy to use, standard	Contains hexavalent chromium
Alodine 5200 and Alodine 5700	Organometallic zirconate complex	One solution, room temperature	Immersion, spray, wipe	C	Easy to use, room temperature, drop-in replacement for chromates	Minimal corrosion inhibition, impractical color change
Bi-K Aklimate	Proprietary	Single solution, room temperature	Immersion, spray, wipe	C	Easy to use, room temperature solution replacement for chromates	Minimal bare corrosion resistance, clear and colorless (no color change)
Boeing Boegel Sol-gel	Organosiloxanes, zirconates	One solution, room temperature	Immersion, spray, wipe	C	Easy to use, room temperature, drop-in replacement for chromates, dry in place	Minimal corrosion inhibition, dry in place, kitting and solution life, clear and colorless (no color change)
Brent Oxsilan AL-0500	Organosilane, ethanol, fluorotitanic acid	One solution, room temperature	Immersion, spray, wipe	C	Easy to use, room temperature solution replacement for chromates, dry in place	Minimal corrosion inhibition, dry in place, clear and colorless (no color change)
MacDermid Chemidize 727ND	Butyl cellosolve, other proprietary	One solution, room temperature	Spray, wipe	C	One solution, room temperature	Minimal corrosion inhibition, clear and colorless (no color change)

NAVAIR TCP	Chromium III sulfate basic, potassium hexafluorozirconate	One solution, room temperature, one to five minute dwell	Immersion, spray, wipe	E, B, C	Easy to use, drop-in replacement for chromates; corrosion inhibition present; toxicology study completed	Contains chromium, impractical color change
Sanchem Safegard 7000 (with Seal #2)	Potassium permanganate, seal: polyacrylic acid, poly propylene glycol, fatty acid esters	Two solution (coating and seal), elevated temp (200 °F) cure on sealer; pretreatment is ambient	Immersion, spray, wipe	C	Pleasing bronze-gold color to coating, easy to use	Minimal corrosion inhibition without sealer. Sealer requires elevated temperature cure and has poor adhesion characteristics.
X-It PreKote	Diethylene glycol monobutyl ether, n-methyl pyrrolidone	One solution, wipe on by mechanical abrasion of substrate, room temperature	Wipe	C	Non-toxic coating left as a result of process	Minimal bare corrosion resistance, laborious manual application required, minimal color change

* E=electrical, B=bare, C=coated

4.0 INITIAL PROCESSING INFORMATION

4.1 Initial Surface Preparation

For painted corrosion tests, coupons were 3 inches wide by 5 inches long and of thickness (0.020-0.125 inch) as supplied by vendor. Test coupons were painted within 24 hours of the application of the pretreatment. For unpainted corrosion and electrical conductivity tests, coupons were 3 inches wide by 10 inches long and of suitable thickness.

4.1.1 Coupon Preparation, Cleaning, and Deoxidizing

In a typical process line, aluminum substrates are cleaned to remove oils, dirt, residue, and then deoxidized to provide an optimum, water-break free surface for reaction with the pretreatment solution. The following general immersion processing procedures were followed for each alternative:

Procurement: Test coupons of alloys 2024-T3, 7075-T6, 6061-T6 and clad 2024-T3 were purchased from Q-Panel. Aluminum alloys 5083-H131 and 2214-T87 were purchased from Pierce Aluminum. Coupons were engraved on the reverse side with a unique tracking number.

Degreasing: The 2024, 7075, clad 2024, and 6061 were degreased and cleaned as supplied. The 2219 and 5083 were received with mill marks and other dirt present and were degreased in methyl ethyl ketone (MEK) immersion followed by acetone immersion. Solvent cleaned coupons were then racked for cleaning per the next step.

Cleaning: Coupons were racked in titanium fixtures and immersed in Turco 4215 at about 120 °F for 15 minutes. Air agitation was maintained in the cleaner tank during processing. Cleaning was followed by two warm tap water rinses for at least one minute each.

Deoxidizing: Immediately following the cleaning rinse, coupon racks were immersed in Turco Smut-Go NC at ambient temperature for 1-15 minutes. There was no solution or rack agitation during this step. Deoxidizing was followed by two cool tap water rinses for at least one minute each followed by a flowing deionized water rinse.

Pretreatment: Immediately following the deoxidizer rinse, coupon racks were processed for each alternative according to vendor instructions.

4.1.1.1 Application Procedure for Each Alternative

Work instructions for the make up and use of each alternative were written based on the technical literature supplied from alternative suppliers. Table 4.1.1.1.1 provides a summary of the general processing protocol for each alternative. All were applied at room temperature and straightforward to set up and apply.

Table 4.1.1.1.1: Processing Details

Alkaline Clean	Deoxidize	Coating	Coating Deposition
15 minute immersion in 120 °F Turco 4215; double rinse in reverse flow hot tap water	Immersion in Turco Smut Go NC; double rinse in static ambient temperature tap water and final rinse in flowing deionized water; 15 minute immersion for aluminum alloys 2024 and 2219, 1 minute immersion for 6061 and 7075 and clad 2024, and 30 second immersion for 5083	Alodine 1200S	1 minute immersion; double rinse in static ambient temperature tap water and final rinse in flowing deionized water
		Alodine 5200	1 minute immersion; double rinse in static ambient temperature tap water and final rinse in flowing deionized water
		Bi-K Aklimate	1 minute immersion; double rinse in static ambient temperature tap water and final rinse in flowing deionized water
		Boegel	Spray applied keeping surface wet for 5 minutes, excess solution drained by inclining coupons at 20 degree angle
		Chemidize 727D	Brush on with 10 minute dwell; double rinse with flowing ambient temperature tap water and final rinse in flowing deionized water
		Oxsilan AL-0500	1 minute immersion; dry in place (no rinse)
		Sanchem Safeguard7000	1 minute spray dwell; double rinse with flowing ambient temperature tap water and final rinse in flowing deionized water
		TCP	2 minute immersion; double rinse in static ambient temperature tap water and final rinse in flowing deionized water
		X-It PreKote	Solution scrubbed onto coupons surface using saturated brown Scratch-Brite pad. Coating air dried in place. Coat re-applied in similar fashion and then double rinsed in flowing ambient temperature tap water and final rinse in flowing deionized water

4.1.1.2 Coating Weight Measurement

Coating weight measurement was used to quantify the amount of coating being deposited by a given process. Coating weights for the alternatives were evaluated using aluminum alloy 2024-T3. Three replicates of each coating were prepared, weighed and stripped per MIL-DTL-81706A: freshly coated coupons were weighed and then immersed in 50% nitric acid solution for five minutes. An aerospace wipe was used to gently rub coupon on both sides to help remove the coating. The coupons were rinsed thoroughly in tap water followed by deionized water and then blown dry with compressed air. The coupons were re-weighed at this time. The difference in weight before and after stripping yields the coating weight in milligrams. The unit of measure for coating weight is milligrams per square foot as specified in MIL-DTL-81706A.

Table 4.1.1.2.1 details coating weight data for each alternative. No alternative deposits as much coating weight as Alodine 1200S or meets the coating weight requirement of MIL-DTL-81706A. TCP and Boegel show the highest coating weight among the alternatives, averaging 22 milligrams per square foot, with the remaining coatings yielding weights in the range of 7 to 16 milligrams per square foot. Coating weights alone are not indicative of corrosion performance or paint adhesion but once a correlation is established, they are a potential method for quality control.

Table 4.1.1.2.1: Coating Weights of Alternative Coatings on 2024-T3

Coating	Coupon #	Total Weight after Coating (gm)	Total Weight after Stripping (gm)	Coating Weight (mg/ft^2)	Average Coating Weight (mg/ft^2)
Alodine 1200S	1	21.6601	21.6522	37.92	37.44
	2	21.6437	21.6350	41.76	
	3	21.6192	21.6124	32.64	
Alodine 5200	1	21.6395	21.6369	12.48	14.72
	2	21.6228	21.6197	14.88	
	3	21.5997	21.5962	16.80	
Bi-K Aklimate	1	21.5549	21.5542	3.36	10.88
	2	21.5389	21.5357	15.36	
	3	21.5152	21.5133	13.92	
Boegel (method B)	1	16.9646	16.9592	25.92	22.40
	2	16.7746	16.7703	20.64	
	3	16.9477	16.9434	20.64	
Chemidize 727D	1	21.5235	21.5226	4.32	7.68
	2	21.5056	21.5039	8.16	
	3	21.4832	21.4810	10.56	
Oxsilan AL-0500	1	21.6024	21.5992	15.36	16.00
	2	21.5853	21.5815	18.24	
	3	21.5622	21.5592	14.40	
Sanchem 7000	1	21.5445	21.5413	15.36	14.40
	2	21.5268	21.5238	14.40	
	3	21.5040	21.5012	13.44	
TCP	1	21.6262	21.6215	22.56	22.88
	2	21.6095	21.6045	24.00	
	3	21.5865	21.5819	22.08	
X-It PreKote	1	21.7740	21.7729	10.56	[illegible]6
	2	21.7793	21.7783	9.60	
	3	21.7780	21.7768	11.52	

4.1.1.3 Coupon Handling After Coating

Following pretreatment, coupons were allowed to stand 24 hours before handling.

4.2 Initial Paint Application

Each coating system's respective primer coats were applied following pretreatment application. The topcoats were applied after 24-hour primer cure. The full coating system was then cured at ambient conditions for 14 days before testing. Coupons were then sorted for each JTP test.

4.2.1 Description of Paints

In order to closely match conditions found in currently fielded equipment, five organic coating systems commonly used in DoD systems were selected. The following primers and topcoats were used in the Phase I Study. These primers and topcoats represent a cross-section of those used in the joint community.

4.2.1.1 MIL-PRF-23377G, Type I, Class C

MIL-PRF-23377G is a two component, low volatile organic compound (VOC), solvent-borne, epoxy primer coating that is corrosion inhibiting and chemical and solvent resistant. The maximum VOC content of the admixed primer coatings is 340 grams per liter (2.8 pounds per gallon). Type I specifies standard pigments. Class C is for strontium chromate based corrosion inhibitors and Class N is for non-chromate based corrosion inhibitors. Revision F took effect in 1989 and was superseded by Revision G in 1994.

4.2.1.2 MIL-PRF-85582 C, Type II, Class C2 and N

MIL-PRF-85582C is a waterborne, epoxy primer coating that is corrosion inhibiting, chemical and solvent resistant, and has a maximum VOC content of 340 grams per liter (2.8 pounds per gallon). Type II specifies low infrared reflective pigments. Class C2 is for strontium chromate based corrosion inhibitors and Class N is for non-chromate based corrosion inhibitors. Revision B took effect in 1994 and was superseded by Revision C in 1997.

4.2.1.3 MIL-P-53022

MIL-P-53022 is a flash drying, corrosion inhibiting epoxy primer for ferrous and nonferrous metals. The primer is lead and chromate free and meets the air pollution requirements for solvent emissions. Revision A took effect in 1983 and was superseded by Revision B in 1998.

4.2.1.4 MIL-P-53030

MIL-P-53030 is a water-reducible, air-drying, corrosion inhibiting, epoxy-type primer for pretreated ferrous and non-ferrous metals. The primer is lead and chromate-free and is compatible with chemical agent resistant aliphatic polyurethane topcoats. The primer contains no more than 340 grams per liter (2.8 pounds per gallon) of VOCs, as applied. Revision A took effect in 1992.

4.2.1.5 MIL-PRF-85285C Topcoat

MIL-PRF-85285 topcoat is a high-solids, aliphatic polyurethane coating with the maximum VOC content specified by type. Type I is for aircraft application and has a maximum VOC content of 420 grams per liter. Type II is for ground support equipment application and has a maximum VOC content of 340 grams per liter. Revision B took effect in 1988 and was superseded by Revision C in 1997.

4.2.1.6 MIL-C-53039

MIL-C-53039 topcoat specifies Chemical Agent Resistant Coating (CARC) topcoats. This specification covers both camouflage and noncamouflage, one component chemical agent resistant, aliphatic polyurethane coating for use as a finish coat on military combat equipment.

The coating is lead and chromate (hexavalent) free and has maximum of 420 gram s/liter (3.5 lbs/gallon) VOC content. Revision A took effect in 1988.

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5.0 TEST METHODS AND RESULTS

5.1 Neutral Salt Fog on Unpainted Substrate with Pretreatment

5.1.1 Test Description

This test method evaluates a coating system's ability to prevent substrate corrosion. Operation of the fog chamber for this test is in accordance with ASTM B 117 [*Standard Practice for Operating Salt Spray (Fog) Apparatus*].

The five replicates of each coating per alloy were placed into a fog chamber at a 6-degree angle. The coupons were not allowed to contact other surfaces in the chamber, and condensate from a coupon also did not contact any other coupons. The salt solution and the fog chamber were prepared as specified in the Test Methodology of the JTP. The nozzles were adjusted in the fog chamber so that sprayed salt solution did not directly impinge on the coupon surfaces. The fog chamber was operated continuously for the test duration. Coupons were then evaluated per ASTM D 1654 Method B for surface corrosion at 24-hour intervals for the first 4 days, then at 7, 10 and 14 days. This rating method allows for performance evaluation of coatings that do not meet MIL-OTL-81706A, which requires no evidence of corrosion after 2 weeks of ASTM B 117 exposure. The coupons were carefully removed at the end of the test duration and cleaned by gently flushing with running water [water temperature less than 38 degrees °C (100°F)]. The coupons were air-dried at ambient conditions then visually examined for corrosion, ignoring edges and contact points.

5.1.2 Test Results

Three of the eight alternatives were chosen for this test: TCP, Alodine 5200 and Sanchem 7000 with Seal #2. Prior testing demonstrated that the other alternatives have poor bare corrosion resistance and would not be candidates for unpainted applications. Sanchem 7000 without sealing shows poor bare corrosion performance, so Seal #2 was used for this particular test.

Alodine 1200S and TCP coatings exposed to 1-week and 2-week Neutral Salt Fog Exposure show no corrosion on 2024-T3, 7075-T6, and 5083-H131. Alodine 5200 and Sanchem 7000 with Seal #2 show surface corrosion within 48 hours on 2024-T3 and 7075-T6. Alodine 5200 and Sanchem 7000 with Seal #2 show some corrosion on 5083-H131 after 2-week exposure. TCP performs best on 2219-T87 showing some minor pitting after 2 weeks of exposure. The tables and photos below detail corrosion performance for pretreatments on each alloy. Each rating is an average of 5 test coupons.

Table 5.1.2.1: Aluminum alloy 2024-T3

Pretreatment	Average Rating (5 Panels) after Exposure to ASTM B 117 Neutral Salt Fog (ASTM D 1654 Method B)			
	24 hrs	48 hrs	168 hrs	336 hrs
Alodine 1200S	10.0	10.0	10.0	10.0
Alodine 5200	9.0	8.0	3.0	-
Sanchem 7000 with Seal #2	9.0	8.0	2.0	-
TCP	10.0	10.0	10.0	10.0

Table 5.1.2.2: Aluminum alloy 7075-T6

Pretreatment	Average Rating (5 Panels) after Exposure to ASTM B 117 Neutral Salt Fog (ASTM D 1654 Method B)			
	24 hrs	48 hrs	168 hrs	336 hrs
Alodine 1200S	10.0	10.0	10.0	10.0
Alodine 5200	10.0	9.0	6.0	-
Sanchem 7000 with Seal #2	9.0	8.0	2.0	-
TCP	10.0	10.0	10.0	10.0

Table 5.1.2.3: Aluminum alloy 2219-T87

Pretreatment	Average Rating (5 Panels) after Exposure to ASTM B 117 Neutral Salt Fog (ASTM D 1654 Method B)			
	24 hrs	48 hrs	168 hrs	336 hrs
Alodine 1200S	10.0	10.0	5.4	5.0
Alodine 5200	0.0	-	-	-
Sanchem 7000 with Seal #2	9.0	8.0	0.0	-
TCP	10.0	10.0	9.0	9.0

Table 5.1.2.4: Aluminum alloy 5083-H131

Pretreatment	Average Rating (5 Panels) after Exposure to ASTM B 117 Neutral Salt Fog (ASTM D 1654 Method B)			
	24 hrs	48 hrs	168 hrs	336 hrs
Alodine 1200S	10.0	10.0	10.0	10.0
Alodine 5200	10.0	10.0	9.0	7.0
Sanchem 7000 with Seal #2	10.0	10.0	9.0	8.0
	10.0	10.0	10.0	10.0

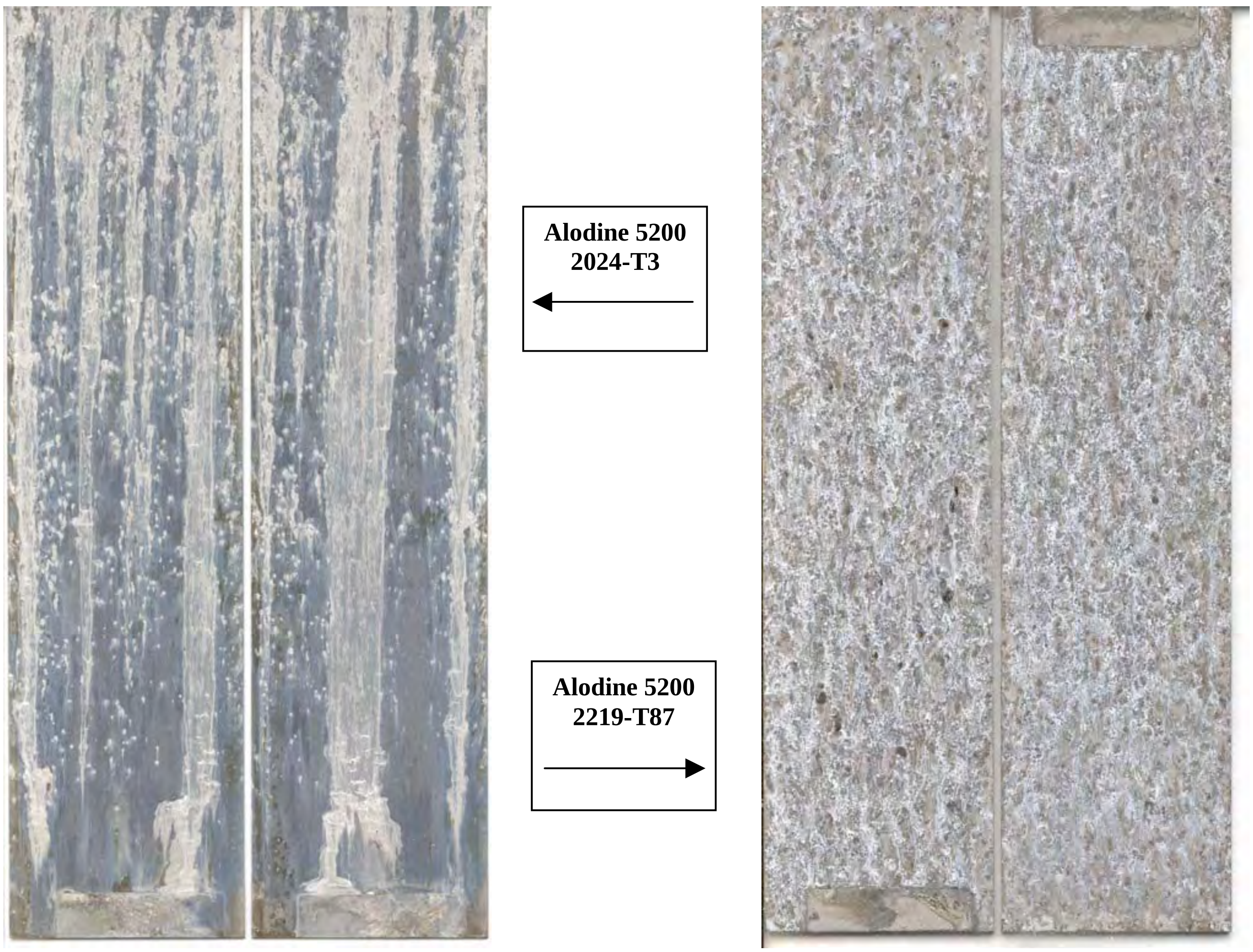


Figure 5.1.2.1: Alodine 5200 on 2024 and 2219 After 1 Week Exposure

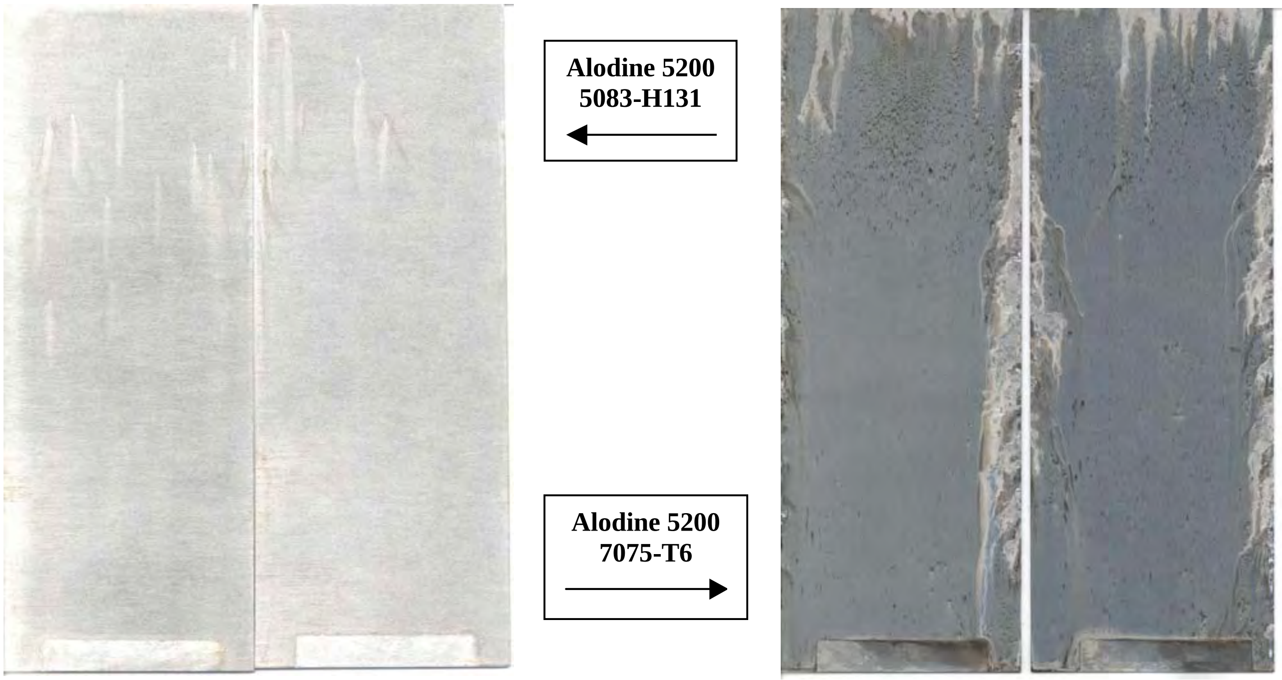


Figure 5.1.2.2: Alodine 5200 on 5083 and 7075 After 1 Week Exposure

Figure 5.1.2.3: Sanchem 7000 With Sealer # 2 on 5083-H131 After 2 Weeks Exposure

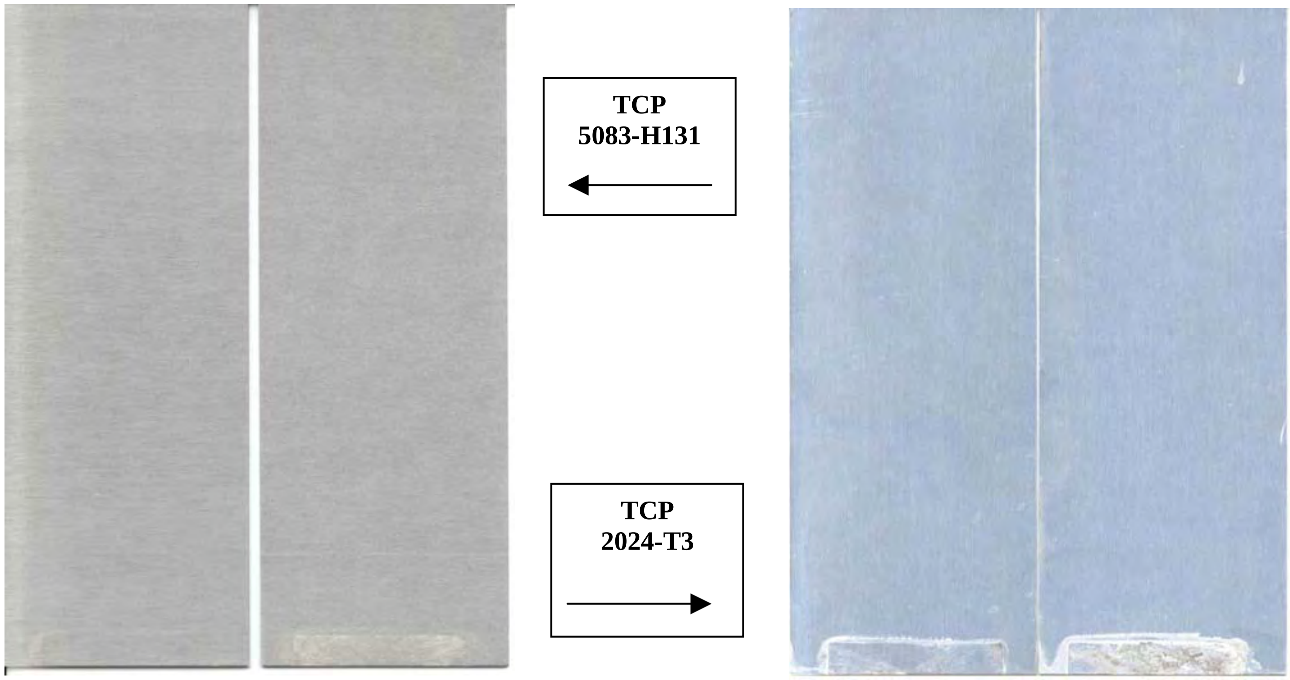


Figure 5.1.2.4: TCP on 5083 and 2024 After 2 Weeks Exposure

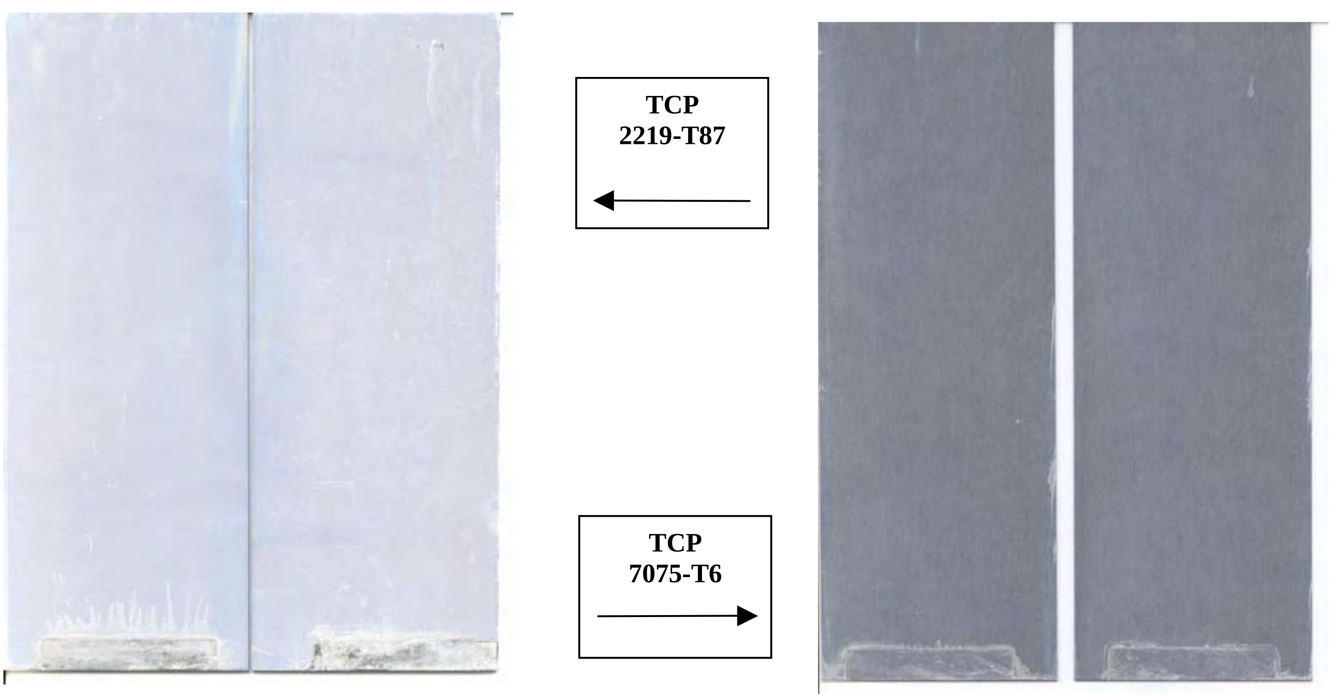


Figure 5.1.2.5: TCP on 2219 and 7075 After 2 Weeks Exposure

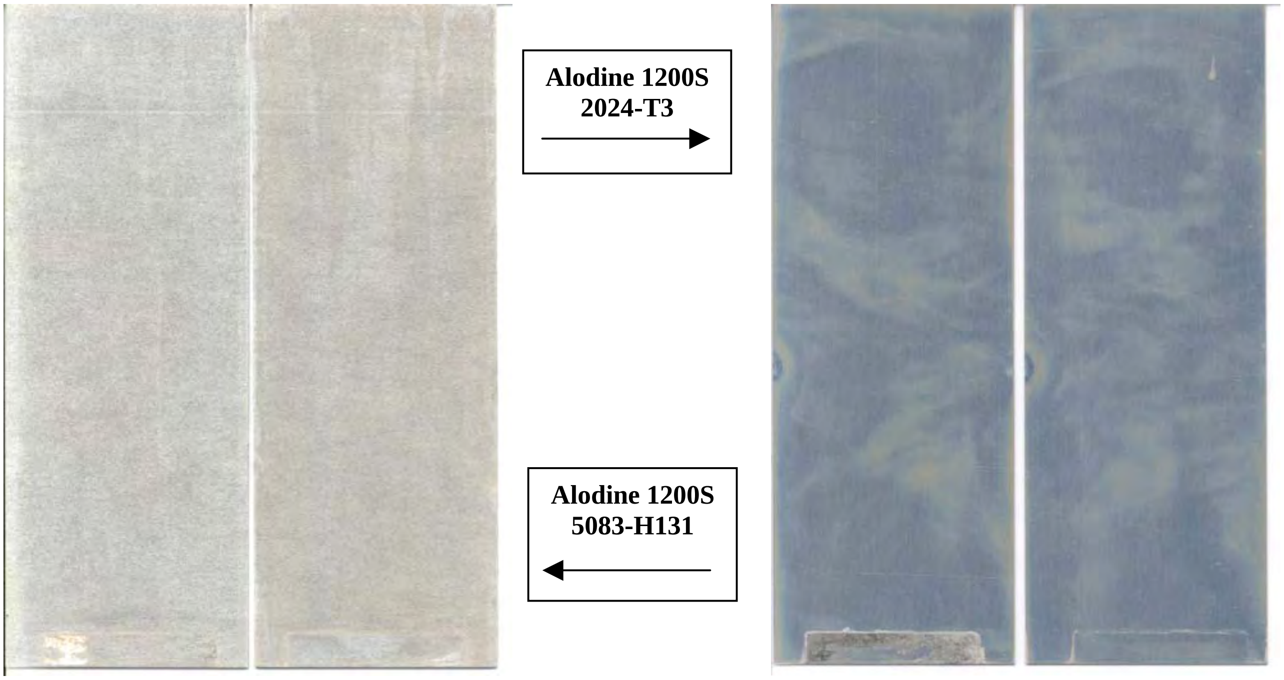


Figure 5.1.2.6: Alodine 1200S on 5083 and 2024 After 2 Weeks Exposure

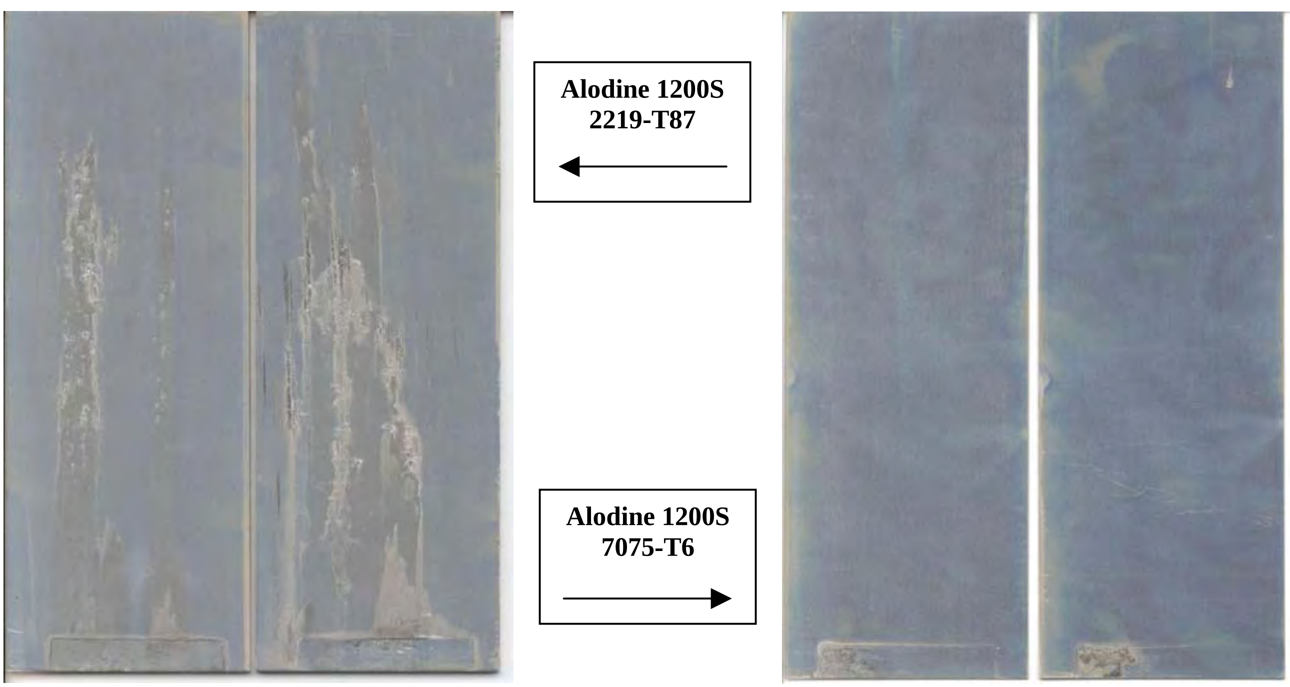


Figure 5.1.2.7: Alodine 1200S on 2219 and 7075 After 2 Weeks Exposure

5.2 Electrical Contact Resistance Unpainted, Pretreated Substrates

5.2.1 Test Description

This test method evaluates a coating system's ability to provide initial electrical contact resistance after application of pretreatment and after exposure to a corrosive environment. Pretreated aluminum 6061-T6 coupons were evaluated for electrical conductivity using apparatus and method described in MIL-DTL-81706A. Operation of the fog chamber for this test is in accordance with ASTM B 117 [*Standard Practice for Operating Salt Spray (Fog) Apparatus*]. Testing was completed by NAVAIR personnel at the Patuxent River, MD test facility.

In order to expose substrate to corrosive environment, they were placed into a fog chamber at a 6-degree angle for 168 hours. The coupons were not allowed to contact other surfaces in the chamber, and condensate from a coupon did not contact any other coupons. The salt solution and the fog chamber were prepared as specified in the Test Methodology of the JTP. The nozzles were adjusted in the fog chamber so that sprayed salt solution did not directly impinge on the coupon surfaces. The fog chamber was operated continuously for 168 hours. The coupons were then carefully removed at the end of the test duration, and cleaned with running water (water temperature less than 38 °C (100°F)). The coupons were then air-dried at ambient conditions, and then visually examined for corrosion.

5.2.2 Test Results

All eight alternatives and the chromate control were coated onto the 6061 test coupons and evaluated for initial electrical contact resistance. A sister set was exposed to salt fog and evaluated for corrosion resistance.

All coatings passed the initial electrical conductivity test by measuring less than 5 milli-ohms per square inch per the JTP. Only Alodine 1200S and TCP completed the salt fog test with no signs of corrosion on any coupon. The seven other alternatives all began corroding before the end of the test duration and therefore do not meet the test criteria. Due to the corrosion on the substrate, electrical contact resistance measurements could not be completed for those coatings.

Data for as-coated TCP and Alodine 1200S are presented in Tables 5.2.2.1, 5.2.2.3, and 5.2.2.5. Alodine 1200S was coated at two different immersion times to evaluate potential impact on contact resistance. As the tables show, TCP and Alodine 1200S deposited by 30- and 60- second immersion times meet the contact resistance test criteria.

After the coupons with Alodine 1200S and TCP coatings were removed from the salt fog chamber, rinsed and dried, they were subjected to electrical contact resistance measurement. Tables 5.2.2.2, 5.2.2.4, and 5.2.2.6 show the test results for all 15 coupons. Although each coating showed average measurement increases over the as-coated set, all coatings met the test criteria by measuring less than 10 milli-ohms per square inch. Most measurements still fell below the more strict as-coated requirement.

The Alodine 1200S with 60-second immersion time did show higher measurements than the 30-second immersion set, especially after salt fog. The 60-second immersion time was used for all other coupons in the JTP tests showing that one immersion time can satisfy bare corrosion, paint adhesion, painted corrosion, and electrical contact resistance requirements. This is true for the TCP coating as well. A 2-minute immersion time was used for the electrical contact resistance test, the same as for all the other testing.

Table 5.2.2.1: Contact Resistance of As-Coated TCP

As-Coated	**Spot Measurements on Coupon (milliohms/in^2) per MIL-DTL-81706**												
Coupon #	1	2	3	4	5	6	7	8	9	10	Average	50 Avg	Standard Deviation
1	1.52	1.66	1.79	1.46	1.80	1.26	1.67	1.59	2.01	1.16	1.59		
2	1.35	1.47	1.36	1.34	1.51	1.22	1.25	1.25	1.20	1.33	1.33		
3	1.42	1.72	2.15	2.14	1.55	1.34	1.72	1.54	1.05	1.58	1.62	1.57	0.30
4	1.33	1.69	1.70	1.97	1.07	1.33	1.57	1.54	1.36	1.83	1.54		
5	1.33	1.82	1.81	1.92	2.18	1.54	1.85	2.21	1.09	1.86	1.76		

Table 5.2.2.2: Contact Resistance of TCP after exposure to Salt Fog for 168 hours

After Exposure to Salt Fog for 168 hours	**Spot Measurements on Coupon (milliohms/in^2) per MIL-DTL-81706**												
Coupon #	1	2	3	4	5	6	7	8	9	10	Avg	50 Avg	Std Dev
1	3.05	4.46	3.48	3.36	4.25	2.70	2.42	3.72	2.43	5.16	3.50		
2	5.39	2.93	6.18	3.03	7.27	3.20	4.67	4.44	4.15	2.94	4.42		
3	2.40	2.36	2.50	3.94	2.45	2.11	4.23	2.40	1.25	3.83	2.75	3.19	1.45
4	3.18	1.83	3.01	1.45	4.35	7.65	5.20	2.39	1.52	1.89	3.25		
5	2.34	1.80	2.19	2.13	2.06	2.45	2.10	1.71	1.69	1.80	2.03		

Table 5.2.2.3: Contact Resistance of Alodine 1200S As-Coated (30-Second Immersion)

As-Coated	**Spot Measurements on Coupon (milliohms/in^2) per MIL-DTL-81706**												
Coupon #	1	2	3	4	5	6	7	8	9	10	Avg	50 Avg	Std Dev
1	2.09	2.18	2.26	2.23	2.47	1.49	1.46	1.68	1.23	0.84	1.79		
2	1.34	1.42	1.56	1.28	1.26	1.40	1.21	1.25	1.09	0.73	1.25		
3	1.01	1.50	1.49	1.92	1.34	1.70	1.40	1.44	1.33	1.08	1.42	1.48	0.37
4	1.95	1.56	2.01	1.22	1.40	1.70	1.63	1.47	1.30	0.99	1.52		
5	1.42	1.23	0.98	1.12	1.57	1.58	1.51	1.81	1.10	1.67	1.40		

Table 5.2.2.4: Contact Resistance of Alodine1200S After Exposure (30-Second Immersion)

After Exposure to Salt Fog for 168 hours	Spot Measurements on Coupon (milliohms/in^2) per MIL-DTL-81706											
Coupon #	1	2	3	4	5	6	7	8	9	10	Avg	50 Avg	Std Dev
1	2.32	3.52	3.39	2.08	1.33	1.55	2.07	1.31	1.34	1.70	2.06		
2	2.96	1.75	2.68	2.07	1.66	3.11	1.98	1.64	2.44	2.23	2.25		
3	1.66	2.11	0.74	1.23	0.90	2.54	2.46	2.24	1.65	2.03	1.76	1.98	0.68
4	2.07	2.53	2.97	2.12	1.09	1.56	2.33	2.34	1.00	1.15	1.92		
5	1.84	3.07	1.02	1.12	1.03	1.63	2.59	2.56	2.41	1.66	1.89		

Table 5.2.2.5: Contact Resistance of Alodine 1200S, As-Coated (60-Second Immersion)

As-Coated	Spot Measurements on Coupon (milliohms/in^2) per MIL-DTL-81706												
Coupon #	1	2	3	4	5	6	7	8	9	10	Avg	50 Avg	Std Dev
1	1.25	2.23	2.20	2.14	1.90	1.19	1.22	1.10	0.93	1.08	1.52		
2	1.41	2.44	1.49	1.27	1.06	0.99	1.36	1.41	1.56	1.70	1.47		
3	2.08	1.42	1.46	2.25	1.76	1.91	2.27	2.80	2.25	1.77	2.00	1.71	0.48
4	1.86	1.23	1.18	1.12	0.93	1.70	2.13	2.06	2.00	2.03	1.62		
5	1.88	2.30	2.26	2.13	2.17	1.54	2.66	1.78	1.32	1.40	1.94		

Table 5.2.2.6: Contact Resistance of Alodine 1200S After Exposure (60-Second Immersion)

After Exposure to Salt Fog for 168 hours	Spot Measurements on Coupon (milliohms/in^2) per MIL-DTL-81706												
Coupon #	1	2	3	4	5	6	7	8	9	10	Avg	50 Avg	Std Dev
1	4.89	4.76	4.54	2.61	2.83	5.06	4.03	4.73	3.62	2.80	3.99		
2	4.06	3.22	6.92	4.62	3.36	5.28	2.63	7.47	3.05	3.04	4.37		
3	4.89	7.23	6.18	8.64	6.54	1.65	1.75	5.07	9.42	6.92	5.83	4.58	2.15
4	5.03	8.31	9.20	4.66	6.49	6.80	6.82	5.66	7.28	3.15	6.34		
5	3.10	1.42	0.88	1.72	2.63	2.70	3.02	3.33	2.25	2.91	2.40		

5.3 Dry Tape Adhesion of Painted Substrates

5.3.1 Test Description

This test method describes a procedure for establishing adequacy of intercoat and surface adhesion of an organic coating by applying pressure sensitive tape over a scribed area of the coating. Method A testing was completed by NAVAIR personnel and Method B testing was completed by Army Research Laboratory (ARL) personnel at the Patuxent River, MD test facility.

Dry tape adhesion testing was conducted in accordance with ASTM D 3359, Methods A and B (Standard Test Methods for Measuring Adhesion by Tape Test, Test Method B-Cross-Cut Tape Test).

For Method A, two parallel lines were then scribed approximately one inch apart, making sure that the coating was scribed all the way through and into the substrate. Two angled "X" incisions were scribed through the coating across the parallel lines to create an "X" so that the smaller angle of the "X" was 30 to 45 degrees, making sure that the coating was scribed all the way through and into the substrate. Each line of the "X" was approximately 1.5 inches long. Figure 5.3.1.1 shows an example coupon with Method A (top) and Method B (bottom) scribe patterns. A piece of tape was immediately placed over the incisions parallel to the parallel scribe lines, and the tape was smoothed by rolling a 3-lb roller over it once. The tape was then removed rapidly at approximately a 180-degree angle. The incision area was then inspected for damage.

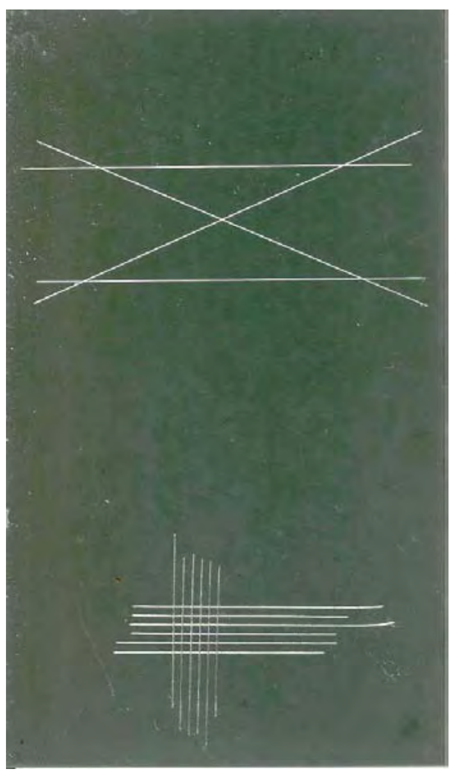


Figure 5.3.1.1: Example Coupon with Scribe Pattern After Testing

For tape adhesion testing according to ASTM D 3359, Method B; each test panel was subjected to a crosshatch tape test (minimum tape adhesion rating of 45 oz. per inch of width). The test pattern was 4 x 4 scribe lines to the metallic layer at 2-millimeter (mm) intervals (approximate) and was no closer than 12 mm from any edge. Each line was cut sequentially. Ratings were assigned in accordance with the ASTM D 3359, Method B rating scale shown in Table 5.3.1.1. The loss of two or more complete primer squares constituted failure.

Table 5.3.1.1: Rating Scale for ASTM D 3359 Method B Tape Adhesion Test

Rating Number	Description of Failure
5	The edges of the cuts are completely smooth; none of the squares of the lattice are detached.
4	Small flakes of the coating are detached at intersections; less than 5% of the area is affected.
3	Small flakes of the coating are detached along edges and at intersections of cuts. The area affected is 5 to 15% of the lattice.
2	The coating has flaked along the edges and on parts of the squares. The area affected is 15 to 35% of the lattice.
1	The coating has flaked along the edges of cuts in large ribbons and whole squares have detached. The area affected is 35 to 65% of the lattice.
0	Flaking and detachment worse than Rating 1.

5.3.2 Test Results

An additional surface treatment was included in the adhesion test to study the effectiveness of a manually cleaned and scrubbed surface to provide adequate paint adhesion. To evaluate this type of process, one set of aluminum alloys was thoroughly scrubbed with an Alconox saturated Scotch-Brite pad until a water break free surface was obtained. Coupons were then thoroughly rinsed in tap water and final deionized water rinse and allowed to stand overnight with other alternative pretreatments coatings before priming.

The tables below detail the results of dry tape adhesion per ASTM D 3359 Method A and Method B. All coatings performed acceptably in both adhesion methods with most coatings scoring 5 out of 5 per the ASTM rating method. ***Note:*** *The Boegel coating for all adhesion tests was applied by an incorrect procedure where the coating was dried in place without draining. This led to beach marks on the coupon surfaces and uneven coating thicknesses. This error was corrected in subsequent painted corrosion test coatings.*

Method A

Table 5.3.2.1: Dry Tape Adhesion per ASTM D 3359 Method A (X scribe) for Aluminum Alloys Coated with Mil-PRF-23377 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	5.0	5.0
Boegel	5.0	5.0	5.0	5.0
Chemidize 727ND	5.0	5.0	5.0	5.0
Oxsilan Al-0500	5.0	4.0	5.0	5.0
Sanchem 7000	5.0	5.0	5.0	5.0
Scrub with Alconox	5.0	5.0	5.0	5.0
TCP	5.0	4.0	5.0	3.0
X-It PreKote	5.0	5.0	5.0	4.0

Table 5.3.2.2: Dry Tape Adhesion per ASTM D 3359 Method A (X scribe) for Aluminum Alloys Coated with Mil-PRF-85582 C2 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	5.0	5.0
Boegel	5.0	5.0	5.0	5.0
Chemidize 727ND	5.0	5.0	5.0	5.0
Oxsilan Al-0500	5.0	5.0	5.0	5.0
Sanchem 7000	5.0	5.0	5.0	5.0
Scrub with Alconox	5.0	5.0	5.0	5.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.3.2.3: Dry Tape Adhesion per ASTM D 3359 Method A (X scribe) for Aluminum Alloys Coated with Mil-PRF-85582 NC Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	4.0	5.0	5.0
Bi-K Aklimate	4.0	5.0	5.0	5.0
Boegel	4.0	5.0	5.0	5.0
Chemidize 727ND	5.0	5.0	5.0	5.0
Oxsilan Al-0500	5.0	5.0	5.0	5.0
Sanchem 7000	4.0	5.0	5.0	5.0
Scrub with Alconox	4.0	5.0	5.0	5.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.3.2.4: Dry Tape Adhesion per ASTM D 3359 Method A (X scribe) for Aluminum Alloys Coated with Mil-P-53030 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	5.0	5.0
Boegel	5.0	5.0	5.0	5.0
Chemidize 727ND	4.0	5.0	5.0	5.0
Oxsilan Al-0500	5.0	5.0	5.0	5.0
Sanchem 7000	5.0	5.0	5.0	5.0
Scrub with Alconox	5.0	5.0	5.0	5.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.3.2.5: Dry Tape Adhesion per ASTM D 3359 Method A (X scribe) for Aluminum Alloys Coated with Mil-P-53022 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	4.0	5.0	5.0	4.0
Boegel	4.0	5.0	5.0	4.0
Chemidize 727ND	5.0	5.0	5.0	5.0
Oxsilan Al-0500	5.0	5.0	5.0	5.0
Sanchem 7000	4.0	5.0	5.0	4.0
Scrub with Alconox	4.0	5.0	5.0	4.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	4.0	5.0	4.0	5.0

Method B

Table 5.3.2.6: Dry Tape Adhesion per ASTM D 3359 Method B (Crosshatch) for Aluminum Alloys Coated with Mil-PRF-23377 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	5.0	5.0
Boegel	5.0	5.0	5.0	5.0
Chemidize 727ND	5.0	5.0	5.0	5.0
Oxsilan Al-0500	5.0	5.0	5.0	5.0
Sanchem 7000	5.0	5.0	5.0	5.0
Scrub with Alconox	5.0	5.0	5.0	5.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.3.2.7: Dry Tape Adhesion per ASTM D 3359 Method B (Crosshatch) for Aluminum Alloys Coated with Mil-PRF-85582 C2 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	5.0	5.0
Boegel	5.0	5.0	5.0	5.0
Chemidize 727ND	5.0	5.0	5.0	5.0
Oxsilan Al-0500	5.0	5.0	5.0	5.0
Sanchem 7000	5.0	5.0	5.0	5.0
Scrub with Alconox	5.0	5.0	5.0	5.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.3.2.8: Dry Tape Adhesion per ASTM D 3359 Method B (Crosshatch) for Aluminum Alloys Coated with Mil-PRF-85582 NC Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	4.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	5.0	5.0
Boegel	5.0	5.0	5.0	5.0
Chemidize 727ND	5.0	5.0	5.0	5.0
Oxsilan Al-0500	5.0	5.0	5.0	5.0
Sanchem 7000	5.0	5.0	5.0	5.0
Scrub with Alconox	5.0	5.0	5.0	5.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.3.2.9: Dry Tape Adhesion per ASTM D 3359 Method B (Crosshatch) for Aluminum Alloys Coated with Mil-P-53030 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	5.0	5.0
Boegel	5.0	5.0	5.0	5.0
Chemidize 727ND	5.0	5.0	5.0	5.0
Oxsilan Al-0500	5.0	5.0	5.0	5.0
Sanchem 7000	5.0	5.0	5.0	5.0
Scrub with Alconox	5.0	5.0	5.0	5.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.3.2.10: Dry Tape Adhesion per ASTM D 3359 Method B (Crosshatch) for Aluminum Alloys Coated with Mil-P-53022 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	5.0	5.0
Boegel	5.0	5.0	5.0	5.0
Chemidize 727ND	5.0	5.0	5.0	5.0
Oxsilan Al-0500	5.0	5.0	5.0	5.0
Sanchem 7000	5.0	5.0	5.0	5.0
Scrub with Alconox	5.0	5.0	5.0	5.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	4.0	5.0	5.0	5.0

5.4 Wet Tape Adhesion and Water Resistance of Painted Substrates

5.4.1 Test Description

This test method covers a procedure for establishing adequacy of intercoat and surface adhesion of an organic coating immersed in water by applying pressure sensitive tape over a scribed area of the coating. The test also measures the coating's ability to resist penetration by water. Coatings were evaluated by immersion at room temperature for 24 hours, 120º F for 96 hours, and 150º F for 168 hours. Coupons are immersed in deionized water and let stand without disturbing for duration of immersion. This test was performed in accordance with Method 6301 of FED-STD-141 [*Paint, Varnish, Lacquer and Related Materials; Methods of Inspection Sampling and Testing*], and ASTM 3359 Method A. Testing was completed by NAVAIR personnel at the Patuxent River, MD test facility.

Ratings were assigned in accordance with the ASTM D 3359, Method A rating scale shown in Table 5.4.1.1.

Table 5.4.1.1: Rating Scale for ASTM D 3359 Method A Tape Adhesion Test

Rating Number	Description of Failure
5	No peeling or removal.
4	Trace peeling or removal along incisions or at their intersection.
3	Jagged removal along incisions up to 1/16 inch on either side
2	Jagged removal along most of incisions up to 1/8 inch on either side.
1	Removal from most of the area of the X under the tape.
0	Removal beyond the area of the X.

5.4.2 Test Results

The tables below detail the results of wet tape adhesion.

24-Hours (1 Day Test) at room temperature

Table 5.4.2.1: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-PRF-23377 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	5.0	5.0
Boegel	5.0	5.0	5.0	5.0
Chemidize 727ND	5.0	5.0	5.0	5.0
Oxsilan Al-0500	5.0	5.0	5.0	5.0
Sanchem 7000	5.0	5.0	5.0	5.0
Scrub with Alconox	5.0	5.0	5.0	5.0
TCP	4.0	4.0	4.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.4.2.2: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-PRF-85582 C2 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	2.0	0	2.0	2.0
Boegel	2.0	0	2.0	2.0
Chemidize 727ND	0	0	3.0	2.0
Oxsilan Al-0500	0	0	3.0	1.0
Sanchem 7000	2.0	0	2.0	2.0
Scrub with Alconox	2.0	0	2.0	2.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.4.2.3: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-PRF-85582 NC Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	4.0	5.0	5.0
Boegel	5.0	4.0	5.0	5.0
Chemidize 727ND	5.0	4.0	5.0	5.0
Oxsilan Al-0500	4.0	4.0	5.0	4.0
Sanchem 7000	5.0	4.0	5.0	5.0
Scrub with Alconox	5.0	4.0	5.0	5.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.4.2.4: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-P-53030 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	4.0	5.0
Boegel	5.0	5.0	4.0	5.0
Chemidize 727ND	4.0	5.0	5.0	5.0
Oxsilan Al-0500	3.0	3.0	5.0	4.0
Sanchem 7000	5.0	5.0	4.0	5.0
Scrub with Alconox	5.0	5.0	4.0	5.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.4.2.5: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-P-53022 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	5.0	5.0
Boegel	5.0	5.0	5.0	5.0
Chemidize 727ND	5.0	1.0	5.0	5.0
Oxsilan Al-0500	4.0	4.0	5.0	4.0
Sanchem 7000	5.0	5.0	5.0	5.0
Scrub with Alconox	5.0	5.0	5.0	5.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	2.0	3.0	5.0	0

Coatings tested for adhesion after a 24-hour immersion in room temperature deionized water generally performed well. For the 23377 primer, all alternatives provided acceptable adhesion ratings of 4 or 5 out of 5. For the 85582 C2 primer, Alodine 1200S, TCP, Alodine 5200 and X-It

PreKote performed well. All other coating syst ems performed poorly, failing on all alloys. For the 85582 N primer, all coatings again performed well, with no failures noted.

Coatings again performed well with the 53030 pr imer with only Oxsilan Al-0500 showing some marginal performance on 2024 and 7075. W ith the 53022 primer, all coatings perform ed well except for X-It PreKote with showed poor re sults on 2024 and 2219 and m arginal performance, rating of 3, on 7075. Chemidize 727D performed well on all alloys except 7075.

Interestingly, the Scrub with Alconox contro l performed well with all prim ers except the 85582 C2 where it showed equally poor performance with a number of alternatives.

96-Hours (4 Day Test) at 120º F

Table 5.4.2.6: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-PRF-23377 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	5.0	5.0
Boegel	5.0	5.0	5.0	5.0
Chemidize 727ND	5.0	5.0	5.0	5.0
Oxsilan Al-0500	5.0	5.0	5.0	5.0
Sanchem 7000	5.0	5.0	5.0	5.0
Scrub with Alconox	5.0	5.0	5.0	5.0
TCP	4.0	4.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.4.2.7: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-PRF-85582 C2 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	3.0	1.0	3.0	3.0
Boegel	3.0	1.0	3.0	3.0
Chemidize 727ND	3.0	3.0	3.0	3.0
Oxsilan Al-0500	0	0	3.0	0
Sanchem 7000	3.0	1.0	3.0	3.0
Scrub with Alconox	3.0	1.0	3.0	3.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.4.2.8: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-PRF-85582 NC Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	2.0	3.0	5.0	4.0
Boegel	2.0	3.0	5.0	4.0
Chemidize 727ND	5.0	4.0	4.0	5.0
Oxsilan Al-0500	5.0	5.0	5.0	5.0
Sanchem 7000	2.0	3.0	5.0	4.0
Scrub with Alconox	2.0	3.0	5.0	4.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.4.2.9: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-P-53030 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	4.0	4.0	4.0	4.0
Alodine 5200	4.0	4.0	4.0	4.0
Bi-K Aklimate	4.0	4.0	3.0	5.0
Boegel	4.0	4.0	3.0	5.0
Chemidize 727ND	3.0	4.0	3.0	4.0
Oxsilan Al-0500	3.0	3.0	4.0	4.0
Sanchem 7000	4.0	4.0	3.0	5.0
Scrub with Alconox	4.0	4.0	3.0	5.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	4.0	4.0	4.0	4.0

Table 5.4.2.10: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-P-53022 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	5.0	5.0
Boegel	5.0	5.0	5.0	5.0
Chemidize 727ND	5.0	5.0	5.0	5.0
Oxsilan Al-0500	1.0	5.0	5.0	5.0
Sanchem 7000	5.0	5.0	5.0	5.0
Scrub with Alconox	5.0	5.0	5.0	5.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	3.0	4.0	5.0	3.0

Coatings tested for adhesion after a 96-hour immersion in 120 F deionized water did not perform as well as in the 24-hour test. Coatings performed best with the 23377 primer with all systems achieving acceptable adhesion. The same four coatings that performed well with the 85582 C2 primer in the 24-hour test did well in the 96 -hour test. Although the remaining coatings all showed unacceptable adhesion for all alloys, ratings were generally better than in the 24-hour test.

For the 85582 N primer, whereas all coatings performed well in the 24-hour test, Sanchem 7000, Bi-K Aklimate, Scrub with Alconox, and Boegel Method A all showed unacceptable adhesion on 2024 and 7075. The 53030 primer systems saw similar incremental decreases in performance by Sanchem 7000, Bi-K Aklimate, Scrub with Alconox and Boegel Method A on 5083 where all performed marginally, scoring 3. Oxsilan Al -0500 had marginal performance with 2024 and 7075 for this primer and Chemdize 727D on 5083. For 53022, only X-It PreKote and Oxsilan Al-0500 did not rate 5 for all alloys.

168-Hours (7 Day Test) at 150º F

Table 5.4.2.11: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-PRF-23377 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	5.0	5.0
Boegel	5.0	5.0	5.0	5.0
Chemidize 727ND	5.0	5.0	5.0	5.0
Oxsilan Al-0500	5.0	5.0	5.0	5.0
Sanchem 7000	5.0	5.0	5.0	5.0
Scrub with Alconox	5.0	5.0	5.0	5.0
TCP	5.0	4.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.4.2.12: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-PRF-85582 C2 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	1.0	1.0	3.0	2.0
Boegel	1.0	1.0	3.0	2.0
Chemidize 727ND	2.0	2.0	3.0	2.0
Oxsilan Al-0500	0	0	3.0	1.0
Sanchem 7000	1.0	1.0	3.0	2.0
Scrub with Alconox	1.0	1.0	3.0	2.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	4.0

Table 5.4.2.13: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-PRF-85582 NC Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	0	0	3.0	1.0
Boegel	0	0	3.0	1.0
Chemidize 727ND	3.0	0	4.0	4.0
Oxsilan Al-0500	3.0	5.0	5.0	5.0
Sanchem 7000	0	0	3.0	1.0
Scrub with Alconox	0	0	3.0	1.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Table 5.4.2.14: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-P-53030 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	4.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	4.0	4.0	4.0	4.0
Boegel	4.0	4.0	4.0	4.0
Chemidize 727ND	3.0	4.0	4.0	4.0
Oxsilan Al-0500	3.0	3.0	4.0	4.0
Sanchem 7000	4.0	4.0	4.0	4.0
Scrub with Alconox	4.0	4.0	4.0	4.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	4.0	5.0	5.0	4.0

Table 5.4.2.15: Wet Tape Adhesion for Aluminum Alloys Coated with Mil-P-53022 Primer

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	5.0	5.0	5.0	5.0
Alodine 5200	5.0	5.0	5.0	5.0
Bi-K Aklimate	5.0	5.0	5.0	5.0
Boegel	5.0	5.0	5.0	5.0
Chemidize 727ND	5.0	5.0	5.0	5.0
Oxsilan Al-0500	4.0	4.0	5.0	5.0
Sanchem 7000	5.0	5.0	5.0	5.0
Scrub with Alconox	5.0	5.0	5.0	5.0
TCP	5.0	5.0	5.0	5.0
X-It PreKote	5.0	5.0	5.0	5.0

Coatings tested for adhesion after a 168-hour immersion in 150 °F deionized water generally performed better than in the 96- hour test. This performance trend is not unusual where in many cases the 96-hour test proves to be the most severe on many coatings. For this test, all coatings again performed well with the 23377 primer with virtually all coatings rating 5. For the 85582 C2, the same four coatings that performed well in the 24- and 96-hour test performed well in the 168-hour test. All others showed marginal to poor performance on all alloys. The same four coatings, Alodine 1200S, TCP, Alodine 5200 and X-It PreKote performed well with the 85582 N primer. All others performed significantly worse than in the 96-hour test, with many coatings failing completely and rating 0. Aluminum 2024 and 7075 were especially prone to complete failures with these coatings. Performance of all coatings with 53030 and 53022 was acceptable on all alloys with the exception of marginal performance of Oxsilan Al-0500 on 2024 and 7075 and Chemidize 727D on 2024 using the 53030 primer.

Summary of Alternative Performance

Table 5.4.2.16 details the summary performance of each alternative pretreatment by primer system. It also shows an average rating for each primer across all pretreatments. Only the Alodine 1200S control, TCP and Alodine 5200 rated 4 or 5 on all adhesion tests. This is a very important measure of the overall adhesion quality of these coatings and their flexibility to be used on any alloy. It is comforting to re-validate the adhesion promoting qualities of Alodine 1200S. These tests also point out the extreme difficulty in achieving robust pretreatment coating characteristics on a variety of aluminum surfaces with a variety of organic coatings.

Table 5.4.2.16 Summary Ratings for Pretreatments and Primer Systems in Wet Tape Adhesion Tests

	Primer					
Pretreatment	23377	85582 C2	85582 N	53022	53030	All Coatings
Alodine 1200S (control)	5.0	5.0	5.0	5.0	4.6	4.9
Alodine 5200	5.0	5.0	5.0	5.0	4.7	4.9
Bi-K Aklimate	5.0	1.9	3.1	5.0	4.3	3.9
Boegel	5.0	1.9	3.1	5.0	4.3	3.9
Chemidize 727ND	5.0	2.2	4.0	4.7	4.0	4.0
Oxsilan Al-0500	5.0	0.9	4.6	4.3	3.6	3.7
Sanchem 7000	5.0	1.9	3.1	5.0	4.3	3.9
Scrub with Alconox	5.0	1.9	3.1	5.0	4.3	3.9
TCP	4.5	5.0	5.0	5.0	5.0	4.9
X-It PreKote	5.0	4.9	5.0	3.8	4.5	4.6
Overall Alternative Average	**5.0**	**3.1**	**4.1**	**4.8**	**4.3**	**4.2**

5.5 Neutral Salt Fog on Scribed, Painted Substrate

5.5.1 Test Description

This test method evaluates a coating system's ability to prevent substrate corrosion and the effect that corrosion has on adhesion of the coating system. Operation of the fog chamber for this test is in accordance with ASTM B 117. Testing was completed by Army Research Laboratory (ARL) personnel at the Aberdeen, MD test facility.

Prior to exposure, an "X" incision was manually scribed through the test coupon coating using a carbide tip scribe as per ASTM D 1654, making sure that the coating was scribed all the way through and into the substrate. The smaller angle of the "X" was 30 to 45 degrees and each line of the "X" was approximately 4 inches long. The back and edges of the test coupons were primed to prevent corrosion products from contaminating the chamber. The salt solution and the fog chamber were prepared as specified in the Test Methodology of the JTP. The nozzles were adjusted in the fog chamber so that sprayed salt solution did not directly impinge on the coupon surfaces. The fog chamber was operated continuously for 3,000 hours. Coupons were evaluated for surface corrosion and creepage from the scribe at weekly intervals up to 3 weeks and then at 500-hour intervals. The coupons were carefully removed at the end of the test duration and cleaned by gently flushing with running water [water temperature less than 38 degrees °C (100°F)]. The coupons were air-dried at ambient conditions and then visually examined without magnification.

5.5.2 Test Results

This test specifically examines ASTM B 117 accelerated corrosion exposure of aluminum alloys 2024, 2219, 5083, and 7075 specimens treated with the candidate hexavalent chromium free pretreatments as well as one hexavalent chromium based pretreatment (Alodine 1200S) used as a control. Twenty-five panels with each pretreatment combination were prepared for each alloy for neutral salt fog exposure. Each set of 25 panels was further subdivided to 5 groups, one for each of the 5 selected DoD coatings. The large corrosion test chamber which was used to evaluate all of the coated aluminum test panels is depicted in Figure 5.5.2.1.

Figure 5.5.2.1: Test Chamber and Panels Used for ASTM B 117

In order to chronicle the corrosion, specimens were numerically rated for damage at prescribed intervals. Specimen group failures were defined when for 3 or more of the panels in a particular alloy/pretreatment/coating set were measured with a rating of 0 under method ASTM D 1654. In addition, the representative panels rated from each of the five test panels were digitally scanned at 600 dpi resolution and saved as high quality graphics files. With the exception of the early failures defined above under ASTM D 1654, the coated panels were all subjected to 3000 hours of ASTM B 117. The prevalent failure mode for the most of the panels was blistering along the scribe.

The tables below detail corrosion performance for pretreatments on each alloy.

Table 5.5.2.1: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated with Mil-PRF-23377 Primer and Mil-C-85285 Topcoat Exposed to 3000 Hours

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S	8.3	9.0	9.4	9.2
Alodine 5200	9.0	9.0	9.2	8.8
Bi-K Aklimate	7.8	9.0	9.0	8.4
Boegel	9.0	9.0	9.0	4.2
Chemidize 727ND	7.6	8.8	9.0	4.8
Oxsilan Al-0500	9.4	9.0	9.0	8.6
Sanchem 7000	3.2	9.0	6.0	3.2
TCP	8.8	8.4	8.4	7.2
X-It PreKote	8.6	8.8	9.0	7.2

Table 5.5.2.2: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated with Mil-PRF-85582 C2 Primer and Mil-C-85285 Topcoat Exposed to 3000 Hours

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S	9.2	9.0	8.8	9.0
Alodine 5200	9.0	9.0	9.0	9.0
Bi-K Aklimate	8.0	5.8	9.0	6.6
Boegel	9.0	9.0	9.6	5.6
Chemidize 727ND	8.4	2.0	8.2	3.6
Oxsilan Al-0500	9.2	-	9.0	8.6
Sanchem 7000	7.4	1.4	8.0	6.2
TCP	8.8	9.0	9.0	8.4
X-It PreKote	8.8	8.6	9.0	9.0

Table 5.5.2.3: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated with Mil-PRF-85582 N Primer and Mil-C-85285 Topcoat Exposed to 3000 Hours

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S	7.0	9.0	9.0	5.6
Alodine 5200	6.4	8.8	8.8	6.0
Bi-K Aklimate	-	-	-	-
Boegel	6.6	7.8	8.2	3.8
Chemidize 727ND	2.2	-	-	2.2
Oxsilan Al-0500	6.6	8.8	8.2	5.4
Sanchem 7000	-	1.4	2.4	-
TCP	4.2	8.0	9.0	4.4
X-It PreKote	-	1.6	0.4	-

Table 5.5.2.4: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated with Mil-PRF-53030 Primer and Mil-C-53039 Topcoat Exposed to 3000 Hours

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S	7.4	7.8	5.8	6.0
Alodine 5200	7.8	6.0	7.8	4.6
Bi-K Aklimate	-	-	2	-
Boegel	4.4	2.8	6.4	1.4
Chemidize 727ND	-	-	-	-
Oxsilan Al-0500	-	0.8	-	-
Sanchem 7000	-	-	2.4	-
TCP	4.8	6.4	7.4	5.0
X-It PreKote	-	1.2	4.2	-

Table 5.5.2.5: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated with Mil-PRF-53022 Primer and Mil-C-53039 Topcoat Exposed to 3000 Hours

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S	3.8	6.6	3.6	1.0
Alodine 5200	6.4	6.4	5.4	3.2
Bi-K Aklimate	-	-	-	-
Boegel	6.6	4.6	3.2	0.6
Chemidize 727ND	-	-	-	2.4
Oxsilan Al-0500	-	3.2	-	-
Sanchem 7000	-	4.2	-	-
TCP	4.2	8.6	6.8	4.6
X-It PreKote	-	-	-	-

Aluminum 2024

For Al 2024, the top performing pretreatments were clearly evident. For this particular alloy it was the Cr^{+6} free coating systems that most aided in revealing the better performers. With the exception of the Sanchem process, all of the pretreatments for the hexavalent chromium bearing 23377/85285 coating system performed well and completed 3000 hours with the highest ratings among the coating systems.

The 85582 C2/85285 coating system containing hexavalent chromium performed similar when compared to the 23377/85285 system for the same pretreatments. As with 23377/85285, Sanchem showed degradation though not as severe. In addition to problems on Sanchem treated panels, the Bi-K pretreatment had blistering *away* from the scribed areas past 2500 hours.

The non-chromate coating systems, 85582 N/85285, 53030/53039, and 53022/53039, provided a much greater challenge for the pretreatments. At the conclusion of 3000 hours, all of the pretreatments, including Alodine 1200S, showed significant corrosion damage. Many of the pretreatments were unable to sustain acceptable performance levels and were terminated prior to the end of 3000 hours. The most consistent performance among the three chromate free coating systems was provided by the Boegel, Alodine 5200, NAVAIR TCP, and Alodine 1200S pretreatments. Figure 5.5.2.2 shows the results of Al 2024 alloy coated with 85582 N/85285 coating sytem at 3000 hours exposure. Figure 5.5.2.3 shows that in the specific case of the 53030/53039 system, Alodine 5200 even *exceeded* the performance for Alodine 1200S. The Brent Oxsilan pretreatment rendered respectable performance at or near the leaders for the 85582 N/85285 system but performed poorly on the 53030/53039 and 53022/53039 coating systems.

Aluminum 2219

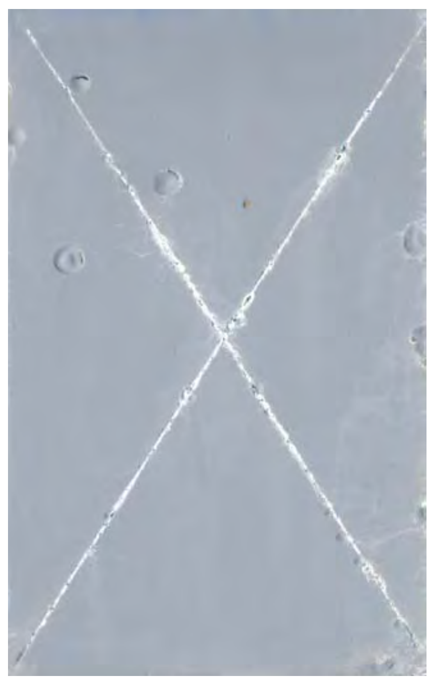
Of all of the Al alloys examined in this study, Al 2219 with its high Cu content is by far the most corrosion prone and provides a difficult situation for even Alodine 1200S. For the chromate-based 23377/85285 coating system, although all pretreatments lasted the full 3000-hour duration, significant corrosion damage occurred on most of the pretreatments. The best performers for this coating system were Alodine 1200, Alodine 5200, Oxsilan, and Bi-K. It should be noted that NAVAIR TCP had mixed results, two panel replicates rated “4” and “5” and the remaining 3 panels all rated at “9”. For the chromate containing 85582 C2/85285 system, the best performers were Alodine 1200, Alodine 5200, NAVAIR TCP, X-It PreKote, and Oxsilan. The remaining pretreatments performed in the intermediate range with ratings ranging from 4 to 7.

For the three-chromate free coating systems, 85582 N/85285, 53030/53039, and 53022/53039, there was significant corrosion damage with many of the pretreatments unable to endure 3000 hours without complete failure. The most consistent performers for these systems were NAVAIR TCP, Alodine 1200 and Alodine 5200. Figures 5.5.2.4 and 5.5.2.5 show that Boegel pretreatment produced somewhat modest ratings versus the leaders for the 85582 N/85285 coating system but performed much more poorly on the CARC based systems.

(a) Alodine 1200S

(b) TCP

(c) Alodine 5200



(d) Oxsilan AL-0500

Figure 5.5.2.2: Aluminum 2024 Coated With 85582 N/85285 Coating System at 3000 Hours Duration

(a) Alodine 1200S

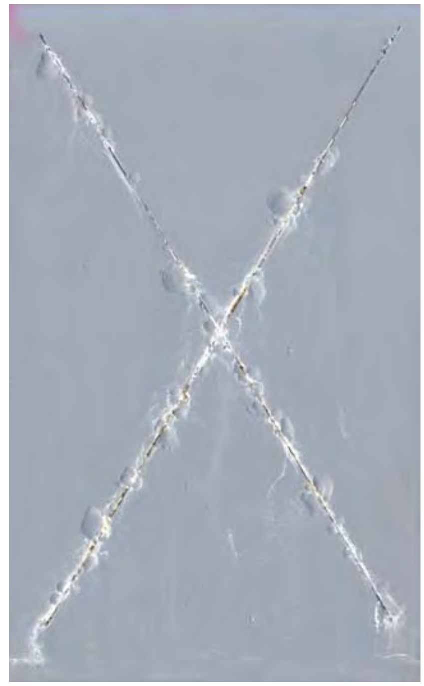
(b) TCP

(c) Alodine 5200

(d) Boegel

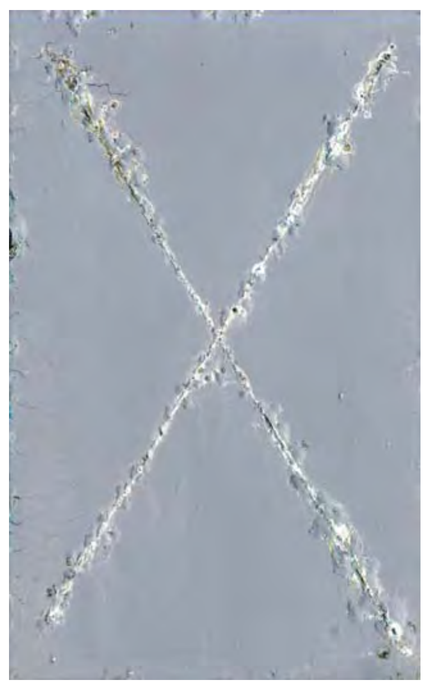
Figure 5.5.2.3: Aluminum 2024 Coated With 53030/53039 Coating System at 3000 Hours Duration

(a) Alodine 1200S



(b) TCP

(c) Alodine 5200

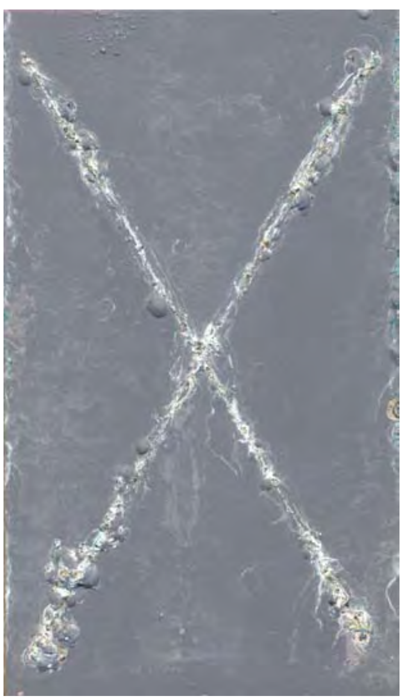


(d) Boegel

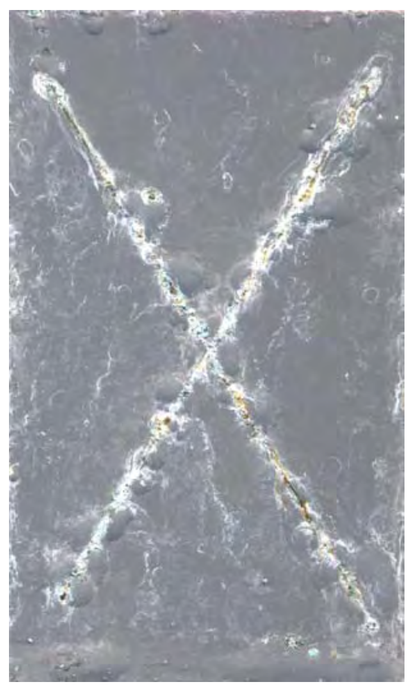
Figure 5.5.2.4: Aluminum 2219 Coated With 85582 N/85285 Coating System at 3000 Hours Duration

(a) Alodine 1200S

(b) TCP



(c) Alodine 5200



(d) Boegel

Figure 5.5.2.5: Aluminum 2219 Coated With 53030/53039 Coating System at 3000 Hours Duration

Aluminum 5083

Al 5083, well known for its stable protective oxide layer, does not usually significantly corrode, even under uncoated accelerated conditions. Due to its widespread use in ground systems, accelerated corrosion methods such as ASTM B 117 are still necessary for this alloy to detect potential adhesion and quality control issues. In contrast to the cyclic accelerated corrosion exposure studies under GM 9540P (Section 5.7), surprisingly significant amounts of creepback corrosion via blistering were measured on the chromate-free coating systems as shown in Figures 5.5.2.6 and 5.5.2.7. As with other alloys, the 23377/85285 coating system proved superior and there was no significant creepback resulting from corrosion or coating system delamination for any pretreatment. For 85582 C2/85285, blistering away from the scribe appeared at 1000 hours for Sanchem 7000. The Chemidize and Bi-K pretreatments also showed blistering away from the scribe appearing at 1500 and 2000 hours respectively. Corrosion was most severe for the Oxsilan pretreatment, which rated a "7" beginning at 2500 hours. For 3000 hours, the best performers were NAVAIR TCP, Alodine 1200, and Alodine 5200, and Boegel, which achieved these ratings free of any other defects such as coating delamination.

For the 85582 N/85285 and 53022/53039 coating systems, the superiority of Alodine 1200S, Alodine 5200, and NAVAIR TCP pretreatments was obvious. For the 53030/53039 coating system, the ratings were significantly lower, however Alodine 1200, Alodine 5200, and NAVAIR TCP pretreatments still performed better than the other pretreatments.

Aluminum 7075

For the coating system 23377/85285, as in the other alloys, most of the pretreatments performed well with little or no damage to the scribed region. All of the pretreatments rated "9" at the conclusion of 3000 hours. One item of note was a slight lifting or delamination along the length of the entire scribe of the NAVAIR TCP. This delamination first measured at 1 week was very slight and never progressed during the remainder of the test.

For the 85582 C2/85285 coating system, the top performers with little or no damage were Alodine 1200S, Alodine 5200, TCP, X-It PreKote, and Boegel. As with the 23377/85285 coating system, NAVAIR TCP displayed the same minor delamination issue. The other pretreatments for this system were disqualified either by lower ratings due to corrosion, delamination, or both. Oxsilan Al-0500 pretreatment catastrophically failed prior to 2 weeks exposure across the majority of its 5 panels. Figures 5.5.2.8 and 5.5.2.9 show the massive delamination of this particular pretreatment.

For the chromate-free paint systems the most consistent performers were Alodine 1200S, Alodine 5200, and NAVAIR TCP. Figures 5.5.2.10 and 5.5.2.11 show that unlike the chromate containing coating systems, NAVAIR TCP pretreatment showed none of the minor coating delamination issue. Two notable but inconsistent performers were Oxsilan Al-0500 and Boegel, which performed extremely well on 85582 N/85285 yet performed poorly on the CARC systems.

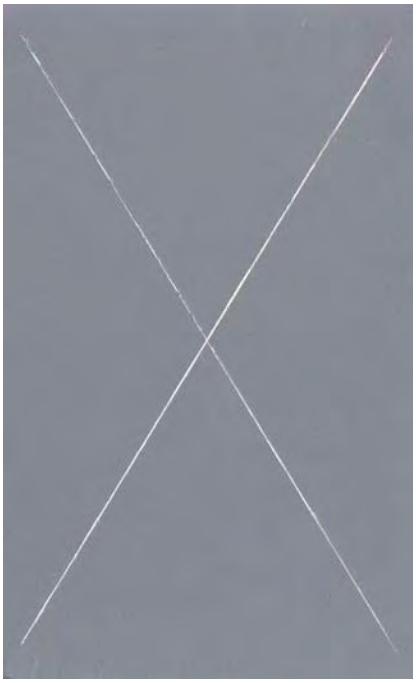
(a) Alodine 1200S

(b) TCP

(c) Alodine 5200

(d) X-It PreKote

Figure 5.5.2.6: Aluminum 5083 Coated With 53030/53039 Coating System at 3000 Hours Duration



(a) Alodine 1200S (b) TCP

(c) Alodine 5200 (d) Boegel

Figure 5.5.2.7: Aluminum 5083 Coated With 53022/53039 Coating System at 3000 Hours Duration

Figure 5.5.2.8: Severe Delamination of Oxsilan AL 0-500 Pretreated on Al 7075 Coated With 85582C2/25285 Coating System at 1 Week Exposure

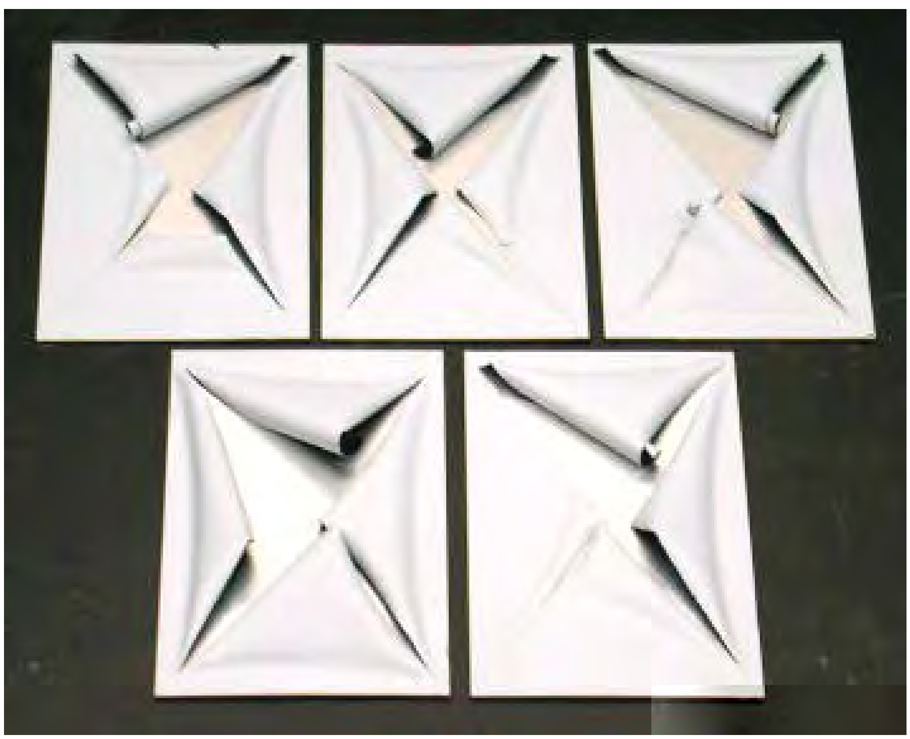
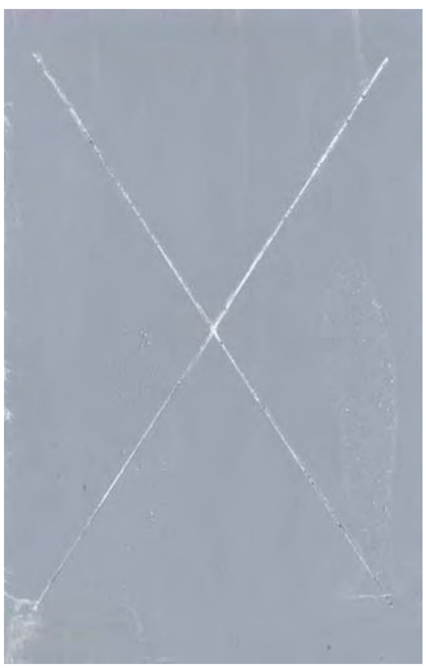


Figure 5.5.2.9: Severe Delamination of Oxsilan AL 0-500 Pretreated on Al 7075 Panels with 85582C2/25285 Coating System at 2 Weeks Exposure

(a) Alodine 1200S

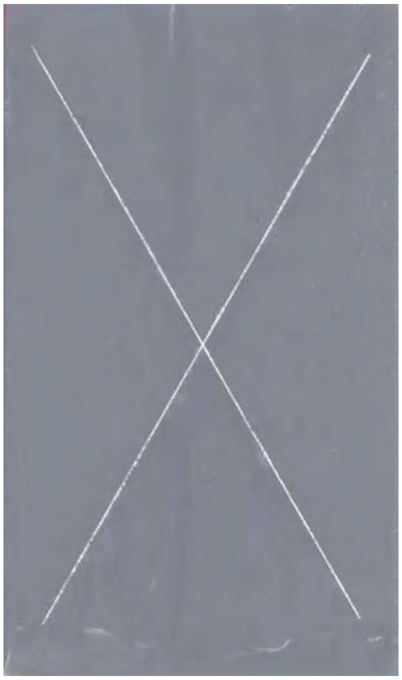
(b) TCP



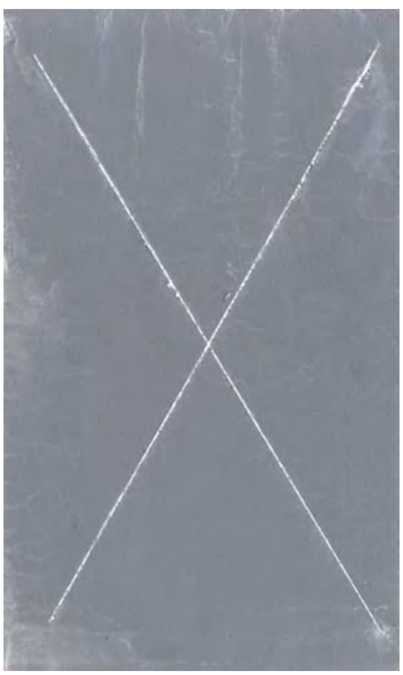
(c) Alodine 5200

(d) Oxsilan AL-0500

Figure 5.5.2.10: Aluminum 7075 Coated With 85582 N/85285 Coating System at 3000 Hours Exposure


(a) Alodine 1200S


(b) TCP


(c) Alodine 5200


(d) Boegel

Figure 5.5.2.11: Aluminum 7075 Coated With 53022/53039 Coating System at 3000 Hours Exposure

Summary of Alternative Performance

Table 5.5.2.6 details the summary performance of each alternative pretreatment by primer system. It also shows an average rating for each primer across all pretreatments. Alodine 5200 slightly edges out TCP as the best overall performer and is slightly better than the Alodine 1200S control. TCP performs about the same as the control, Boegel ranks third and the other 5 alternatives rank a distant fourth. This data highlights the strong influence pretreatments can have on the full coating system, with much more variation in performance noted for the non-chromate primer systems.

Table 5.5.2.6: Summary Ratings for Pretreatments and Primer Systems exposed to 3000 hours of ASTM B117 Salt Fog (Ratings per ASTM D 1654A)

	Primer					
Pretreatment	23377	85582 C2	85582 N	53022	53030	All Coatings
Alodine 1200S (control)	8.9	9.0	7.7	3.8	6.8	7.2
Alodine 5200	9.0	9.0	7.5	5.4	6.6	7.5
Bi-K Aklimate	8.6	7.4	0.0	0.0	0.5	3.3
Boegel	7.8	8.3	6.6	3.8	3.8	6.0
Chemidize 727ND	7.6	5.6	1.1	0.6	0.0	3.0
Oxsilan Al-0500	9.0	6.7	7.3	0.8	0.2	4.8
Sanchem 7000	5.4	5.8	1.0	1.1	0.6	2.7
TCP	8.2	8.8	6.4	6.1	5.9	7.1
X-It PreKote	8.4	8.9	0.5	0.0	1.4	3.8
Overall Alternative Average	**8.0**	**7.8**	**3.8**	**2.1**	**2.6**	**4.8**

In an effort to display the extremes in alloy corrosion susceptibility, Figures 5.5.2.12 and 5.5.2.13 show the performance of various coating systems on Al 2219 and Al 5083 alloys over the duration of the netural salt fog test. Pretreatments include Alodine 1200S and 5700 and NAVAIR TCP, which, on average, were the best performers in this test. Primers are 53022 and 85582 Class N. Whereas all systems perform equally well on 5083, dramatic differences are apprarent on 2219, the most corrosion prone alloy in this test. As indicated, the alloys used and performance requirements for the coating systems are critical for the selection of an acceptable chromate-free coating system.

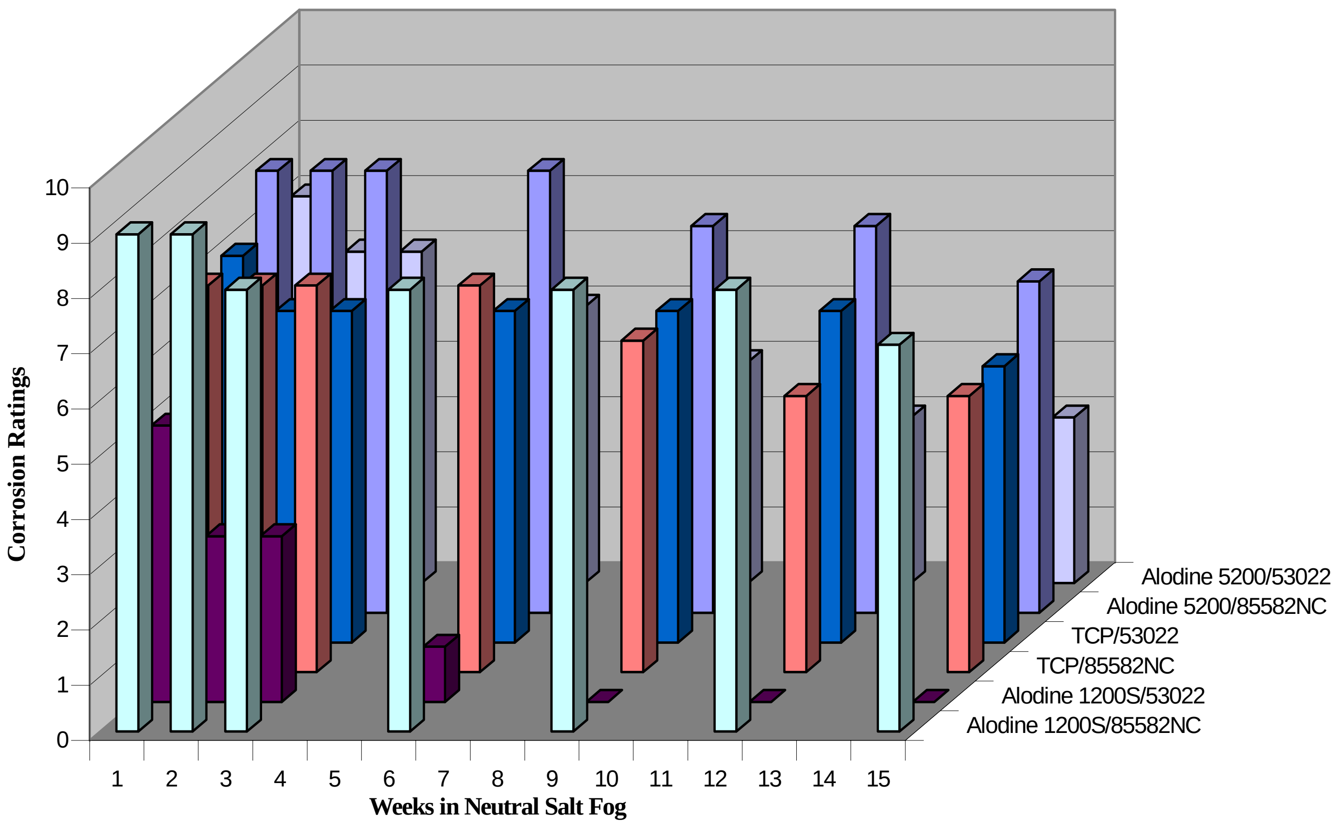


Figure 5.5.2.12: Coating System Performance of Aluminum 2219

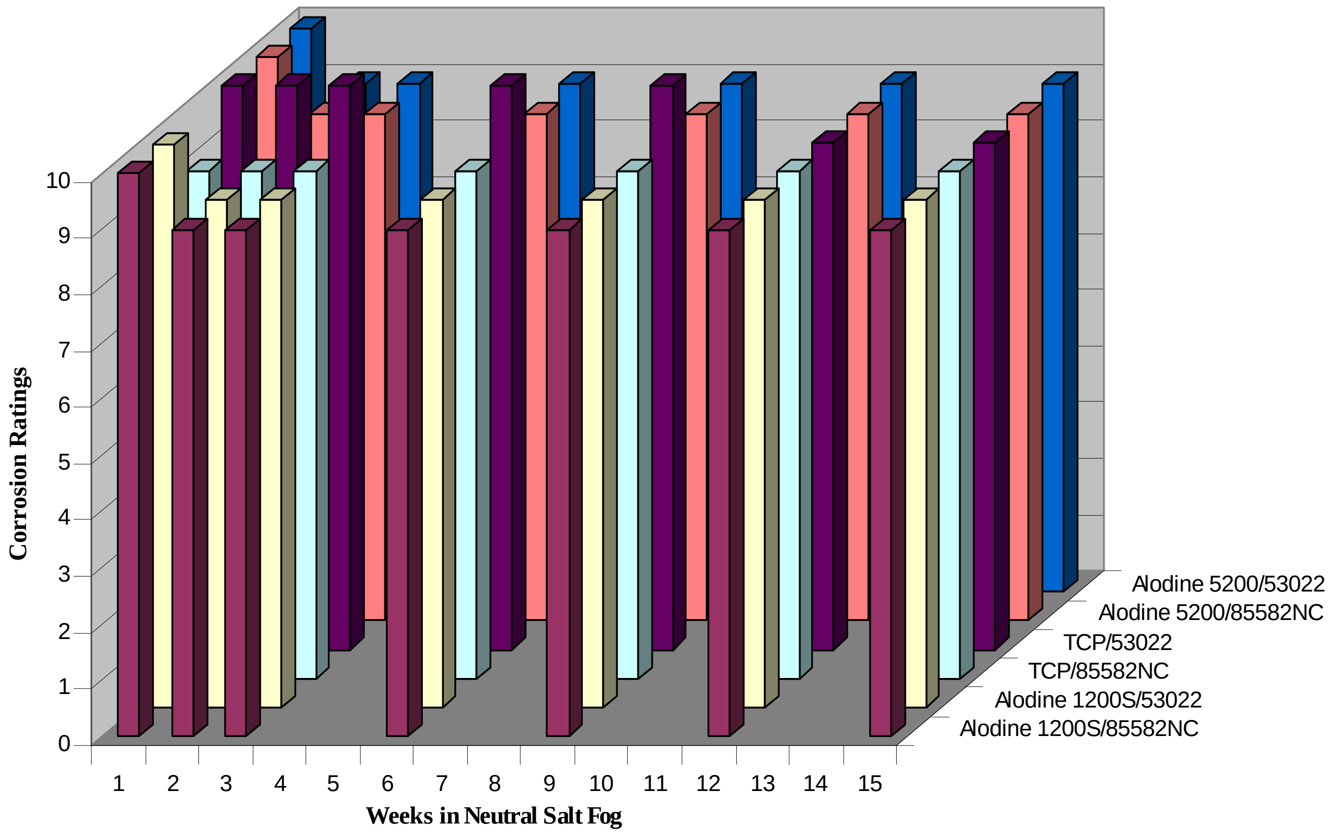


Figure 5.5.2.13: Coating System Performance of Aluminum 5083

5.6 SO_2 Salt Fog on Scribed, Painted Substrates

5.6.1 Test Description

This test method evaluates a coating system's ability to prevent substrate corrosion and the effect that corrosion has on adhesion of the coating system while subjected to an acidified, corrosive environment. Operation of the fog chamber for this test is in accordance with ASTM G 85 Annex 4 [*Standard Practice for Modified Salt Spray (Fog) Testing*]. Testing was completed by NAVAIR personnel at the Patuxent River, MD test facility.

The SO_2 salt fog test is typically required by NAVAIR for the laboratory evaluation of any new coating system. This test is used to simulate the stack gases from aircraft carriers and supporting surface ships as well exhaust gases from aircraft to which the aircraft on the deck of carriers are constantly exposed. These gases are usually present in combination with chloride containing seawater and mists that constantly contact aircraft coating systems.

Prior to exposure, an "X" incision was manually scribed through the test coupon coating using a carbide tip scribe as per ASTM D 1654, making sure that the coating was scribed all the way through and into the substrate. The smaller angle of the "X" was 30 to 45 degrees and each line of the "X" was approximately 4 inches long. The back and edges of the test coupons were primed to prevent corrosion products from contaminating the chamber. The scribed coupons were placed into the fog chamber at a 15-degree incline. The coupons were not allowed to contact other surfaces in the chamber and condensate from a coupon also did not contact any other coupons. The salt solution and the fog chamber were prepared as specified in the Test Methodology of the JTP. The nozzles were adjusted in the fog chamber so that sprayed salt solution did not directly impinge on the coupon surfaces. The fog chamber was operated continuously for 500 hours. Coupons were evaluated for surface corrosion and creepage from the scribe weekly. The coupons were carefully removed at the end of the test duration and cleaned with running water [water temperature less than 38 °C (100°F)]. The coupons were air-dried at ambient conditions and then visually examined.

Per the JTP, a total of 1000 test coupons were exposed to the SO_2 salt fog environment. Due to size limitations of the test chamber, eight racks of 20 coupons were tested in batches. This resulted in approximately 6 months of serialized testing in the same SO_2 cabinet to complete the full coupon set. Racks were removed at 1, 2 and 3-weeks (completion) and one representative coupon of each set of five duplicates scanned. After testing all coupons were rated per ASTM D 1654 method A.

5.6.2 Test Results

The performance of the eight candidate non-chromate aluminum pretreatments with five organic military coating systems was evaluated on four aluminum alloys: 2024, 7075, 5083, and 2219. Significant differences in coating system performance were noted amongst the various alloys and coating systems. Typical high-performance chromated coating systems showed no or very little signs of corrosion after the test when evaluated on Al 2024 and 7075 substrates.

Tables 5.6.3.1 through 5.6.3.5 present corrosion rating results for candidate coating systems. Ratings are the average of 5 test panels.

Aluminum 2024
TCP, Alodine 5200 and Boegel performed consistently well across all primers. In most cases they performed as well as or slightly better than the Alodine 1200S control. Performance of the other alternatives was highly variable from primer to primer, in general being better with the two chromate primers than the non-chromates. X-It PreKote, for example, performed relatively well with the 23377, 85582 and 53030 systems but not with the 53022 system. In another example, the Chemidize 727ND rated 5 to 7 on the 23377, 85582 C2, 53030 and 53022 systems and then very poorly on the 85582 N system.

Aluminum 2219
The 2219 was the most difficult alloy of the group to protect and had the lowest overall ratings. For the 23377 and 85582 C2 primers, most coating ratings were grouped in the 4 to 6 range. Strong differences in performance were evident with the non-chromate primers. TCP and Alodine 5200 performed the same as the Alodine 1200S control for all three non-chromates. Boegel performed next best, followed by the remaining alternatives. Interestingly, the 85582 N primer performed on average much better than the 53030 and 53022 primers for the lesser performing pretreatments.

Aluminum 5083
The SO_2 corrosion test showed unusual results for 5083. Whereas this alloy is usually the most corrosion resistant, in this test the overall performance was about the same as for 2024. TCP did especially well with the chromate primers, equaling the performance of the Alodine 1200S control. Most other coatings rated in the 6 to 7 range. For 85582 N, no coating was as good as the control, but Boegel, Oxsilan and Alodine 5200 came in a close second. TCP and X-It PreKote followed, with the rest of the coatings a distant fourth. For 53022, the Boegel rated far above any other coating, with TCP and Alodine 5200 rating the same as the control. For 53030, TCP, Alodine 5200 and Boegel rated one unit better than the control, with all others worse than the control. Overall, Boegel performed the best on this alloy, with Alodine 1200S and TCP close behind. Alodine 5200 rated fourth, the other alternatives were 1 to 2 rating units behind.

Aluminum 7075
Corrosion on 7075 was worse on average than for 2024 in the SO_2 salt fog test. On average, the Alodine 1200S control performed the best. TCP was second and performed consistently across all primers. Alodine 5200 and Boegel rated third, about 1 unit behind TCP, and performed consistently across all primers. The remaining coatings performed very inconsistently across the primers and all rated on average 2 to 3 units below the Alodine 5200 and Boegel.

The 23377 primer performed the best across all pretreatments. TCP performed notably well here and X-It PreKote poorly. The 85582 C2 primer was next best with Alodine 5200, TCP, Oxsilan and Boegel a distant second to the control. All three non-chromate primers performed about the same on average, with TCP, Alodine 5200 and Boegel performing consistently about the same as the control.

Table 5.6.3.1: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated With Mil-PRF-23377 Primer and Mil-C-85285 Topcoat and Exposed to 500 Hours

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	8.0	7.0	8.0	6.0
Alodine 5200	8.0	5.0	6.0	5.0
Bi-K Aklimate	4.0	6.0	6.0	4.0
Boegel	7.0	6.0	8.0	5.0
Chemidize 727ND	5.0	6.0	7.0	5.0
Oxsilan Al-0500	6.0	6.0	8.0	5.0
Sanchem 7000	3.0	5.0	6.0	4.0
TCP	8.0	8.0	8.0	5.0
X-It PreKote	8.0	1.0	6.0	6.0

Table 5.6.3.2: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated With Mil-PRF-85582 C2 Primer and Mil-C-85285 Topcoat and Exposed to 500 Hours

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	7.0	9.0	9.0	6.0
Alodine 5200	6.0	6.0	8.0	6.0
Bi-K Aklimate	9.0	4.0	8.0	4.0
Boegel	9.0	6.0	7.0	6.0
Chemidize 727ND	7.0	0	7.0	5.0
Oxsilan Al-0500	7.0	6.0	6.0	4.0
Sanchem 7000	6.0	4.0	7.0	0
TCP	8.0	6.0	9.0	6.0
X-It PreKote	7.0	3.0	6.0	4.0

Table 5.6.3.3: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated With Mil-PRF-85582 NC Primer and Mil-C-85285 Topcoat and Exposed to 500 Hours

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	8.0	8.0	8.0	5.0
Alodine 5200	8.0	6.0	7.0	5.0
Bi-K Aklimate	1.0	1.0	4.0	3.0
Boegel	9.0	5.0	7.0	3.0
Chemidize 727ND	1.0	1.0	4.0	3.0
Oxsilan Al-0500	7.0	0	7.0	5.0
Sanchem 7000	0	1.0	4.0	1.0
TCP	9.0	6.0	6.0	5.0
X-It PreKote	6.0	0	5.0	3.0

Table 5.6.3.4: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated With Mil-P-53030 Primer and Mil-C-53039 Topcoat 500 Hours

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	8.0	6.0	5.0	5.0
Alodine 5200	8.0	5.0	6.0	5.0
Bi-K Aklimate	0	0	1.0	3.0
Boegel	8.0	5.0	6.0	3.0
Chemidize 727ND	7.0	0	1.0	0
Oxsilan Al-0500	0	4.0	4.0	1.0
Sanchem 7000	0	3.0	4.0	1.0
TCP	9.0	6.0	6.0	5.0
X-It PreKote	5.0	2.0	4.0	2.0

Table 5.6.3.5: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated with Mil-P-53022 primer and Mil-C-53039 topcoat and Exposed to 500 Hours

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	7.0	6.0	5.0	5.0
Alodine 5200	8.0	6.0	5.0	5.0
Bi-K Aklimate	0	6.0	1.0	1.0
Boegel	8.0	5.0	9.0	5.0
Chemidize 727ND	6.0	0	1.0	0
Oxsilan Al-0500	0	0	0	1.0
Sanchem 7000	0	0	1.0	0
TCP	9.0	6.0	5.0	5.0
X-It PreKote	0	2.0	4.0	0

Summary of Alternative Performance

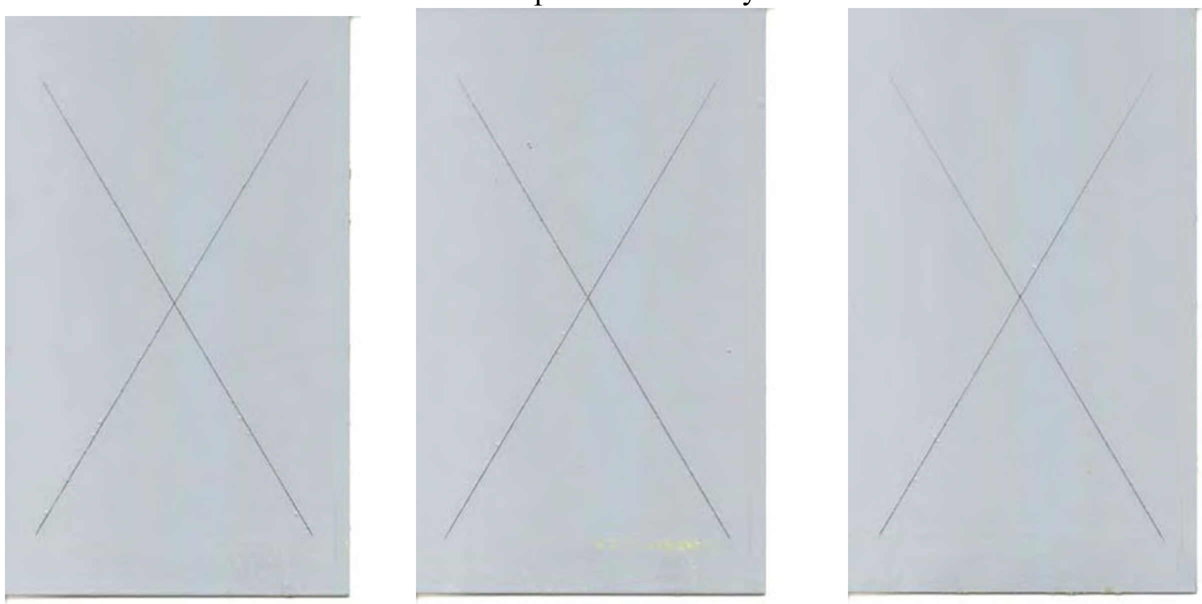
Table 5.6.3.6 details the summary performance of each alternative pretreatment by primer system. It also shows an average rating for each primer across all pretreatments. TCP performs the best, on average, and is comparable to the Alodine 1200S control. Alodine 5200 and Boegel rank a close second. The other 5 alternatives rank a distant third.

Not surprisingly, the chromate-based primers perform equally well and are the basis of the best coating systems. The non-chromate systems, on average, rank 2 units lower than the chromate systems. This is due to the relative poor performance of most of the alternatives that lower the average of the better-performing alternatives, which rate comparably to the Alodine 1200S control for all three non-chromate primers.

Table 5.6.3.6: Summary Ratings for Pretreatments and Primer Systems exposed to 500 Hours (Ratings per ASTM D 1654A)

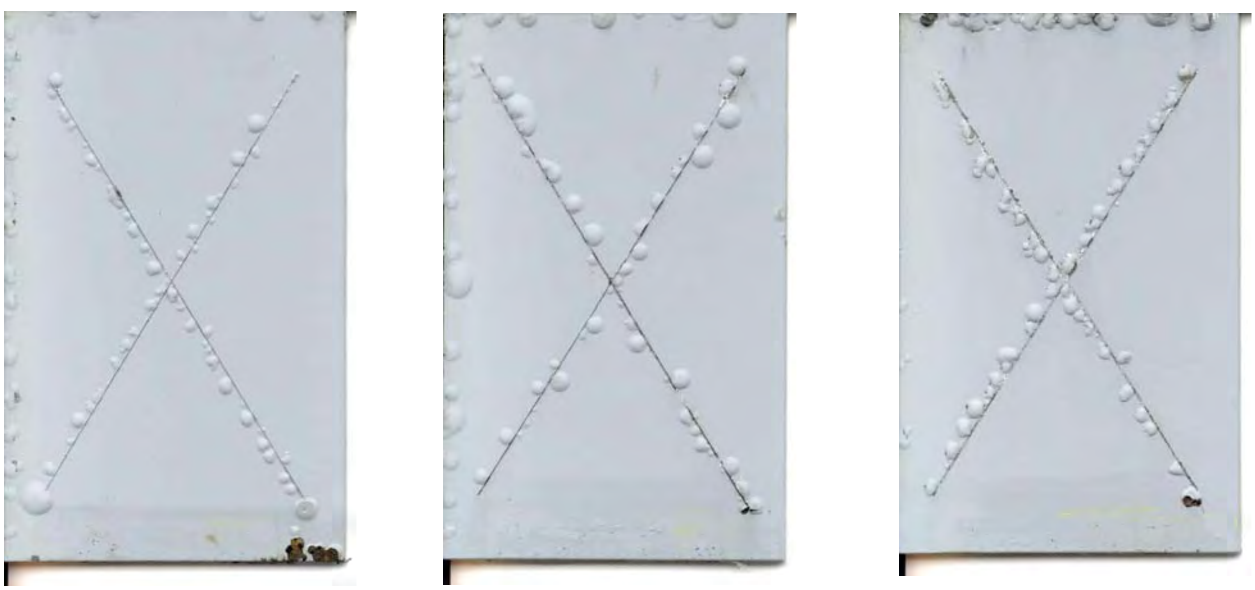
	Primer					
Pretreatment	23377	85582 C2	85582 N	53022	53030	All Coatings
Alodine 1200S (control)	7.3	7.8	7.3	5.8	6.0	6.8
Alodine 5200	6.0	6.5	6.5	6.0	6.0	6.2
Bi-K Aklimate	5.0	6.3	2.3	2.0	1.0	3.3
Boegel	6.5	7.0	6.0	6.8	5.5	6.4
Chemidize 727ND	5.8	4.8	2.3	1.8	2.0	3.3
Oxsilan Al-0500	6.3	5.8	4.8	0.3	2.3	3.9
Sanchem 7000	4.5	4.3	1.5	0.3	2.0	2.5
TCP	7.3	7.3	6.5	6.3	6.5	6.8
X-It PreKote	5.3	5.0	3.5	1.5	3.3	3.7
Overall Alternative Average	**6.0**	**6.1**	**4.5**	**3.4**	**3.8**	**4.8**

Figures 5.6.3.1 through 5.6.3.6 show examples of performance of various pretreatments with different primers and alloys.



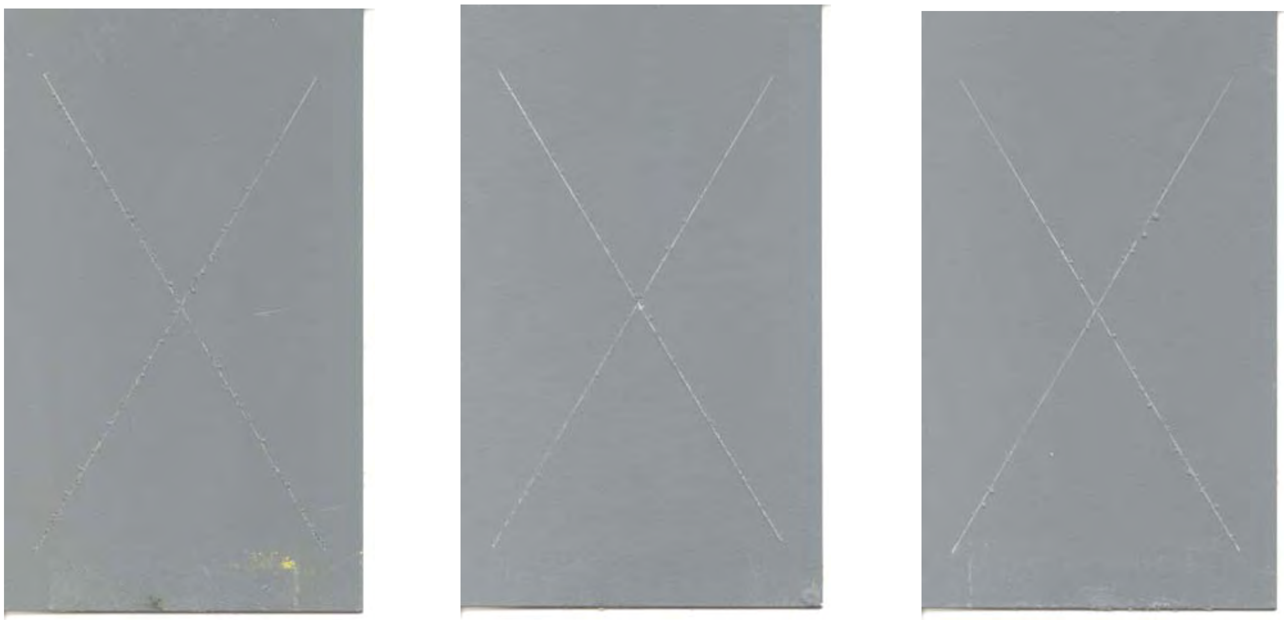
Alodine 1200S TCP Alodine 5200

Figure 5.6.3.1: Pretreatments With 23377/85285 Coating System on Al 2024 after 500 Hour Exposure



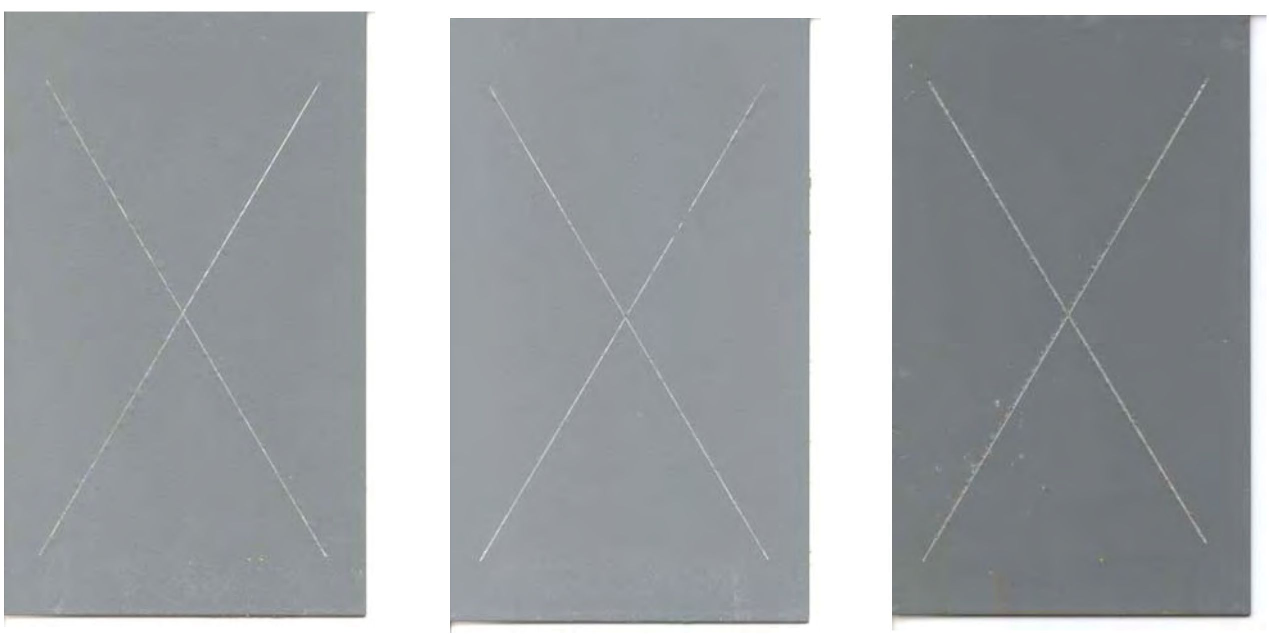
Alodine 1200S TCP Alodine 5200

Figure 5.6.3.2: Pretreatments With 23377/85285 Coating System on Al 2219 After 500 Hour Exposure



Alodine 1200S TCP Alodine 5200

Figure 5.6.3.3: Pretreatments With 53030/53039 Coating System on Al 2024 after 500 Hour Exposure to SO_2 Salt Fog

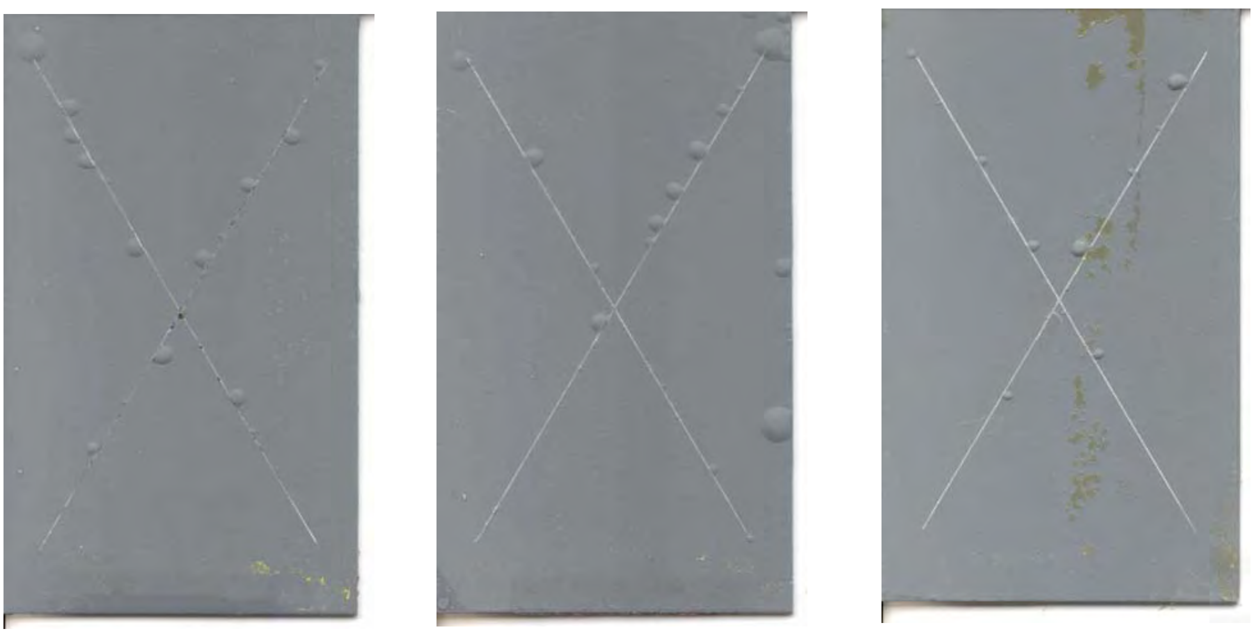


Alodine 1200S TCP Boegel

Figure 5.6.3.4: Pretreatments With 53022/53039 Coating System on Al 2024 after 500 Hour Exposure

Alodine 1200S TCP Alodine 5200

Figure 5.6.3.5: Pretreatments With 85582 NC/85285 Coating System on Al 2219 after 500 Hour Exposure



Alodine 1200S TCP Alodine 5200

Figure 5.6.3.6: Pretreatments With 53022/53039 Coating System on Al 5083 after 500 Hour Exposure

5.7 Cyclic Corrosion on Scribed, Painted Substrates

5.7.1 Test Description

This test method evaluates a coating system's ability to prevent substrate corrosion and the effect that corrosion has on the adhesion of coating system. Operation of the fog chamber for this test is in accordance with GM 9540P (*Accelerated Corrosion Test*). Testing was completed by Army Research Laboratory personnel at the Aberdeen, MD test facility.

Prior to exposure, an "X" incision was manually scribed through the test coupon coating using a carbide tip scribe as per ASTM D 1654, making sure that the coating was scribed all the way through and into the substrate. The smaller angle of the "X" was 30 to 45 degrees and each line of the "X" was approximately 4 inches long. The back and edges of the test coupons were painted to prevent corrosion products from contaminating the chamber. The scribed coupons were placed into a fog chamber at a 15-degree incline. The coupons were not allowed to contact other surfaces in the chamber and condensate from a coupon also did not contact any other coupons. The salt solution and the fog chamber were prepared as specified in the Test Methodology of the JTP. The nozzles were then adjusted in the fog chamber so that sprayed salt solution did not directly impinge on the coupon surfaces. The fog chamber was operated continuously for 120 cycles. Coupons were evaluated for surface corrosion and creepage from the scribe at 20-cycle intervals. The coupons were carefully removed at the end of the test duration and cleaned with running water [water temperature less than 38 °C (100°F)]. The coupons were then air-dried at ambient conditions, and then visually examined.

5.7.2 Test Results

Three cyclic corrosion test chambers (CCTC) were used to evaluate the coated aluminum test panels. In order to maximize uniformity of test conditions, each alloy was given its own specific chamber. Figure 5.7.2.1 depicts the configuration of the test chamber used for GM Standard Test 9540P, which provides more dynamic accelerated conditions versus conventional ASTM B 117 Salt Fog. The GM 9540P test consists of 18 separate stages that include the following: saltwater spray, humidity, drying, ambient, and heated drying.

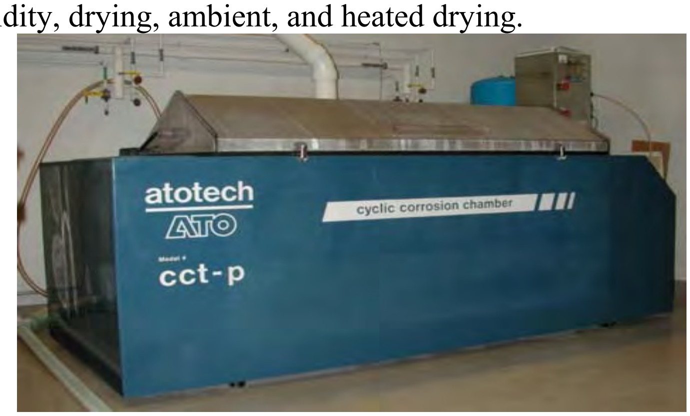


Figure 5.7.2.1: Test Chamber Configuration Used for GM 9540P

The environmental conditions and duration of each stage for one complete 9540P cycle are provided in Table 5.7.2.1. The standard 0.9% NaCl, 0.1% $CaCl_2$, 0.25% $NaHCO_3$ test solution was used. In addition, each chamber was calibrated with standard steel mass loss calibration coupons described in GM Standard Test 9540P and supplied by GM. In order to visibly chronicle the corrosion, one representative panel of each of the five test panels was chosen at 20 cycles of exposure and digitally scanned at 600 dpi resolution. Subsequent scans of the same representative panel were made at every 20 cycles until the conclusion of 120 cycles or until specimen group failure. Specimens were numerically rated for damage at each 20 cycle interval using method ASTM D 1654. Specimen group failures were defined by a rating of 0 under ASTM D 1654 for 3 or more of the panels in a particular alloy/pretreatment/coating set. With the exception of premature failures under ASTM D 1654, the coated panels were all subjected to 120 cycles of GM 9540P.

Table 5.7.2.1: GM 9540P Cyclic Corrosion Test Details

Interval	Description	Time (min)	Temperature ($\pm$3°C)
1	Ramp to Salt Mist	15	25
2	Salt Mist Cycle	1	25
3	Dry Cycle	15	30
4	Ramp to Salt Mist	70	25
5	Salt Mist Cycle	1	25
6	Dry Cycle	15	30
7	Ramp to Salt Mist	70	25
8	Salt Mist Cycle	1	25
9	Dry Cycle	15	30
10	Ramp to Salt Mist	70	25
11	Salt Mist Cycle	1	25
12	Dry Cycle	15	30
13	Ramp to Humidity	15	49
14	Humidity Cycle	480	49
15	Ramp to Dry	15	60
16	Dry Cycle	480	60
17	Ramp to Ambient	15	25
18	Ambient Cycle	480	25

The tables below detail corrosion performance for pretreatments on each alloy.

Table 5.7.2.2: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated with Mil-PRF-23377 Primer and Mil-C-85285 Topcoat

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S	8.8	9.0	9.0	9.0
Alodine 5200	8.2	6.0	9.0	9.4
Bi-K Aklimate	7.8	9.0	9.0	7.0
Boegel	8.4	8.6	9.0	6.2
Chemidize 727ND	7.4	9.0	9.2	4.6
Oxsilan Al-0500	8.2	9.0	9.6	9.4

Table 5.7.2.2: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated with Mil-PRF-23377 Primer and Mil-C-85285 Topcoat (Continued)

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Sanchem 7000	7.6	8.6	6.0	6.8
TCP	8.4	9.0	9.0	8.0
X-It PreKote	7.0	9.0	9.0	5.4

Table 5.7.2.3: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated with Mil-PRF-85582 C2 Primer and Mil-C-85285 Topcoat

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S	8.2	9.0	9.0	9.6
Alodine 5200	7.8	6.0	9.0	9.0
Bi-K Aklimate	7.8	9.0	9.0	5.2
Boegel	8.4	9.0	9.0	7.6
Chemidize 727ND	6.0	5.8	9.4	7.4
Oxsilan Al-0500	4.0	6.2	9.2	9.2
Sanchem 7000	-	-	7.6	6.4
TCP	8.2	9.0	9.0	8.6
X-It PreKote	6.2	9.0	9.0	6.6

Table 5.7.2.4: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated with Mil-PRF-85582 NC Primer and Mil-C-85285 Topcoat

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S	6.4	8.0	9.0	6.0
Alodine 5200	6.0	5.6	9.0	6.0
Bi-K Aklimate	0.6	-	8.4	-
Boegel	2.8	4.8	9.0	-
Chemidize 727ND	1.8	0.6	7.0	-
Oxsilan Al-0500	5.6	7.0	9.0	3.4
Sanchem 7000	-	-	3.0	-
TCP	5.4	6.8	9.0	5.0
X-It PreKote	4.6	2.2	8.2	-

Table 5.7.2.5: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated with Mil-PRF-53030 Primer and Mil-C-53039 Topcoat

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S	6.4	7.0	9.0	3.8
Alodine 5200	6.6	4.0	9.0	2.6

Table 5.7.2.5: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated with Mil-PRF-53030 Primer and Mil-C-53039 Topcoat (Continued)

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Bi-K Aklimate	1.2	-	9.0	-
Boegel	2.2	3.0	9.0	-
Chemidize 727ND	1.2	-	7.8	-
Oxsilan Al-0500	3.4	1.2	9.0	-
Sanchem 7000	4.0	-	6.4	-
TCP	7.8	6.6	9.0	2.0
X-It PreKote	4.6	1.4	9.0	-

Table 5.7.2.6: Average Scribe Failure Rating (5 panels) for Aluminum Alloys Coated with Mil-PRF-53022 Primer and Mil-C-53039 Topcoat

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S	5.8	5.0	9.0	0.0
Alodine 5200	6.4	4.2	9.0	3.2
Bi-K Aklimate	2.8	0.6	7.8	-
Boegel	3.0	2.4	9.0	-
Chemidize 727ND	2.4	-	7.2	-
Oxsilan Al-0500	4.4	3.2	9.0	-
Sanchem 7000	1.8	1.2	8.4	-
TCP	7.8	6.8	9.0	1.6
X-It PreKote	2.2	1.4	9.0	-

Aluminum 2024

For the hexavalent chromium bearing 23377/85285 coating system, all of the pretreatments performed fairly well and completed 120 cycles with the highest ratings among the coating systems. Although the 85582C2/85285 coating system also contains hexavalent chromium, overall it performed much worse when compared versus the 23377/85285 system for the same pretreatments.

For the remaining three coating systems, 85582 N/85285, 53030/53039, and 53022/53039, the best performance was provided by the NAVAIR TCP and Alodine 1200S pretreatments (See Figures 5.7.2.2 and 5.7.2.3). In the specific cases of the 53030/53039 and 53022/53039 CARC system, the TCP pretreatment even *exceeded* the performance for Alodine 1200S. Alodine 5200 pretreatment rendered respectable performance at or near the leaders for these chromium-free coating systems.

Aluminum 2219

Of the aluminum alloys in this test, Al 2219 with its high Cu content is by far the most corrosion prone and provides a difficult task for even hexavalent-chromium-based Alodine 1200S. For the chromate-based 23377/85285 coating system, although all pretreatments lasted the full 120-cycle duration, significant corrosion damage occurred on many of them. The best performers for this coating system were Alodine 1200, Alodine 5200 and Oxsilan. TCP showed mixed performance among its five respective replicates, but overall still performed much better than the remaining pretreatments. For the chromate-containing 85582C2/85285 system, the best performers were Alodine 1200 and Alodine5200, NAVAIR TCP, Oxsilan and Boegel. Figures 5.7.2.4 and 5.7.2.5 show that the remaining pretreatments performed in the intermediate range with ratings ranging from 5 to 7.

For the three chromate free coating systems, 85582 N/85285, 53030/53039, and 53022/53039, there was significant corrosion damage and most of the coating systems were unable to endure 120 cycles without early specimen group failure. Although the corrosion damage was severe, the most consistent performers for these systems were NAVAIR TCP, Alodine 1200 and Alodine 5200. Oxsilan rated only marginally better than the remaining pretreatments for the chromate free coatings but only by virtue of not completely failing as soon.

Aluminum 5083

Al 5083, an alloy known for its stable protective oxide layer, does not usually significantly corrode, even under accelerated conditions. Due to its widespread use in tactical ground systems, accelerated corrosion methods such as GM 9540P are still necessary for this alloy for quality assurance and also for detecting potential coating adhesion issues. As expected, most coating systems completed the full 120 cycle duration without any noticeable damage. As in Al 2024 the 23377/85285 coating system proved superior and there was no significant creepback resulting from corrosion or coating system delamination. For 85582 C2/85285, there were adhesion issues with the Sanchem 7000 pretreatment, which rated a 7 by 60 cycles and then stabilized for the balance of the 120 cycles. For the non-chromium based formulation 85582 N/85285, the problems with the Sanchem process were more pronounced with more severe creepback resulting from actual corrosion. Any damage for Al 5083 is significant since even in a bare uncoated and untreated condition this alloy will not significantly corrode. For this same coating system, the Chemidize 727ND pretreatment also showed blistering though to a somewhat less severe degree along the scribe. For the waterborne 53030 primer based CARC system, Sanchem exhibited damage due to adhesion failure similarly as noted above. For the solvent primer based 53022/53039 CARC system, the only noticeable damage occurred on the Bi-K Aklimate pretreated system.

Aluminum 7075

For the coating system 23377/85285 as in the other alloys, most all of the pretreatments performed well with little or no damage to the scribed region. The exception for this case was Alodine 5200 with damage characterized by coating delamination from the scribed regions.

For the 85582 C2/85285 system, the top performers with little or no damage were Alodine 1200S, TCP, X-It PreKote, and Boegel. Other pretreatments for this system were disqualified either by lower ratings due to corrosion, delamination, or both. Sanchem 7000 pretreatment failed across the majority of its 5 panels by 100 cycles.

The only top performers were Alodine 1200S and TCP for the chromate free 85582 N/85285 system. The next best performing alternatives Alodine 5200 and Boegel, which both rated a “5” through 120 cycles. Panels failing the exposure for this coating system were Sanchem and Bi-K Aklimate. In particular, the failure for Sanchem was severe with partial series failures at 20 cycles and specimen group failure by 40 cycles exposure.

As in previous alloys, the CARC systems were more susceptible to corrosion attack than their aircraft coating counterparts. For the waterborne primer system 53030/53039, Alodine 1200S and TCP pretreatments performed best. The mode of creepback progression on the TCP treated panel was due to delamination of the coating. The next best performers for this coating system were Alodine 5200 and Boegel, however their performance at best was fair with both pretreatments only rating a “4” at the conclusion of 120 cycles. Series that failed prior to completion of 120 cycles in order of decreasing severity included: Chemidize 727ND, Bi-K Aklimate, and Sanchem 7000.

The 53022/53039 system performance for all pretreatments overall was better than for the waterborne primer CARC series for Al 7075. The NAVAIR TCP pretreatment was clearly superior for this group as shown in Figure 5.7.2.6. Next best finishers were Alodine 5200 and Alodine 1200S with ratings at 120 cycles of “6” and “5” respectively. Boegel rated a “3” with the others all rating a “2” or lower at 120 cycles. The only failure prior to 120 cycles was the Chemidize 727ND pretreatment, which failed as a set by 60 cycles.

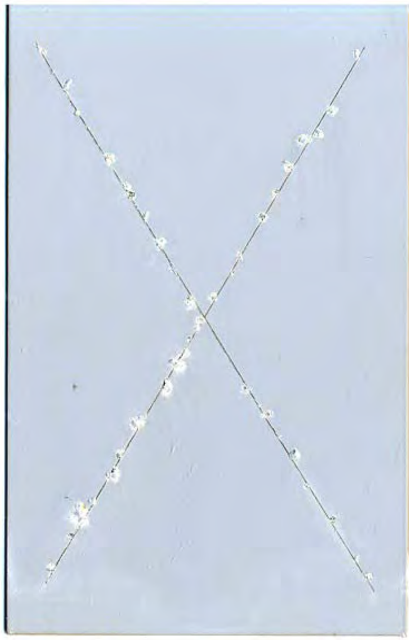
Summary of Alternative Performance

Table 5.7.2.7 details the summary performance of each alternative pretreatment by primer system. It also shows an average rating for each primer across all pretreatments. TCP performs the best overall, generally as good as the control. Alodine 5200 is a solid second. Oxsilan Al-0500 and Boegel rank third and other 4 alternatives rank fourth.

Interestingly, TCP performs notably better than Alodine 1200S with 53022 primer but not as good with the 85582 N primer. This is similar to the trend in the painted neutral salt fog and SO_2 salt fog tests. Also of note is the consistent performance of TCP for all three non-chromate primers. Alodine 5200 did clearly better with the 85582 N primer compared to the 53022 and 53030 coatings. This trend is evident for the neutral salt fog and SO_2 salt fog tests as well.

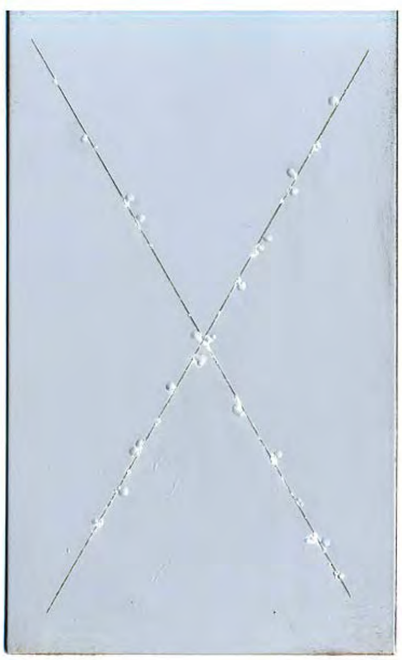
Table 5.7.2.7: Summary Ratings for Pretreatments and Primer Systems exposed to 120 Cycles of GM9540P Corrosion Test (Ratings per ASTM D1654A)

	Primer					
Pretreatment	23377	85582 C2	85582 N	53022	53030	All Coatings
Alodine 1200S (control)	9.0	9.0	7.4	5.0	6.6	7.4
Alodine 5200	8.2	8.0	6.7	5.7	5.6	6.8
Bi-K Aklimate	8.2	7.8	2.3	2.8	2.6	4.7
Boegel	8.1	8.5	4.2	3.6	3.6	5.6
Chemidize 727ND	7.6	7.2	2.4	2.4	2.3	4.3
Oxsilan Al-0500	9.1	7.2	6.3	4.2	3.4	6.0
Sanchem 7000	7.3	3.5	0.8	2.9	2.6	3.4
TCP	8.6	8.7	6.6	6.3	6.4	7.3
X-It PreKote	7.6	7.7	3.8	3.2	3.8	5.2
Overall Alternative Average	**8.0**	**7.4**	**4.3**	**3.8**	**3.9**	**5.5**

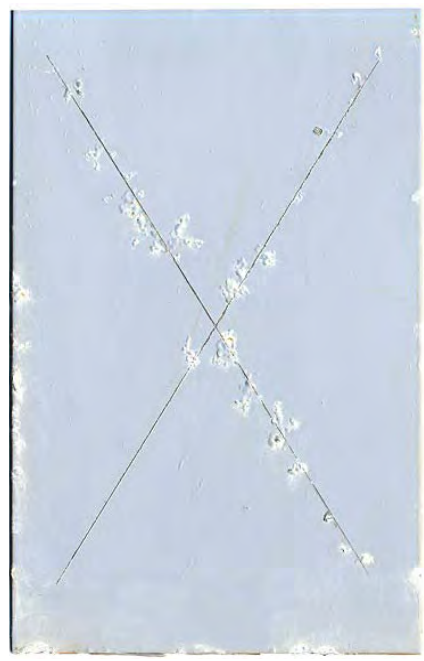


(a) Alodine 1200S

(b) TCP

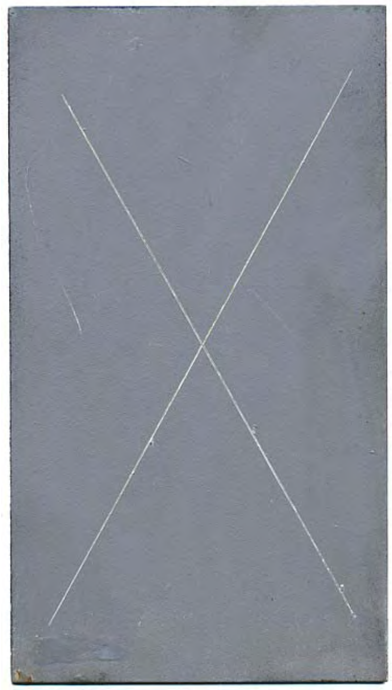


(c) Alodine 5200

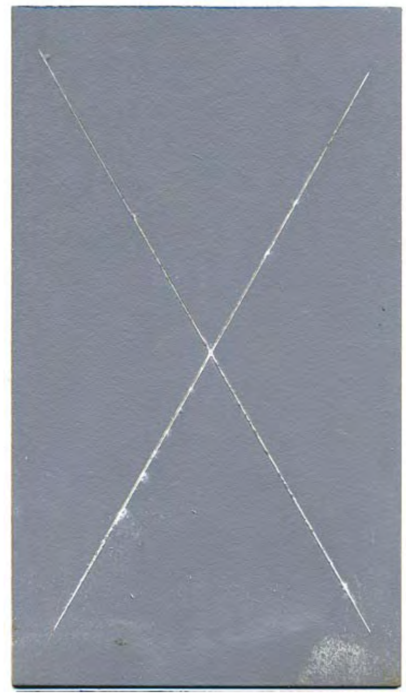


(d) Boegel

Figures 5.7.2.2: Aluminum 2024 Coated With 85582 N/85285 Coating System

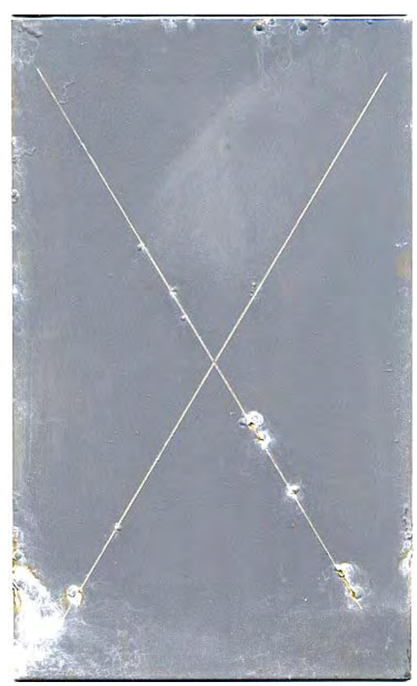


(a) Alodine 1200S



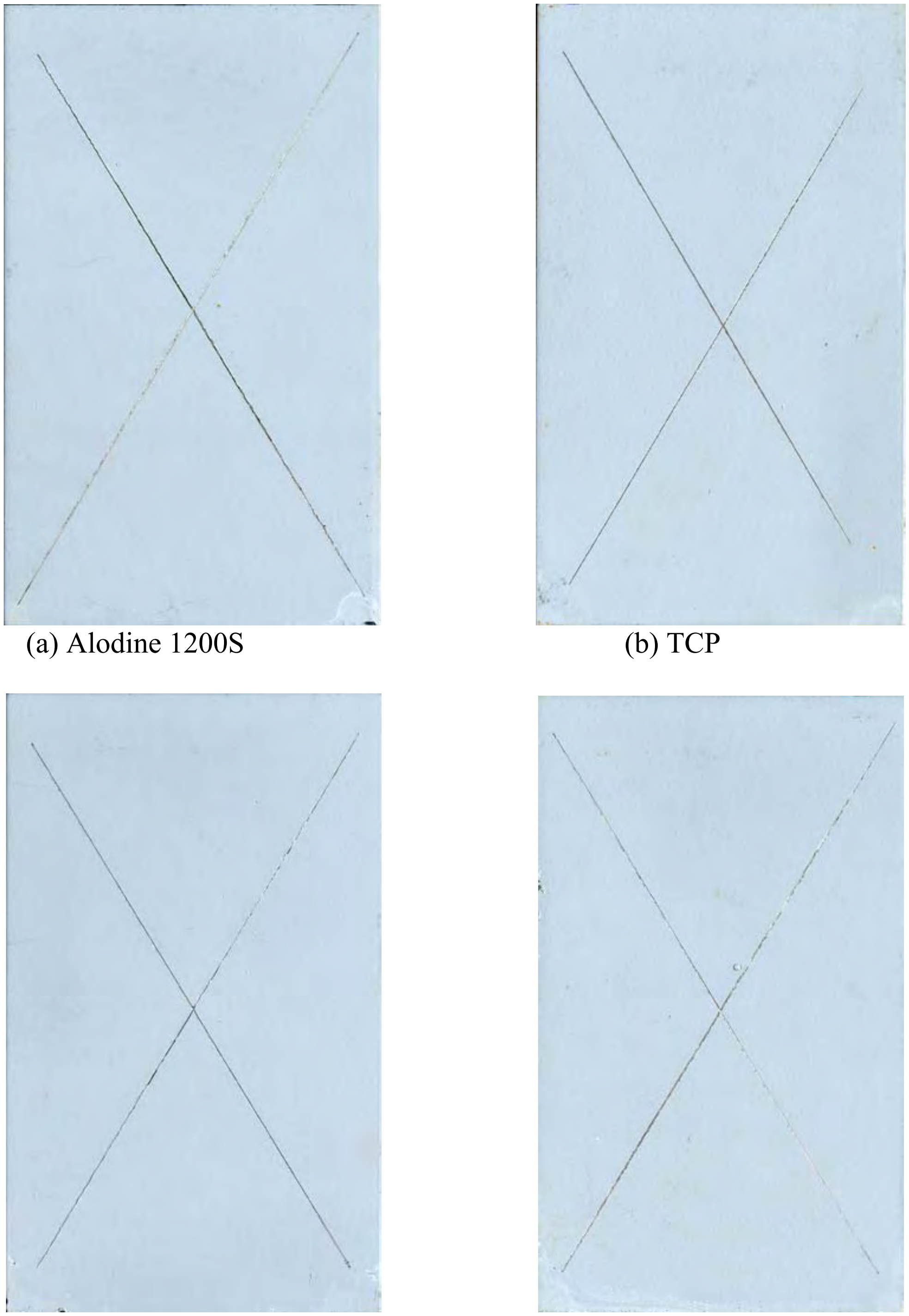
(b) TCP

(c) Alodine 5200



(d) Boegel

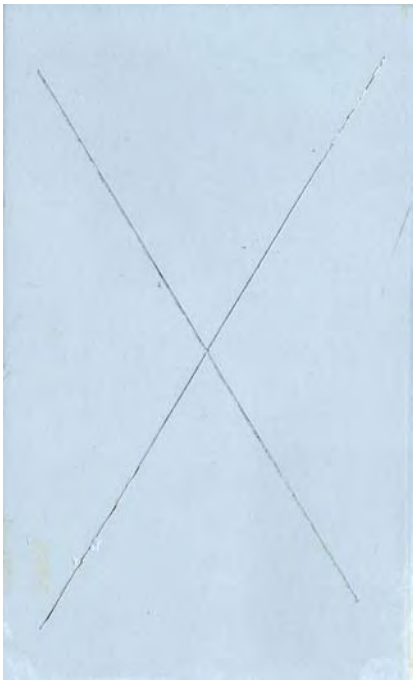
Figure 5.7.2.3: Aluminum 2024 Coated With 53030/53039 Coating System



(a) Alodine 1200S (b) TCP

(c) Alodine 5200 (d) Oxsilan AL-0500

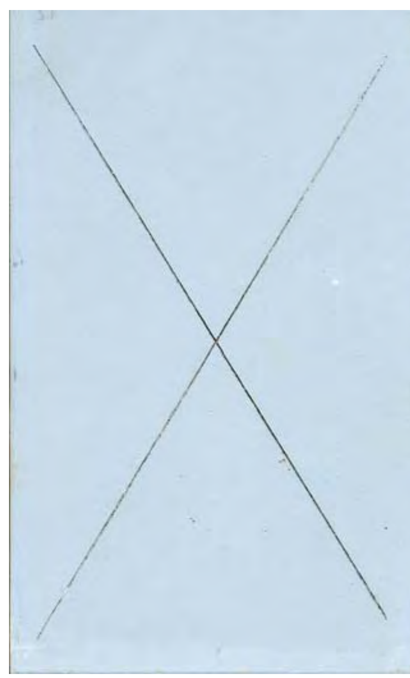
Figure 5.7.2.4: Aluminum 2219 Coated With 85582 C2/85285 Coating System



(a) X-It PreKote

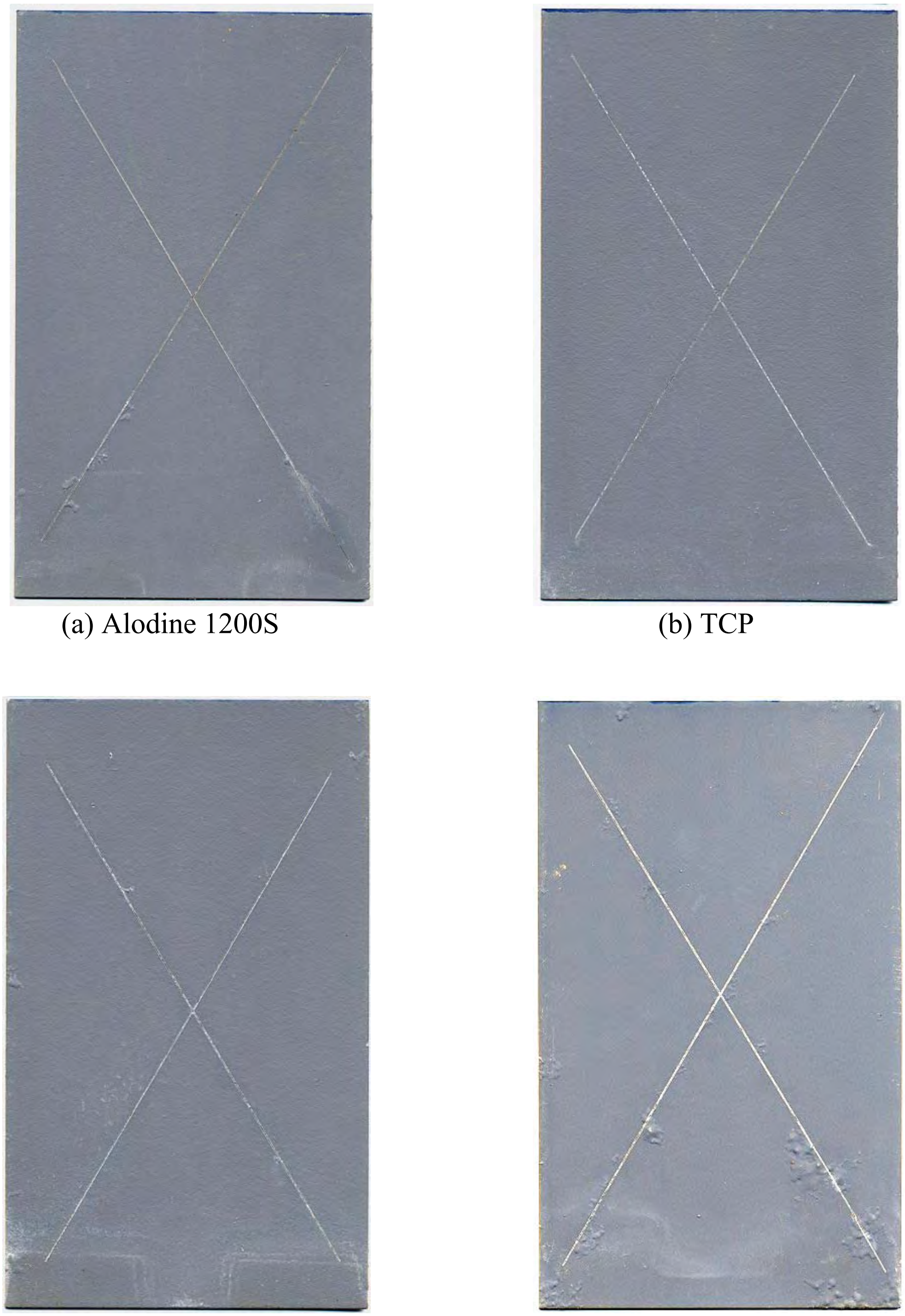
(b) Chemidize

(c) Bi-K Aklimate



(d) Boegel

Figure 5.7.2.5: Aluminum 2219 Coated With 85582 C2/85285 Coating System



(a) Alodine 1200S (b) TCP

(c) Alodine 5200 (d) Boegel

Figure 5.7.2.6: Aluminum 7075 Coated With 53022/53039 Coating System

5.8 Filiform Corrosion Resistance

5.8.1 Test Description

This test measures the ability of a coating system to protect the substrate against the formation of filiform corrosion. Testing was completed by the University of Dayton Research Institute (URDI) under contract to the Air Force Research Laboratory in Dayton, Ohio.

An "X" incision was scribed through the coating so that the smaller angle of the "X" was 30 to 45 degrees, making sure that the coating was scribed all the way through and into the substrate. The scribe had a 45 ° bevel, and each line of the "X" was approximately 4 inches long. The scribed coupons were placed in a desiccator containing 12 N hydrochloric acid (HCl) for one hour at 24 ± 3°C (75 ± 5°F). Within five minutes of removal from the desiccator, the coupons were placed in a humidity cabinet maintained at 40 ± 1.7°C (104 ± 3°F) and 80 ± 5 percent relative humidity (RH) for 1,000 hours. The length of any thread-like filaments was then measured at the end of the test duration. The filiform corrosion test uses clad 2024-T3.

Two methods were used to rate coating resistance to filiform corrosion. Table 5.8.1.1 details a standard method based on measuring the lengths of any filaments and noting their relative density along the scribes. This method yields a two-digit rating with score of 0-0 being the best with no corrosion noted and 5-5 being the worst.

Table 5.8.1.1: Filiform Corrosion Standard Rating Method

Sites (% of scribe affected)	**Length (of filament)**	
0 – none	0 – none	For example, a specimen with no corrosion would be rated as 0-0, or total degradation as 5-5. If sites is 0, length must also be 0. If there are spots at the scribe where it appears corrosion is initiating, but has not yet developed a filiform pattern, rate sites with a length of 0 (i.e., 1-0)
1 - <10%	1 - <1/16"	
2 – 10-50%	2 – 1/16 – 1/8"	
3 – 50-75%	3 – 1/8 – ¼"	
4 - >75%	4 - >1/4"	
5 – 100%	5 - >1/4", solid mass	

An alternative "template" rating method was also used. After rating per the standard method, coatings are stripped from about 50% of the coupon exposing the filiform corrosion on the metal surface. The rating template, detailed in Figure 5.8.1.1, is then centered over one scribe leg with the short end aligned with the intersection of the two scribe lines. The number of squares in which filaments do not appear are counted. The process is repeated for the other leg of the X scribe. Readings for both measurements were added and reported as a total. The maximum rating for no filiform corrosion is 120. Figure 5.8.1.2 shows an example coupon prepared for template rating.

Note: The filiform corrosion rating template consists of a matrix of 60 1/8" squares, arrayed in a 15 x 4 square matrix.

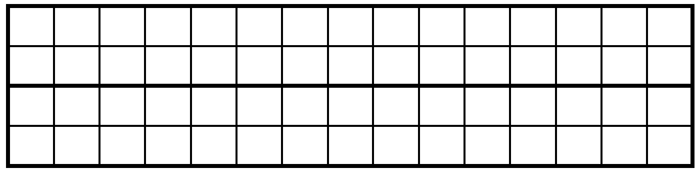


Figure 5.8.1.1: Filiform Corrosion Rating Template Layout

Figure 5.8.1.2: Example Coupon Prepared for Template Rating Method for Filiform Corrosion

5.8.2 Test Results

Filiform corrosion resistance data is presented in Tables 5.8.2.1 and 5.8.2.2. The results from the standard technique do not allow for discrimination of pretreatment performance for any primer except for the excellent performance of Alodine 1200S and TCP with the 85582 C2 primer. The template technique does provide relative performance data that discriminates among the candidate pretreatments for each primer. Based on this data, TCP is the clearly superior performer on average. For the 85582 N and 53022 system it surpasses the performance of any other coating including the Alodine 1200S control. With the 53030 primer it performs poorly, like most of the other coatings. The excellent performance of TCP with the 85582 N primer was recently reconfirmed by an in-house NAVAIR filiform corrosion test.

Notably, the Alodine 5200 and Boegel coatings , which perform ed fairly well with the non-chromate primers in the accelerated corrosion test s do poorly com pared to TCP, especially with the two water-borne non-chrom ates. This appears to be an area where the inheren t corrosion resistance that TCP possesses helps boost performance relative to the other alternatives.

Not surprisingly, the chrom ate primers performe d the best regardless of the pretreatm ent. One unexplained result is the relativ e poor performance of the 23377 primer with Alodine 1200S where strong perform ance was expected. No other evidence of unan ticipated or unusual performance with the 23377 primer was noted in all the JTP testing.

Table 5.8.2.1 Filiform Corrosion Ratings per Standard Technique

	Primer				
Pretreatment	23377/85285	85582 C2/85285	85582 N/85285	53030/53039	53022/53039
Alodine 1200S	4-5 4-5 4-5	1-1 1-1 1-1	3-3 3-4 2-2	4-4 4-4 4-4	4-5 4-4 4-4
Alodine 5200	3-3 3-4 4-4	3-3 2-2 2-2	5-5 3-3 4-3	4-5 4-5 4-5	4-5 4-4 4-5
Bi-K Aklimate	3-4 4-5 4-5	2-4 2-2 3-4	3-4 2-3 3-3	3-4 3-3 3-4	4-5 4-5 4-5
Boegel	3-4 4-5 5-5	2-3 2-4 2-3	4-4 3-4 3-4	4-5 3-4 4-5	5-5 3-4 3-4
Chemidize 727D	4-5 4-5 4-5	3-4 4-4 2-2	3-4 3-3 2-3	3-4 3-4 3-4	4-4 4-5 4-5
Oxsilan AL-0500	3-4 3-5 3-5	3-2 3-4 2-4	4-5 3-4 3-4	3-4 4-4 4-4	4-5 4-5 4-5
Sanchem 7000	2-3 4-5 4-5	4-3 4-5 4-4	4-5 3-4 3-4	4-5 4-5 4-5	4-5 4-4 4-4
TCP	2-2 3-3 2-3	1-1 1-1 1-1	3-4 3-3 3-3	4-5 4-4 4-4	4-4 3-4 3-4
X-It PreKote	2-3 4-5 4-5	3-4 4-4 4-4	4-5 3-4 3-3	4-5 4-5 4-5	4-5 4-4 4-4

Table 5.8.2.2: Filiform Corrosion Ratings per Template Technique

	Primer					
Pretreatment	23377/85285	85582 C2/85285	85582 N/85285	53030/53039	53022/53039	**Average**
Alodine 1200S	16.0 26.0 25.0	84.0 77.0 100.0	58.0 53.0 53.0	12.0 16.0 10.0	13.0 22.0 23.0	**39.2**
Alodine 5200	89.0 55.0 73.0	73.0 63.0 72.0	22.0 4.0 3.0	1.0 2.0 2.0	6.0 3.0 4.0	**31.5**
Bi-K Aklimate	66.0 56.0 50.0	58.0 62.0 41.0	7.0 13.0 7.0	9.0 25.0 27.0	3.0 4.0 10.0	**29.2**
Boegel	40.0 16.0 28.0	19.0 10.0 22.0	14.0 4.0 8.0	12.0 11.0 12.0	44.0 25.0 13.0	**18.5**
Chemidize 727D	63.0 58.0 46.0	68.0 73.0 60.0	17.0 5.0 0.0	0.0 0.0 0.0	0.0 3.0 2.0	**26.3**
Oxsilan AL-0500	63.0 42.0 50.0	65.0 58.0 72.0	8.0 0.0 0.0	17.0 10.0 17.0	7.0 17.0 13.0	**29.3**
Sanchem 7000	75.0 72.0 71.0	76.0 74.0 76.0	11.0 2.0 6.0	0.0 0.0 0.0	2.0 9.0 3.0	**31.8**
TCP	82.0 74.0 69.0	99.0 82.0 90.0	94.0 99.0 97.0	2.0 4.0 4.0	89.0 92.0 102.0	**71.9**
X-It PreKote	50.0 74.0 32.0	32.0 39.0 49.0	48.0 13.0 9.0	0.0 0.0 2.0	5.0 1.0 1.0	**23.7**
Average	**54.1**	**67.4**	**24.3**	**7.2**	**19.1**	

Figures 5.8.2.1 through 5.8.2.5 show a selecti on of coatings and the relative differences in filiform corrosion resistance. Ratings noted in the title are based on the template technique.

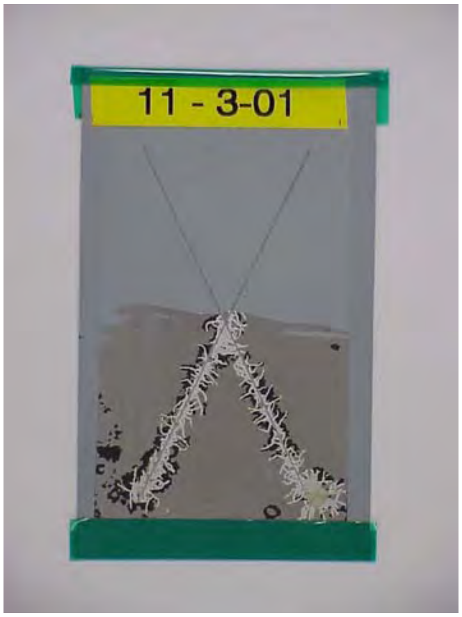


Figure 5.8.2.1: Alodine 1200S with 23377 Primer, Rating: 16

Figure 5.8.2.2: TCP with 23377 Primer, Rating: 82

Figure 5.8.2.3: TCP with 85582 N Primer, Rating: 94

Figure 5.8.2.4: Alodine 5200 with 85582 N Primer, Rating: 22

Figure 5.8.2.5: Sanchem 7000 with 53030 Primer, Rating: 0

5.9 Marine Atmospheric Test (Beach Test) on Scribed, Painted Substrates

5.9.1 Test Description

This test method evaluates a coating system's ability to prevent substrate corrosion and the effect that corrosion has on the adhesion of the coating system. Testing was completed by NASA and contractor personnel at Kennedy Space Center, Florida.

Outdoor exposure testing was conducted at the Kennedy Space Center's Beach Corrosion Test Site. This site is located approximately 1.5 miles south of Launch Complex 39A. Figure 5.9.1.1 shows an aerial view of the Kennedy Space Center's Beachsite.

Figure 5.9.1.1: Kennedy Space Center Beachsite Aerial View

Test stands are located 30 meters (100 feet) from the mean high-tide line and face the water. Test coupons are installed on stainless steel test stands using porcelain insulator stand-offs. The rack angle of the coupons is 30 degrees from horizontal. Figure 5.9.1.2 shows the coupon exposure racks.

Figure 5.9.1.2: Coupon Exposure Racks

An "X" incision was scribed through the coating so that the smaller angle of the "X" was 30 to 45 degrees, making sure that the coating was scribed all the way to the substrate. The scribe had a 45-degree bevel, and each line of the "X" was approximately 4 inches long. The back and edges of the coupon were primed to prevent undercutting and corrosion products from contaminating the test stands.

The coupons were then evaluated for surface corrosion and creepage from the scribe at 3,000-hour (4, 8, and 12 months) intervals for 12 months. Rating based on creepage from the scribe (ASTM D 1654A) are detailed here. Coupon groups rating "3A" or less on average were moved from the test stands. Remaining coatings are being evaluated until failure.

5.9.2 Test Results

The tables below detail corrosion performance for coating systems on each alloy after 12 months.

Table 5.9.2.1: Average Surface Corrosion and Creepage from the scribe (5 panels) for Aluminum Alloys Coated With Mil-PRF-23377 Primer and Mil-C-85285 Topcoat

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	10.0	10.0	10.0	10.0
Alodine 5200	10.0	9.2	10.0	10.0
Bi-K Aklimate	10.0	10.0	10.0	9.8
Boegel	10.0	10.0	10.0	9.3
Chemidize 727ND	10.0	10.0	10.0	7.6
Oxsilan Al-0500	9.6	10.0	10.0	9.8
Sanchem 7000	9.6	10.0	10.0	4.2
TCP	10.0	8.0	10.0	10.0
X-It PreKote	10.0	10.0	10.0	10.0

Table 5.9.2.2: Average Surface Corrosion and Creepage from the scribe (5 panels) for Aluminum Alloys Coated With Mil-PRF-85582 C2 Primer and Mil-C-85285 Topcoat

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	10.0	10.0	10.0	10.0
Alodine 5200	10.0	8.8	10.0	10.0
Bi-K Aklimate	10.0	10.0	10.0	9.8
Boegel	10.0	10.0 10.0		10.0
Chemidize 727ND	9.8	7.6	10.0	9.0
Oxsilan Al-0500	9.6	7.6	10.0	9.4
Sanchem 7000	0.0	3.2	10.0	6.4
TCP	10.0	10.0	10.0	10.0
X-It PreKote	10.0	10.0	10.0	9.8

Table 5.9.2.3: Average Surface Corrosion and Creepage from the scribe (5 panels) for Aluminum Alloys Coated With Mil-PRF-85582 NC Primer and Mil-C-85285 Topcoat

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	10.0	10.0	10.0	10.0
Alodine 5200	10.0	8.8	10.0	9.4
Bi-K Aklimate	0.8	1.0	10.0	0.0
Boegel	5.3	7.3	10.0	0.0
Chemidize 727ND	0.8	1.2	10.0	0.0
Oxsilan Al-0500	7.6	9.2	10.0	2.8
Sanchem 7000	0.0	5.4	9.2	0.0
TCP	10.0	9.6	10.0	9.6
X-It PreKote	3.8	1.4	9.0	0.0

Table 5.9.2.4: Average Surface Corrosion and Creepage from the scribe (5 panels) for Aluminum Alloys Coated With Mil-P-53030 Primer and Mil-C-53039 Topcoat

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	10.0	9.8	10.0	2.4
Alodine 5200	10.0	8.6	10.0	3.4
Bi-K Aklimate	0.8	9.4	9.8	0.0
Boegel	5.7	4.7	10.0	0.0
Chemidize 727ND	4.8	5.8	10.0	0.0
Oxsilan Al-0500	5.8	9.2	10.0	0.0
Sanchem 7000	9.8	0.2	10.0	0.0
TCP	10.0	10.0	10.0	3.6
X-It PreKote	4.2	6.0	10.0	0.0

Table 5.9.2.5: Average Surface Corrosion and Creepage from the scribe (5 panels) for Aluminum Alloys Coated With Mil-P-53022 Primer and Mil-C-53039 Topcoat

Pretreatment	Al 2024	Al 7075	Al 5083	Al 2219
Alodine 1200S (control)	10.0	9.8	10.0	0.4
Alodine 5200	10.0	8.8	10.0	2.4
Bi-K Aklimate	3.2	6.4	10.0	0.0
Boegel	9.5	1.3	10.0	1.0
Chemidize 727ND	6.0	2.2	9.2	0.0
Oxsilan Al-0500	9.4	7.6	10.0	0.8
Sanchem 7000	7.8	6.6	10.0	0.0
TCP	10.0	10.0	10.0	1.4
X-It PreKote	3.4	2.6	10.0	0.0

Aluminum 2024

At four months, only the Bi-K Aklimate coating with 85582 Class N primer showed any degradation, rating an average 9 out of 10. By eight months, corrosion began to appear on a number of coatings, all based on non-chromate primers. For the 85582 Class N system, Sanchem 7000, X-It PreKote, Chemidize 727D, Bi-K Aklimate, and Boegel coatings rated 7 or 8. Alodine 1200S, TCP, Alodine 5200 and Oxsilan Al-0500 remained undamaged. For the 53022 system the coatings performed somewhat better, but the X-It PreKote and Bi-K Aklimate showed initial corrosion damage. The trend continued for the 53030 systems, with Alodine 1200S, TCP, Alodine 5200 and Sanchem 7000 remaining undamaged. The remaining coatings rated 8 or 9 on average.

At 12 months, most alternatives continued to perform well with chromate primers. A notable exception is Sanchem 7000 which rated 0 with the 85582 C2 primer. System degradation continued in the non-chromate primer systems, with only Alodine 1200S, TCP and Alodine 5200 exhibiting no damage on any coupon.

Aluminum 2219

Like the other corrosion tests, aluminum 2219 represents the most serious challenge to the coating systems in the beach exposure test. Minor degradation began to occur in most non-chromate primer systems by four months. By eight months, serious degradation was underway for numerous non-chromate primer systems. Most notable was the lack of degradation in the 85582 N systems with TCP and Alodine 5200. These two alternatives were typically superior for the 53022 and 53030 systems, as well.

At 12 months, all alternatives with primers 23377 and 85582 C2 were performing well with little or no corrosion except for Sanchem 7000, which rated in the 4 to 6 range. Alodine 1200S, TCP and Alodine 5200 were particularly good, showing no evidence of corrosion on any coupon. For the non-chromate primers, Sanchem 7000, X-It PreKote, Chemidize 727ND and Bi-K Aklimate all completely failed, rating 0 for all coupons. Boegel had one coupon rate a 3, with the rest failing completely. Oxsilan Al-0500 maintained some protection with the 85582 N primer, but failed with the 53022 and 53030 systems.

Somewhat surprisingly, TCP and Alodine 5200 performed very well with the 85582 N primer, with all coupons rating 9 or 10 after 12 months. The coatings did not fare as well with the 53022 and 53030 systems, although performance was better than the other alternatives. This performance was, however, similar to the Alodine 1200S control which did very well with the 85582 N system but poorly with the 53022 and 53030 systems.

Aluminum 5083

No significant corrosion appeared on any test coupons in the 12-month period. This is not surprising given the excellent corrosion resistance of the 5083 alloy relative to the others in this test.

Aluminum 7075

Corrosion trends in this alloy were very similar to coating performance on 2024. TCP and Alodine 5200 were again the clear winners among the alternatives, showing performance as good as the Alodine 1200S control in most cases. These two alternatives also maximized the performance of the 85582 N, 53022, and 53030 primers, yielding overall performance as good as the chromate primers. For this alloy, TCP was somewhat better than Alodine 5200, rating 1 unit better for the 85582, 53022, and 53030 coating systems. Among the other alternatives, Oxsilan Al-0500 performed the best, yielding respectable ratings ranging from 7 to 9 on average.

Summary of Alternative Performance

Table 5.9.2.6 details the summary performance of each alternative pretreatment by primer system. It also shows an average rating for each primer across all pretreatments. TCP and Alodine 5200 perform as well as the Alodine 1200S control across most coatings. Their superior performance is strongly evident in the non-chromate primer systems where no other alternative comes close. For the chromated primers, most of the alternatives show good performance, especially X-It PreKote and Bi-K Aklimate, which match the perfect performance of the Alodine 1200S controls.

Like the previous corrosion tests, the chromate-based primer systems perform equally well and are the basis of the best coating systems. The non-chromate systems, on average, rank lower than the chromate systems especially with the poorer performing alternatives. One notable exception is the performance of the 85582 N primer with Alodine 1200S, TCP and Alodine 5200. These non-chromate systems match the performance of the sister systems with chromate primers. No other non-chromate system competes as well.

Table 5.9.2.6: Summary Ratings for Pretreatments and Primer Systems exposed to 12 Months of Outdoor Exposure at Kennedy Space Center Beachfront Corrosion Test Site

	Primer					
Pretreatment	23377	85582 C2	85582 N	53022	53030	All Coatings
Alodine 1200S (control)	10.0	10.0	10.0	7.6	8.1	9.1
Alodine 5200	9.8	9.7	9.6	7.8	8.0	9.0
Bi-K Aklimate	10.0	10.0	3.0	4.9	5.0	6.6
Boegel	9.8	10.0	5.7	5.5	5.1	7.2
Chemidize 727ND	9.4	9.1	3.0	4.4	5.2	6.2
Oxsilan Al-0500	9.9	9.2	7.4	7.0	6.3	7.9
Sanchem 7000	8.5	4.9	3.7	6.1	5.0	5.6
TCP	9.5	10.0	9.8	7.9	8.4	9.1
X-It PreKote	10.0	10.0	3.6	4.0	5.1	6.5
Overall Alternative Average	**9.7**	**9.2**	**6.2**	**6.1**	**6.2**	**7.5**

5.10 Toxicology

A leveraged effort executed by National Defense Center for Environmental Excellence (NDCEE)/ Concurrent Technologies Corporation (CTC) was used to complete toxicology testing requirements per the JTP. Based on technical performance and inputs from users on products they plan to field test, TCP and Alodine 5700 were chosen for toxicological evaluation. Alodine 1200S was tested as the chromate baseline for toxicological properties. Other alternatives may be subjected to similar testing at the discretion of potential users. The following is a summary of the toxicology testing completed by MB Research Laboratories.

5.10.1 Demonstration Report for Non-Chromate Pretreatment for Non-ferrous Metals

Performance testing of alternative aluminum non-chromate pretreatments generated two potential candidates for toxicological evaluation, TCP and Alodine 5700 (Alodine 5700 is prepared by mixing 50mls of Alodine 5200 to 1950 mls of distilled water). TCP, Alodine 5700, Alodine 5200, and the baseline chromate pretreatment process, Alodine 1200S, were subjected to toxicological testing. Toxicological testing included Acute Oral Toxicity, Acute Dermal Toxicity, Acute Inhalation Toxicity, and Skin Sensitization.

The Acute Oral Toxicity test objective was to determine the potential for toxicity of the test article when administered orally. Five male and five female rats were used as the subjects for the test. If any mortality takes place at the initial dose level of 2,000 mg of the test article/kg of animal body weight, at least two additional groups would need to be dosed to determine the LD_{50} level. All animals survived the 2000-mg/kg oral doses of Alodine 1200S, TCP, Alodine 5700, and Alodine 5200. No abnormal physical signs were noted and body weight changes/necropsy results were normal. Therefore, the oral LD_{50} of Alodine 1200S, TCP, Alodine 5700, and Alodine 5200 are all greater than 2000 mg/kg since no mortality occurred during the testing periods. No further testing was required.

The objective of Acute Dermal Toxicity/LD_{50} in Rabbits study was to determine the potential for toxicity of the test article when applied dermally to New England white rabbits. If the limit test of 2,000 mg/kg of body weight produces no mortality, a full LD_{50} test series is not required. If any mortality occurs at the initial dose level, at least two additional groups need be dosed in order to determine the LD_{50}. All animals survived the 2000- mg/kg dermal application of Alodine 1200S, TCP, Alodine 5700, and Alodine 5200. No cases of mortality indicated that the dermal LD_{50} of Alodine 1200S, TCP, Alodine 5700, and Alodine 5200 are greater than 2000mg/kg of body weight

The objective of the Acute Inhalation Toxicity test was to determine the potential for toxicity of the test article due to short-term inhalation exposure. Five male and five female rats were used as subjects for this test. The test article concentration was expressed as the weight of a test substance per unit volume of air (mg/l). If no mortality happens during the limit test, no further testing is required. If compound-related mortality is produced, further study may be needed to establish the Median Lethal Concentration (LC_{50}) value. The LC_{50} is a statistically derived approximation of the concentration of a substance that can be anticipated to cause death to 50 percent of the test subjects during exposure or within a fixed time after exposure. All animals survived the four hour 2.31 mg/l exposure of Alodine 1200S, therefore the LC_{50} is greater than 2.31 mg/l. Every animal survived four-hour 2.25-mg/l exposure to TCP so the LC_{50} is greater than 2.25 mg/l. All animals survived 4-hour 2.02-mg/l exposure to Alodine 5700 and 2.18-mg/l exposure to Alodine 5200. The LC_{50} value is for Alodine 5700 is therefore greater than 2.02 mg/l and the LC_{50} value for Alodine 5200 is greater than 2.18 mg/l.

The objective of the Dermal Sensitization test – Buehler test was to determine the effect of a product to promote skin sensitization after repeated applications. The guinea pig was used as the test subject. Erythema and edema are the external signs of a reaction during this test. Erythema was absent to faint during the induction phase and the challenge phase of Alodine 1200S, TCP, and Alodine 5700. Body weight changes and necropsy results were normal. Based on the results of these tests, Alodine 1200S,TCP , and Alodine 5700 are classified as non-sensitizers. Alodine 5200 wasn't subjected to the skin sensitization test.

All the non-chromate alternatives appeared better than Alodine 1200S from an environment, health and safety perspective, with Alodine 5700 being substantially less harmful than Alodine 1200S. Alodine 5200 is only slightly better than Alodine 1200S. Exposure to it will need to be evaluated since it will be used to produce Alodine 5700 by dilution and making up and adjusting immersion tanks.

Since no mortality occurred in any of the test subjects during any of the toxicological testing for any test article, all test articles met the 2000 milligrams of test article per kilogram of test subject bodyweight limit test requirement. Additionally, the alternatives were less hazardous than Alodine 1200S from an environmental, health and safety perspective. Consequently, Alodine 5700 and TCP are suitable and desirable replacements for Alodine 1200S for pre-treating aluminum substrates from a toxicological point-of-view. Waste treatment of any metal finishing waste will need to be evaluated in addition to toxicological data, including the impact of total chromium on treatment systems (in the case of TCP).

5.11 Repairability

The JTP contains multi-service DoD technical requirements and associated tests necessary to quantify non-chromate conversion coatings for pretreating aluminum and its alloys, including reparability testing. Leveraged funds from NDCEE/CTC were used to evaluate alternatives as used in repair or rework coatings. The project was called "Nonchromated Conversion Coatings for Weapon Systems Rework and Repair". The objective was to test a variety of nonchromated pretreatment alternatives as part of a coating system for use in the repair/rework environment. The project tested the following coatings:

- Henkel Surface Technologies Alodine® 5700
- Fortune Chemical Company X-It PreKote,
- MacDermid Chemidize® 727ND,
- Brent OxSiLAN® AL-0500,
- NAVAIR TCP,
- Boegel Sol-gel, and
- 3M Scotch-Weld 3901 Structural Adhesive Primer.

Two chromated coatings (Alodine 1200S and Touch N Prep Pen) were also tested. The test program included: dry and wet tape adhesion, and neutral salt fog exposure. All the coatings passed the dry tape adhesion results for uncross-cut samples, but cross-cut results were mixed and inconclusive. The wet tape adhesion test was acceptable for all panels coated with MIL-PRF-23377 primer, however, results for samples coated with MIL-PRF-85582 were mixed. All samples performed as well or better than the controls in the salt spray tests. (Reference #??)

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6.0 ISSUES IN EVALUATING NON-CHROMATED SYSTEMS

A number of issues concerning the evaluation of non-chromate coating systems and the coatings that make up these systems are important to consider in the search for high-value alternatives to chromate-based systems. Color change, product maturity, robust inhibition characteristics of hexavalent chromium, and accelerated test methods will be discussed and comparisons made for each issue between chromate and non-chromate coatings.

Chromate conversion coatings yield a practical color change that is relied upon by quality control and assurance personnel as visual proof that coatings were deposited during a given production shift. Only one product evaluated in this project, Sanchem 7000, yielded coatings with a practical color change. Technical performance aside, the lack of color change is an important weakness in alternative coatings when a materials engineer needs to decide whether to implement a product. At least one strong performer from this project (Alodine 5700) is not being implemented by a large user in part because of this issue. A recommendation to all developers of alternatives is to strongly consider color change during the optimization of new products.

Chromate conversion coating products are very mature and typically have good technical support behind them from established manufacturers. They are widely available around the world and are relatively inexpensive. The alternatives in this test are all new to the market. Alodine 5200 is probably the most mature of the group but still unproven in the long term for high volume production. Other products range from medium maturity to new single-batch products from research and development laboratories. This may result in varying consistency between alternatives as tested in this project and what may be available in the future. Specific sources of variability include batch-to-batch variations, marketing and organizational changes and product reformulations. During the course of this effort, one product (Boegel) was licensed from the developer to a manufacturer with a change in the source of the product. The manufacturer of another product (OXSiLAN AL-0500) was acquired by a different manufacturer, which is considering discontinuing the specific alternative tested in this project. These types of events can possibly affect the consistency or availability of any alternative and need to be considered when selecting alternatives for field-testing or implementation.

Another complicating factor in the testing and evaluation of non-chromate pretreatments, primers, and topcoats is the inherent robust corrosion inhibiting properties of hexavalent chromium. It passivates numerous metals and alloys by multiple mechanisms and very small amounts are necessary to be effective. Non-chromate inhibitors are not as robust as their chromated counterparts. High-quality non-chromated organic coatings typically rely on a synergistic combination of inhibitors to achieve their performance. Each pretreatment alternative has a unique chemistry and in many cases offers no corrosion inhibition, only adhesion promotion. Combining alternative pretreatments and primers or self-priming topcoats creates additional coating system performance uncertainty due to largely unknown, and sometimes synergistic, effects between pretreatment and primer or topcoat. The most desirable coating systems are those that perform well despite the alteration of components. Systems containing some chromated components can accommodate changes in other components without necessarily compromising system performance. This co-dependence of inorganic and organic coatings must be taken into consideration when evaluating new coating combinations and contemplating implementation on complex systems.

Finally, the corrosion tests used in this evaluation were conceived to a large extent based on the performance of chromated systems. Discrepancies in the performance of non-chromated versus chromated systems have been observed by NAVAIR beyond the normal test time of 500 hours in SO_2 salt fog testing. This may lead to an increase in the duration of the SO_2 salt fog test to better discriminate amongst candidate coating systems. Care must be taken when using these results to not make sweeping conclusions about actual performance. Rather, this data can be used to lower the risk of field-testing promising alternatives. In the end, while laboratory testing might be able to give a good indication of performance, the only true determination of coating system performance is in-service, on a platform over an extended period of time.

This leads to the next phase of this ESTCP project, which is dedicated to the field-testing of alternative pretreatments. Section 7 describes several efforts underway to field-test or implement alternatives, several of which are leveraged with this project.

7.0 IMPLEMENTAION STATUS OF ALTERNATIVES IN DoD AND NASA

7.1 NASA (Alodine 5700)

The Space Shuttle Solid Rocket Booster (SRB) had only one set of coatings and one type of pretreatment qualified for protection of aluminum hardware. All of the materials contained chromate compounds. A project was conducted to identify and qualify alternatives for the currently qualified coating system and pretreatment. Three alternatives each for pretreatment and coating systems were tested for SRB Program qualification. Baseline materials for candidate comparison were Alodine 1201 (Henkel Corp.) and 44-GN-7 primer with 03W127A topcoat (Deft, Inc). The three pretreatment nominees were Okemcoat 4500 (Oakite Products, Inc.), Alodine 5700 (Henkel Corp.), and Chemidize 727ND (MacDermid Inc.). The coating systems chosen for evaluation were: Hentzen Coatings Inc. 05510WEP-X/05511CEH-X primer with 4636WUX-3/4600CHA-SG topcoat, Lord Corp. 9929A/B primer with A276 topcoat, and PRC-De Soto International, Inc. EEAE152A/B primer with EUAW 098A/EUAC082B topcoat. The Okemcoat 4500 pretreated panels were dropped from the qualification program due to poor performance during the Bond Strength – Flexibility and Water Resistance qualification testing. The PRC-DeSoto EEAE152A/B primer and EUAW098A /EUAC082 B topcoat were dropped from the qualification program due to the manufacturer ceasing production of the topcoat.

Figure 7.1.1: Launch Photo of the SRBs

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Testing gathered information on corrosion protection, bond strength, compatibility with other SRB materials, batch-to-batch consistency, and thermal environments data. Two pretreatments and two coating systems met the SRB program criteria. The recommended products are Henkel Alodine 5700, MacDermid Chemidize 727 ND, and the coating systems submitted by Hentzen and Lord. Coatings were tested in both a primer only and a primer/topcoat configuration. Both were found to be acceptable for flight. There are significant processing advantages for each of the materials depending on how they are used. The Hentzen coatings are chromate free and have very good processing characteristics along with good overall properties and are recommended for first implementation as an alternate. Likewise, Alodine 5700 had very robust processing parameters and is recommended for first implementation as a pretreatment alternate.

NASA's changed to the Hentzen / Alodine 5700 system in June 02. This change affected all structural aluminum (2219, 6061, and 7075) parts of the solid rocket boosters. The first hardware flew in the fall of 2002.

7.2 US Army TACOM (Alodine 5700)

The Army/Tacom is planning to implement Alodine 5200 for use on Al 2024-T4 and 2014-T6 roadwheels. They plan to implement Alodine 5200 in Red River Army Depot's (RRAD) Rubber Products Operations in the Feb-Mar 2003 timeframe.

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7.3 USAF (X-It PreKote)

A multi-year effort at Hill Air Force Base (AFB) was under taken to reduce or eliminate the use of chromate compounds in the paint preparation process for aircraft, predominantly F-16s. Of the four products tested, three were eliminated early through laboratory testing. The fourth candidate, X-It PreKote, was tested extensively against the current process. X-It PreKote performed better than chromate conversion coating in adhesion/flexibility tests and performed equally well in other testing. In addition, it was found that X-It PreKote could eliminate the solvent wipe down and the acid brightener used in conventional paint preparation procedures. Use of X-It PreKote also reduces the need to sand anodized surfaces before repainting, but the limitations are that the application process is labor intensive.

Operational tests have been conducted on several aircraft and are ongoing. Air Education & Training Command (AETC) used X-It PreKote on two aircraft in 1996. In March 1997 an F-16 was scuff sanded and repainted using X-It PreKote in the prep for paint process. In November 1997 two fully stripped F- 16 aircraft had their right wings treated with X-It PreKote while the rest of the aircraft was treated with chromate conversion coating. These aircraft are in service at Eglin and at Homestead. Hill AFB and the owning units have examined each of the test aircraft.

The results so far are very positive and no detrimental effects from the X-It PreKote have been discovered. By September 1999, Hill AFB had painted over fifty aircraft using the X-It PreKote process. The T-38, F-16, A-10, and C-130 aircraft were prepared half with Alodine and half with PreKote. X-It PreKote performed better than the Alodine side in all cases.

The F-16 System Program Office (SPO) has approved the use of the X-It PreKote process in 1F-16-23 Technical Order (TO). All F-16 that are painted at Hill AFB are X-It coated. For the F-16 Program at Hill AFB, the use of X-IT has resulted in 35 % increase in productivity, hazmat reductions, reduction on paint system failures, and no paint failures have occurred in the last three years. The T-1, T-37, and T-38 SPOs are currently revising their TOs to include the use of X-It PreKote.

Figure 7.3.1: Application of X-It PreKote

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7.4 NAVSEA/MARINES (TCP)

A Navy message stipulating non-use of hexavalent chromate coating systems was released in the early 1990's. For potential field testing on the Marine's Landing Craft, two candidates were selected: Brent Chemcote and TCP. The selection criteria was targeted at performance on 5000 series aluminum for anti-corrosion and coating adhesion enhancement properties. TCP was selected for field and beachfront coupon studies. Brent Chemcote is no longer in production.

TCP test patches for use as a surface preparation alternative to abrasive blasting were installed on the decks of the oily waste tank and another void in a Landing Craft, Air Cushion (LCAC) at Assault Craft Unit Four (ACU-4), Naval Amphibious Base, Little Creek, Virginia. LCAC hulls are predominantly aluminum alloy 5456.

A beachfront exposure rack was erected at ACU-4 nearly 1.5 years ago. Coupons of alloys 5083, 5086, and 5456 either received no surface preparation, preparation with TCP, preparation with garnet blasting, or were abrasively blasted and treated with TCP. The coating used was MIL-P-24441B Ty III F 150/151 and each coated coupon was scribed. After approximately six months, the coating on coupons with no surface preparation began to fail by delamination at the scribe mark. As of Dec 02, with the exception of one coupon, coatings on coupons without surface preparation had entirely delaminated. Coupons with either TCP treatment, abrasive blasting, or both, have not shown any failure due to delamination.

For another component of the coupon study, TCP is being evaluated for its anti-corrosion properties. What appears to be critical for the success of TCP as an anti-corrosion method is the deoxidation of the substrate surface prior to application of TCP. Two test patches of TCP have just been installed on the deck of the starboard air inlets of the test platform LCAC. These test patches will be monitored every six months as part of the standard craft corrosion inspections and compared with the port side inlets.

7.5 NAVAIR TCP

To date 4 S-3Bs, 2 F/A-18s and 2 H-46s have been partially or fully coated with TCP during depot maintenance on outer moldine of vehicle. The S-3Bs use a self-priming topcoat and thus have a chromate-free coating on the TCP test areas. The F/A-18s and H-46s use MIL-PRF-85582 C primers and thus the coating system relies heavily on the chromates in the primer for corrosion protection. The last platform was treated in 2001. One F/A-18, with TCP on entire outer surface, inspected after a carrier tour and one year in service was equivalent to other airframes the same squadron and looked, on average, better than most after typical carrier deployment. The 2nd F/A-18 is scheduled for inspection in 2003. Both H-46s have been inspected after 1 year in service and no difference in performance of test coating and control areas were noted. For the S-3s, the first two were treated with TCP on the aft section only. The 3rd and 4th were completely covered with TCP. Of the tail only birds, both have shown equivalent performance to the rest of the airframe over 2 years of service.

Figure 7.5.1: F/A-18 after TCP Application and Painting

Of the fully coated airframes, one has shown normal corrosion compared to similar controls. The 4th S-3 saw a full deployment on the Conestoga, the Navy's last fuel-burning carrier, which generates large amounts of stack gases. The tour was in the South Pacific as well. This airframe showed more corrosion than comparable planes in the squadron. A specific cause was not identified but two potential causes were identified: insufficient corrosion protection by the TCP / (Self Priming Topcoat (SPT) coating system or inadequate rinsing during processing. Excessive TCP residue left during processing may cause corrosion in non-chromate coating systems. Since neither can be proven independently or acting together no conclusion can be reached other than more testing with this coating system is required before use in the field. Another outcome is that the 500 hour SO_2 salt fog test done at NAVAIR on the TCP/SPT coating did not show a difference in performance between the TCP/SPT and Accelagold/SPT system that is currently used on the S-3. When the test was extended to 1000 hours, corrosion in the unscribed areas did appear on non-chromated systems but not systems that had chromate in the pretreatment or primer. More testing is under way to investigate this issue.

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7.6 USMC (TCP and Alodine 5200/5700)

The Advanced Amphibious Assault Vehicle (AAAV) is a new acquisition platform in the SDD phase. Environmental, safety and health restrictions on the platform require the use of chromate and cadmium free coating systems. As a result, the program has evaluated TCP and Alodine 5200 on aluminum 2519 with a variety of non-chromate coating systems for potential use on the platform. In addition, the platform is participating in the field test portion of this project by having a variety of AAAV hulls coated with combinations of TCP and Alodine 5200 with MIL-PRF-85582N and MIL-P-53022 primers. These vehicles will be evaluated over a two year period. Additionally, two rebuilt AAAV prototypes were coated with TCP and a chromate conversion coating control on hull surfaces. These vehicles are currently in service and will be evaluated in 2003 for coating system performance.

Figure 7.6.1: Spray Applied Alodine 5700 to AAAV

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7.7 Joint Boeing/Air Force/Navy (Boegel)

The objective of the program is to develop/demonstrate a coating system process including environmentally friendly cleaning and sol-gel-based conversion coating processes and the Advanced Performance Topcoat. The project was funded by the Aging Aircraft Division of the Aeronautical Enterprise Program Office (ASC/AAAV). The surface treatment system used was Boegel/AC-131 from Advanced Chemistry and Technology in Garden Grove, CA.

The first significant milestone of the project was to investigate ways to make Boegel/AC-131 visibly inspectable. Pigments or fillers where added to Boegel/AC-131, however they did not provide sufficient differentiation between coated and uncoated surfaces. The addition of the pigments and fillers caused degradation of the adhesion promoting characteristics of the coating. Dyes, on the other hand, were successfully heat-added to the conversion coating promoting color definition. . Additional work is needed to define the adhesion performance of the colored coatings and to determine the effect of the dye on long term coating system performance.

The second milestone was to validate the adhesion promoting characteristics of Boegel/AC-131 on a variety of metal substrates and metal surface conditions. To accomplish this goal, the team worked to define the cleaning and deoxidizing requirements for aluminum and titanium surfaces required for good adhesion. Based on the ability of Boegel/AC-131 to bond to oxidized surfaces, the goal was to reduce the aggressiveness of the deoxidation/brightening step or to eliminate it. Adhesion to all of these surfaces was good when a conversion coating, either Boegel/AC-131 or Alodine 1200S was used. When no conversion coating was applied, wet adhesion failures were observed. The waterborne primer (MIL-PRF-85582) showed poor adhesion to surfaces treated with Cee-Bee R-66C. The solvent borne primer (MIL-PRF-23377) showed poor adhesion to surfaces rinsed with water or exposed to high humidity. In other adhesion tests, adhesion of a solventborne coating system to Boegel/AC-131 or Alodine 1200 on titanium and bare and clad aluminum were equivalent. The values for wet tape adhesion and HATE adhesion were the same for the two conversion coatings. In reverse impact testing, interfacial failure between the primer and Alodine conversion coating was observed whereas the failure mode was primarily in the primer for the Boegel/AC-131 coated panels. Further testing will be conducted to fully determine adhesion performance of coatings to aluminum, titanium, magnesium, and steel substrates. (Osborn, 2003)

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8.0 CONCLUSIONS AND RECOMMENDATIONS

All alternatives are aqueous solutions designed to deposit a very thin coating on the aluminum substrate to enhance paint adhesion and painted corrosion protection. Some alternatives provide unpainted corrosion protection as well as electrical conductivity in corrosive environments. Alternatives face the challenge of the low cost and ease of application of the chromate conversion coatings while providing a coating that provides acceptable technical performance. Along with technical performance, processing and toxicity issues are important to consider in capturing the overall impact of an alternative.

The only compositions that come close to matching the technical, process, cost, and flexibility of chromates are based on trivalent chromium. They offer coatings with excellent unpainted or bare corrosion resistance on a broad range of alloys, most notably on 2000-series aluminum where performance excels over any other alternatives. They also provide excellent paint adhesion and painted corrosion performance as well as meeting the requirements for electrical conductivity. These formulations are used at room temperature and can be applied by immersion, spray or wipe on techniques. The main drawback to the process is the presence of trivalent chromium. Although trivalent chromium is present in the solution and coating, toxicity studies and OSHA PELs suggest that the use of TCP is acceptable, especially given its well-rounded performance. Users will need to balance total chromium, heath and technical performance requirements when deciding if TCP is a viable chromate substitute for their facilities and platforms.

The second-best product in these tests was Alodine 5200/5700. Although it does not perform well in unpainted applications, it performs similarly to TCP in most painted systems. One important exception is the filiform corrosion test where TCP was clearly superior. Alodine 5200/5700 contains no chromium, is process flexible and can be applied like chromate conversion coatings.

The remaining alternatives performed variably in the evaluation. So, although none can compete with the overall performance of TCP and Alodine 5200/5700, many could be selected for specific coating system application and achieve the desired performance. The choice of any alternative will depend on prior testing and comfort with products, institutional leverage, and other sources of information regarding performance.

A clear outcome of this study is the superior performance of chromate-based primers compared to their non-chromate counterparts. For the more challenging alloys, the better non-chromate systems in some cases approached or equaled the performance of systems with chromate primers, but generally, performance is not as good. More work needs to be put toward developing improved non-chromate organic systems as well as pretreatments. In most cases with the better performing pretreatments, the primers drive the corrosion performance. This is good in the sense that there are opportunities to replace chromate conversion coatings used under chromated primers and maintain overall system performance.

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