FINAL REPORT

Demonstration of Steel Pretreatments on High Hard Armor Steel

ESTCP Project WP-200906

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List of Acronyms

ANAD	Anniston Army Depot
AP	Armor Piercing
ARL	Army Research Laboratory
ASTM	American Society of Testing and Materials
CARC	Chemical Agent Resistant Coating
CCPE	Corrosion Control and Prevention Executive
CTC	Concurrent Technologies Corporation
DOD	Department of Defense
DM	Depot Maintenance
DRCF	Depot Repair Cycle Float
EAC	Environmentally Assisted Cracking
ECAM	Environmental Cost Analysis Methodology
ESTCP	Environmental Security Technology Certification Program
FY	Fiscal Year
HAP	Hazardous Air Pollutants
HATE	Hydraulic Adhesion Test Equipment
HHA	High Hard Armor
IAW	In Accordance With
IR	Infrared
JTP	Joint Test Protocol
K_{1EAC}	Mode 1 stress intensity factor in service environment
MRAP	Mine Resistant Ambush Protected Armored Vehicles
MSDS	Material Safety Data Sheet
NAWCAD	Naval Air Warfare Center
NDCEE	National Defense Center for Energy and Environment
OEM	Original equipment manufacturer
OSD	Office of the Secretary of Defense
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PMO	Program Managers Office
RTU	Ready to use
SAE	Society of Automotive Engineers
SBCT	Stryker Brigade Combat Team
SCC	Stress Corrosion Cracking
SERDP	Strategic Environmental Research and Development Program
SPOTA	Sustainable Painting Operations for Total Army
SSPC	Society for Protective Coatings
TCP	Trivalent Chrome Pretreatment
VOC	Volatile Organic Compound

1.0 INTRODUCTION

1.1 BACKGROUND

The high hard armor steels that are used on Strykers, Mine Resistant Ambush Protected (MRAP) vehicles, and a wide range of other systems provide good protection against armor piercing (AP) threats. However, these steels corrode rapidly without good corrosion protective coatings. High Hard Armor (HHA) is also susceptible to structural damage from environmentally assisted cracking (EAC) whenever residual stresses are present, especially when inferior plate cutting and welding procedures are used. For decades these corrosion problems have been well documented for HHA steels. More recently, photos of newly fabricated, unfielded MRAP vehicles showing significant corrosion have circulated within the DoD community. While some may dismiss this rusting as merely cosmetic corrosion, the reality is that such corrosion on military ground vehicles increases the infrared (IR) signal from the vehicle that the topcoat camouflage is designed to inhibit, making the vehicle more vulnerable to detection by the enemy.

Corrosion costs the Department of Defense (DOD) $22.5B annually, with more than 25% of Depot Maintenance (DM) costs attributed to corrosion of Army ground vehicle[1]. Many of the coatings and pretreatments that the Army currently uses to mitigate corrosion contain toxic heavy metals, volatile organic compounds (VOC), and hazardous air pollutants (HAPs). For the wash primer pretreatment process alone, the Army uses an annual average of 400,000 gallons of the DOD-P-15328 wash primer that generates 2.4 million pounds of VOC, 852,000 pounds of HAPs, and 24,000 pounds of hexavalent chrome. Although effective at mitigating corrosion for many years, products such as DOD-P-15328 are targeted for elimination because they are risks to human health and the environment. Under the regulation AR 750-12[2], all Army based ground equipment is required to have a full Chemical Agent Resistant Coating (CARC) system. The description of what typically comprises a full CARC system is defined in MIL-DTL-53072[3]. The typical CARC system consists of: a) a conversion coating or pretreatment in direct contact with a properly prepared substrate, (in this case, the high hard steel on armored vehicles); b) followed by an epoxy primer IAW MIL-DTL-53022[4] or MIL-DTL-53030 and c) the polyurethane based topcoat IAW MIL-DTL-53039[5] or MIL-DTL-64159[6]. A coating exception/variation was granted to the Stryker OEM to allow the omission of the pretreatment/conversion coating step. Permission was also extended to Mine Resistant Ambush Protected (MRAP) OEMs to omit pretreatments on that platform allowing the primer to be directly applied to the high hard steel substrate prior to topcoating. As can be seen from the photos in figure 1-1; on the left is a newly received vehicle with corrosion through the paint clearly visible on the roof; on the right is an 18 month old vehicle showing extensive corrosion. Omission of the pretreatment/conversion coating step makes the coating process far less robust and also requires significantly more quality control diligence during coating application.[7]

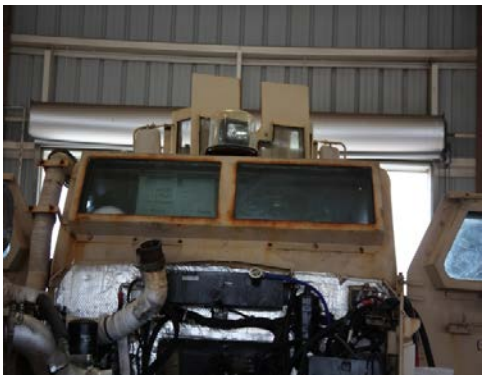


Figure 1-1: Two examples of CARC coated MRAPs with pretreatment step omitted.

The original reasons that justified skipping this pretreatment/conversion coating step were: (1) hexavalent chromium based pretreatments such as DoD-P-15328[8] wash primer were (and are) typically prohibited from use on new ground systems; and 2) viable alternatives, while promising in laboratory studies, had still not been demonstrated on fielded high-hard armor based systems such as Stryker[9]. It was felt that the alternatives could not be reliably implemented in time to meet urgent fielding requirements.[10] Subsequently, the Strykers and MRAPs were fielded without any pretreatment, making them more susceptible flash rust prior to the application of the primer. This resulted in immediate cosmetic corrosion problems and also increased the need for additional maintenance in order to prevent more serious corrosion from affecting system performance. With the continued production of more vehicles with high hard steel armor and substandard coating system, this means that corrosion will become an ever increasing problem for these vehicles.

Significant progress has been made during the execution of SERDP Project WP1521, "Non-Chromate, Non-VOC Coating Systems for DoD Applications." The project, which was completed in FY2008 assessed a number of promising coatings and pretreatments in the laboratory when used singularly or in combination with each other, with the ultimate goal of elimination and/or reduction of VOCs and hexavalent chromium based processes. The system for steel substrates consisted of a pretreatment such as trivalent chromium conversion coating or non-chromium solution applied directly to a properly prepared substrate, primed with non-chromated primer and topcoated with Low-VOC CARC topcoat. However, these systems required additional demonstration on Army weapons systems before they could be considered ready for full implementation.

Finally, the overall goal of project WP-200906 is to investigate non-chromate, ZVOC coatings for steel substrates. As the title implies, this is a unique project as it covers a wide range of coatings and pretreatments for steel. Demonstrations were divided up into three technology areas: 1) Pretreatments for high hard armor (HHA) steel, 2) non-chromate primer, ZVOC topcoat for ground support equipment, and 3) non-chromate sealers for zinc phosphate. This final report will only cover the demonstration of technology area 1, Pretreatments on HHA.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of this demonstration is to determine the viability of non-chromate pretreatments for High Hard armor steel in order to improve the long term corrosion resistance of the Low-VOC CARC system to reduce lifecycle costs for these weapon systems. As noted earlier, Stryker and MRAP vehicle contracts are prohibited from using hex-chrome and are currently coated without any corrosion inhibitive pretreatment or conversion coating. The products demonstrated here satisfy the hexavalent chrome prohibition for both vehicles while minimizing environmental impact and promoting worker safety. This demonstration was designed to generate the data necessary for the authorization and implementation decisions by appropriate authorities within the DOD.

Table 1-1 describes the hazards targeted and components used for the demonstration on Stryker and MRAP vehicles. To validate performance of the proposed coating systems on the Stryker demonstration, ARL was given the opportunity to use parts of 3 Stryker vehicles (power entry panel hatch, front access hatch, and side egress hatch) at Anniston Army Depot during an ongoing Reset of the Depot Repair Cycle Float (DRCF-3) vehicles. These were former 1/25 SBCT Stryker vehicles, that were tracked in order to determine the overall corrosion performance of the pretreatments vs. the control (current) process during use in the field.

Table 1-1. Target Hazardous Material (HazMat) Summary.

Target HazMat	Current Process	Applications	Current Specifications	Affected Programs	Candidate Parts and Substrates
Hexavalent Chromium	Direct-to-metal prime and painting with no chemical pretreatment	Steel substrates, specifically High Hard Armor	MIL-A-46100[11] TT-C-490 SSPC-SP10 MIL-DTL-53072	Stryker and MRAP family of vehicles	-Three access hatches on Stryker (PEP Hatch, Front access hatch, and side egress hatch), -Exterior of MRAP vehicle

Army Research Laboratory (ARL) was presented with the opportunity to use fully functional MRAP vehicles located at Camp Lejeune, NC. These MRAP's were part of a lot of 33 vehicles returning from Afghanistan to Camp Lejeune for repair/Reset. CWO5 Mark Schmidt, II MEF Motor Transport Officer, Camp Lejeune, NC agreed to provide two (2) full vehicles and directed his staff to help perform some processing duties. Both vehicles were completely abrasive blasted to near-white metal (SSPC-SP10) in order to create adequately prepared surfaces for the conversion coating. Additionally, PM-MRAP separately donated 2 rear doors from an MRAP located at Aberdeen Proving Ground MD for a smaller scale demonstration.

1.3 REGULATORY DRIVERS

The Occupational Safety and Health Administration (OSHA) Final Rules effective May 30, 2006, Federal Register #71:10099-10385 states in part that OSHA has amended the standard limiting occupational exposure to hexavalent chromium (Cr^{6+}). OSHA determined that at the current permissible exposure limit (PEL) for Cr^{6+} workers face a significant risk to hexavalent chrome related heath disorders. The evidence in the record for this rulemaking indicates that

workers exposed to Cr^{6+} are at an increased risk of developing lung cancer. The record also indicates that occupational exposure to Cr^{6+} may result in asthma and damage to the nasal epithelia and skin. The final rule establishes an 8-hour time-weighted average (TWA) exposure limit of 5 micrograms of Cr^{6+} per cubic meter of air (5 $\mu g/m^3$). This is a considerable reduction from the previous PEL of 1 milligram per 10 cubic meters of air (1 mg/10 m^3, or 100 $\mu g/m^3$) reported as CrO_3, which is equivalent to a limit of 52 $\mu g/m^3$ as Cr^{6+}. The final rule also contains extensive ancillary provisions for worker protection. These requirements for exposure determination and preferred exposure control methods include a compliance alternative for the limited manufacturing sector for whom the new PEL is cost prohibitive and infeasible. Respiratory protection, protective clothing and equipment, hygiene areas and practices, medical surveillance, record-keeping, and start-up dates that include four years for the implementation of engineering controls to meet the PEL are necessary. The PEL established by this rule purportedly reduces the significant risk posed to workers by occupational exposure to Cr^{6+} to the maximum extent that is technologically and economically feasible.

In April of 2009, a memo from The Under Secretary of Defense, and signed by Mr. John Young was released outlining a new policy for reducing the use of Cr^{6+} for DOD applications. The memo specifically directs the military to approve the use of alternatives to Cr^{6+} where they can perform adequately for the intended application and operating environment, update relevant technical documents and specifications to authorize the use of qualified alternatives, and require the Program Executive Office (PEO) or equivalent, in coordination with the Military Department's Corrosion Control and Prevention Executive (CCPE), to certify that there is no acceptable alternative to the use of Cr^{6+} on a new system. Effectively, the memo directs DoD Military Departments to restrict the use of Cr^{6+} unless no cost-effective alternative with satisfactory performance is identified.

1.4 STAKEHOLDER/END-USER ISSUES

The process has the potential to be transitioned to any DoD facility that processes steel based systems, as well as OEMs and their subcontractors. The business case for each location will have to be completed on a site specific basis depending upon the processes and coatings used. Benefits to the stakeholders include reduction/elimination of Cr^{6+} in pretreatment processes for steels and the reduction or elimination of VOCs and HAPs from a potential wash primer replacement and during subsequent coating applications. As noted earlier, the Army uses 400,000 gallons of DOD-P-15328 that generates 2.4 million pounds of VOC, 852,000 pounds of HAP and 24,000 pounds of hexavalent chrome annually. Although effective at mitigating corrosion for many years, products such as DoD-P-15328 are targeted for elimination because they are risks to human health and the environment.

Finally, it is anticipated that lifecycle cost will be reduced because of the enhanced corrosion inhibition of the total CARC system. This demonstration plan will benefit all ground vehicles utilizing high hard armor steel, but will initially focus on the Stryker Combat Vehicle and MRAP. Therefore, the primary stakeholders identified here are PM-SBCT and PM-MRAP as witnessed by the letters of support in appendix D.

2.0 TECHNOLOGY

The proposed alternative coatings can, in many cases, be used in place of chromated zinc phosphate and DoD-P-15328 wash primer. The technologies being demonstrated were spray applied pretreatments for steel substrates. They are applied directly to a properly prepared, clean steel surface. The technologies being investigated include trivalent chromium and two non-chromium coatings that are commercially available: Surtec 650, Chemetall Oxsilan 9810/2, and PPG Zircobond 4200. Below are descriptions of each of the technologies that were demonstrated.

2.1 TECHNOLOGY DESCRIPTION: Trivalent Chrome Pretreatment (TCP)

TCP was developed by NAVAIR in an effort to replace chromated sealers, post-treatments, and conversion coatings and evaluated as part of SERDP project WP-1521 "Non chromate/No VOC Coating System for DoD Applications"[12]. The majority of conversion coating work thus far has focused on the use of TCP on aluminum alloys. In recent years TCP has enjoyed good success on aluminum. However, for steel alloys and phosphated surfaces, further development is needed. One of the key advantages to using TCP is that the processing and maintenance requirements are similar to currently used technologies, thus making it a favorable alternative for depots and OEMs. TCP-type conversion coatings eliminate much of the need for additional training of personnel and large equipment purchases, yielding a seamless transition to new technology. TCP is based on a fluorozirconate complex with a trivalent chromium salt. TCP contains significantly less total chromium than the current hexavalent chromium conversion coatings and has no hexavalent chromium. The use of TCP eliminates personnel exposure to hexavalent chromium, saving labor and reporting costs associated with PPE. This reduces worker safety regulations and eliminates much of the hazardous waste disposal associated with hexavalent chromium bearing pretreatments. Additionally, it saves time and money by eliminating the need to treat the waste stream for hexavalent chromium.

Through the prior effort funded by SERDP it was established that TCP forms a mostly zirconium oxide/fluoride, chromium oxide conversion coating on the aluminum alloy surface. Previous work has been conducted on hexavalent chromium films, suggesting a film backbone consisting of polymerized trivalent chromium hydroxide species, with a loosely hydrogen-bonded active chromate inhibitor species. Chromate films tend to be very thin over precipitates and inter-metallics, only releasing the inhibitor species after the film has broken down and substrate metal is exposed. Electrochemical evidence suggests that the TCP forms a much more uniform film thickness across these inter-metallic sites with improved barrier coating properties from the denser zirconium oxide and localized corrosion inhibition through the ability of the trivalent chromium species to slow the reaction kinetics of metal attacking anions, such as chloride.

Some work has been done to develop the TCP formulas for a conversion coating directly onto steel substrates. This is a novel application as there were no chromate conversion coatings other than wash primer, for steel surfaces as there are for pretreating aluminum surfaces. The initial expectation for TCP as a conversion coating on steel is to provide flash-rust inhibition for the substrates between surface preparation and the painting process. Currently an organic-based, temporary flash rust inhibitor is applied to newly prepared steel surfaces that must be removed

prior to primer application. The TCP provides a permanent surface conversion that functions to inhibit flash-rusting while promoting subsequent adhesion of organic coatings, thus eliminating the additional production step of the flash-rust inhibitor removal. Figure 2-1 shows evidence of the improved wet adhesion of an abrasive blasted substrate when treated with TCP.

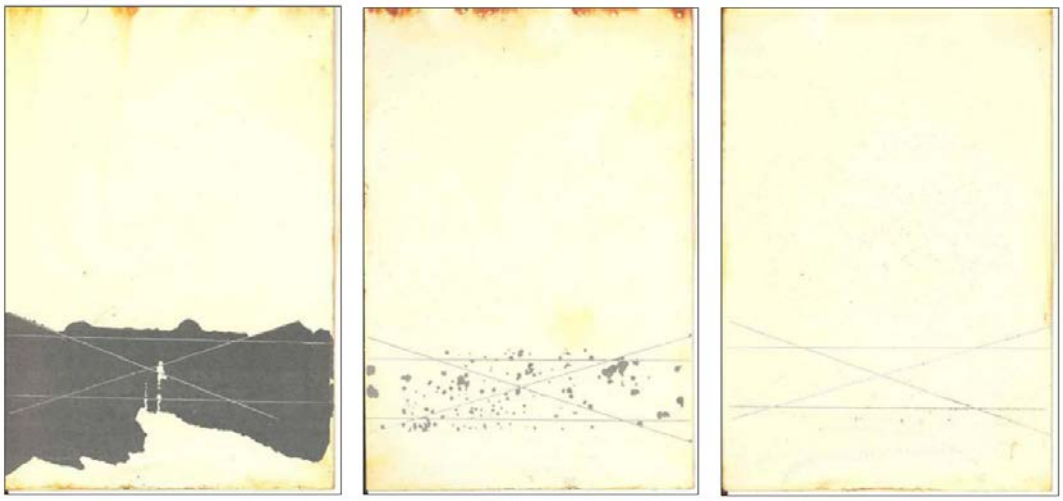


Figure 2-1: Results of 7 day Wet-tape-adhesion test. Acetone wipe (left), abrasive blast only (center), abrasive blast with TCP (right). All with MIL-DTL-53022 Type I primer.

One technology demonstrated is a product manufactured by SurTec International (a TCP licensee). It is a green, clear-turbid liquid with a density of 1.00-1.01 g/ml and an approximate pH of 3.8. The SurTec 650 was the TCP product tested in the ARL study funded by SERDP. In this study, the SurTec 650 was shown to demonstrate benefits as a flash rust inhibitor as well as an adhesion promoter. Below in figure 2-2 is the schematic of the process that was followed for the application of the SurTec 650 on the Stryker demonstration performed at Anniston Army Depot.

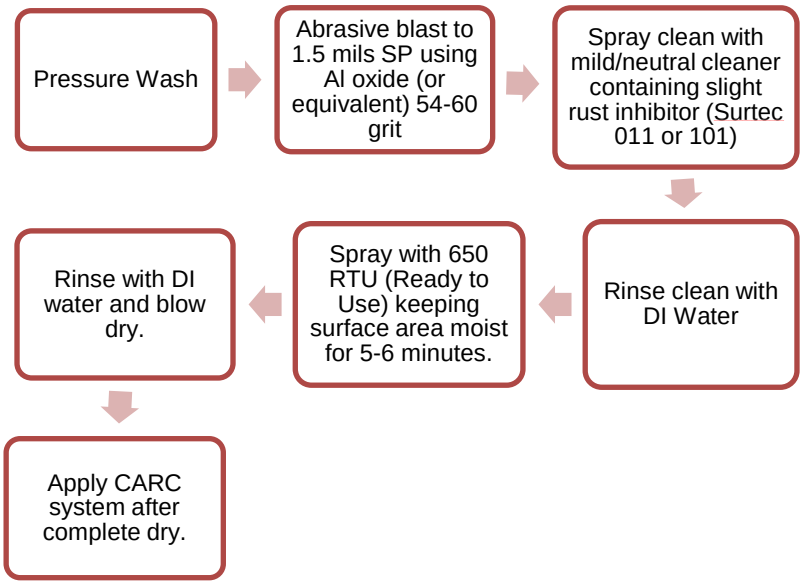


Figure 2-2: Schematic of the SurTec 650 Trivalent Chrome Pretreatment (TCP) application process.

2.2 TECHNOLOGY DESCRIPTION: Oxsilan 9810/2

Chemetall's Oxsilan 9810/2 is a silane product modified with metallic acids. A simple silane molecule consists of a silicon atom combined with an organic molecule. For paint pretreatment, however, more complex silane described as "organofunctional" such as the Oxsilan 9810/2 are used. Through proper selection of the organic constituents used in the silane molecule an organofunctional silane molecule is created which reacts and forms bonds with metal hydroxides on the substrate and organic groups on paint resins. These organofunctional silanes are then reacted with water introduced during the pretreatment supplier's manufacturing process. They form what are called "polycondensates." This complex retains the paint and metal-bonding properties of the silane, but in an easy-to-use form. The polycondensate is the innocuous chemical form in which silane products are usually made commercially available to metal finishers. Unlike zinc phosphate coatings for steel, silanes create little or no precipitate sludge during the conversion coating process.

In use, as the silane film dries on the pretreated substrate, neighboring hydroxyl groups on the silane molecule react with each other to form a dense cross-linked network. Finally, in order to further enhance performance, non-regulated group IV-B metals, such as zirconium, are used to selectively and preferentially bond to the metal substrate, providing improved corrosion resistance compared to a silane-only process. The composition of these group IV-B metals in the silane product is carefully balanced in order to provide the optimized deposition rate of the metal onto the substrate, which maximizes paint performance. In effect, a dual coating is formed in one step: an inorganic coating comprised of zirconium and other unregulated metals, and an organofunctional silane coating. During coating dry off and/or paint cure, the silane coating crosslinks to provide a durable robust coating.

The silane product that was demonstrated, Oxsilan 9810/2, is a phosphorus free liquid, slightly acidic RTU (pH 4-6), silane-based product that is intended to enhance the performance of

organic coatings. When applied to the substrate, the Oxsilan organo-silane polymers react at room temperature with hydroxides present in the metal oxide layer of cleaned metal substrates to form strong covalent bonds with the metal substrate. As the film dries, neighboring hydroxyl groups react with each other to form a dense, interpenetrating, cross linked network that is chemically bound to the metal surface (figure 2-3).

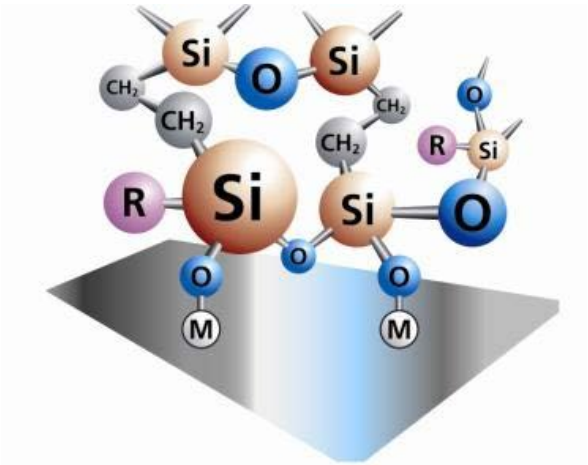


Figure 2-3: A schematic of the Oxsilan technology after reaction with the substrate has occurred.

The Oxsilan 9810/2 used for the demonstration at Anniston Army Depot and Camp Lejeune was RTU so that there would be no issues with pH adjustment or admix concentrations. Normally the Oxsilan is handled as a 2-component material that is mixed at the application site. After the admix and addition of water to achieve proper concentration and a pH adjustment, the solution is ready for application. Controls for the application are limited to a minimum surface temperature of 70 degrees Fahrenheit (F) and an application dwell of 60-90 seconds. It may be spray-applied or used in an immersion bath. CARC application may begin immediately after the surface is dry or after masking for paint.

Oxsilan 9810/2 is formulated for use on multiple metals including steel, iron, aluminum, and zinc substrates. It is free of any regulated heavy metals. It is applied at ambient temperature by either spray or immersion. [13]. Below in figure 2-4 is a schematic of the spray applied process required for Oxsilan 9810/2. At Anniston on the Stryker demonstration, a dedicated hand pump sprayer was used to apply each of the pretreatments (Figure 2-5 left). Because the MRAP had far more surface area than the Stryker hatches, an electric sprayer with a flow rate of 1.0 gallons per minute was chosen to apply the Oxsilan 9810/2 (Figure 2-5 right). In the subsequent smaller demonstration on MRAP doors at APG a Yamada NDP-15 BPT pump sprayer with an 80 degree nozzle and rated at 4.0 gpm was used. The application was conducted using an approximate 10 psi nozzle pressure and a flow-rate of 2 gpm.

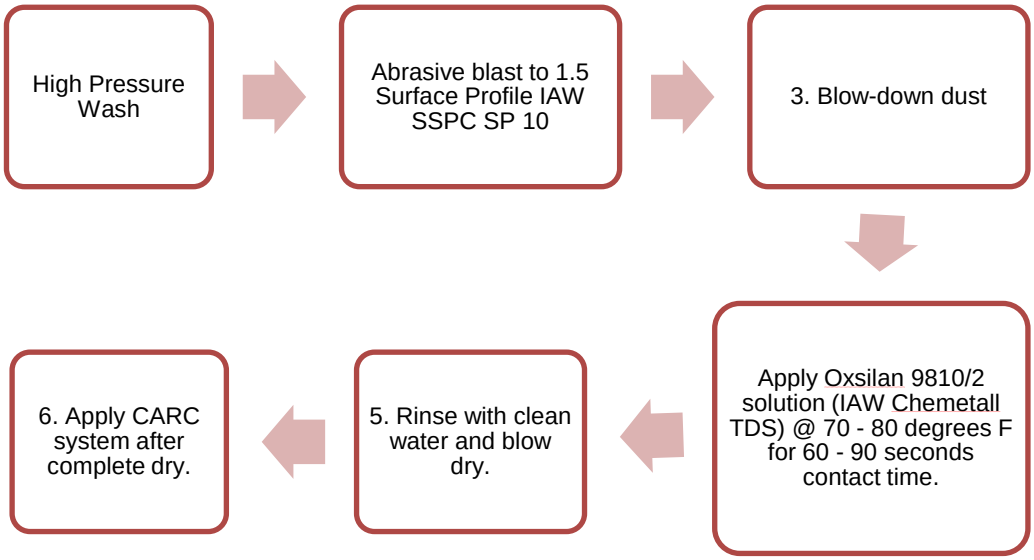


Figure 2-4: Schematic of the Oxsilan application process used on high hard steel for the Stryker demonstration.

Figure 2-5: Pressure pump sprayer used on Strykers (left), Electric sprayer used on MRAP (right)

2.3 TECHNOLOGY DESCRIPTION: *Zircobond 4200*

PPG has developed Zircobond 4200 pretreatment, an alternative pretreatment based on zirconium chemistry and a proprietary blend of additives. Zircobond 4200 pretreatment reduces sludge by-product from the pretreatment process by at least 80 percent compared to zinc-phosphate-based products and it can be used as a drop in replacement in existing pretreatment lines. The Zircobond 4200 system is formulated to provide corrosion resistance for steel, galvanized steel and aluminum substrates. It is a clear light blue liquid with a specific gravity of 1.104 and has a diluted working pH of between 4.0 and 5.0.

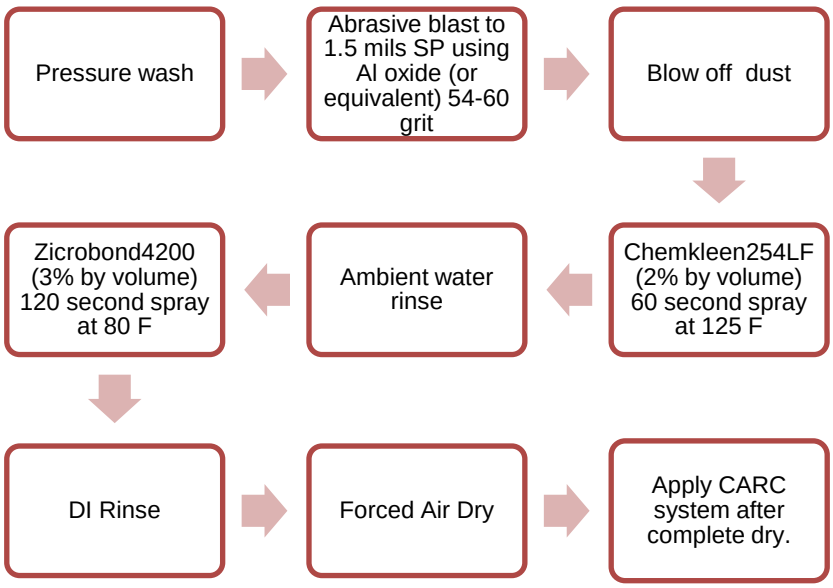


Figure 2-6: Schematic of the PPG Zircobond 4200 application process used on high hard steel for the Stryker demonstration.

2.4 TECHNOLOGY DEVELOPMENT

The primary motivation for this project is the promise of transitioning the success of the TCP technology to steel. Trivalent chrome pretreatments were studied for use on steel substrates as part of SERDP project WP1521. This project evaluated two additional products: Chemetall Oxsilan 9810/2, and PPG Zircobond 4200.

Trivalent chromium compositions and processes were originally developed as a hexavalent chromate conversion coating alternative for aluminum alloys, and the vast majority of research has been focused on non-ferrous applications. Dr. Vinod Agarwala is the original inventor of the TCP technology. In 1994 he studied the electrochemical impedance of trivalent chrome pretreatments on aluminum. The results showed a 10 to 100 fold increase in the polarization resistance of the surface films compared to the untreated aluminum alloy. These electrochemical results compared well with the corrosion behavior in B117 neutral salt fog testing. The trivalent chromium treated surfaces showed no corrosion for up to 200 hours in 5% salt spray. A post-treatment with an oxidizer even further raised the coating's resistance due to an improved corrosion protection.[14]

A modified version of the trivalent chrome was later developed by NAVAIR, Patuxent River, Maryland. Among the inventors are Dr. Michael Kane and Craig Matzdorf. Mr. Matzdorf and Dr. Kane conducted a demonstration of the technology on the aft section of two U.S. Navy S-3 Viking aircraft using a spray-on process at the Naval Aviation Depot (FRC SW), North Island, California. The report included toxicology information consistent with what is presently stated in the current SurTec 650 materials safety data sheets (MSDS) for trivalent chromium. Results of the demonstration were not available at the time of their report.[15]

"Trivalent Chrome Process as a Sealer for MIL-A-8625F Type II, IIB, and IC Anodic Coatings"[15] documents evaluations of TCP as sealers for various anodic coatings conducted by

Materials Engineering, NAWCAD Patuxent River, Maryland. The performance of TCP as a sealer was compared to standard sealers like dichromate and water which are commonly used in aerospace and other industries. Paint adhesion testing was carried-out with commonly used high-solids and water- borne chromated and chromate-free primers qualified to MIL-PRF-23377 and MIL-PRF-85582 performance requirements. In these evaluations, TCP performs as good as or better than hexavalent chrome in corrosion resistance and equal to hexavalent chrome in paint adhesion. TCP is superior to water for sealing the anodized film. An additional benefit is that the TCP is applied at ambient conditions for 5 to 10 min, yielding savings in energy costs. Chromate and water sealers are applied at 190°F to 200°F for up to 25 min.[16]

Many other studies have been conducted by the U.S. Army Research Laboratory to validate the performance of TCP on various aluminum substrates. One such study focused on aluminum alloy 5059-H131 under different surface treatment conditions. The surface treatment conditions included abrasive blasted, with a commercial TCP and with the NAVAIR TCP . Corrosion resistance was evaluated using GM 9540P accelerated cyclic corrosion testing and ASTM B117 neutral salt fog methods. Adhesion was assessed both dry using ASTM D 4541 pull-off and wet using ASTM D3359A methods. TCP showed excellent performance and was recommended as the pretreatment of choice based upon its qualification with the conversion coating specifications MIL-DTL-5541 and MIL-DTL-81706 and its ability to sustain performance on bare aluminum substrates..[17]

In recent years, TCP was qualified to replace hexavalent chromate conversion coatings on zinc-nickel plated steel. Unpainted test panels exhibited at least 1008 hours of resistance to cyclic salt fog. These panels lasted at least 4 days when subjected to cyclic sulfur dioxide and cyclic salt fog testing with full red rust evident on the seventh day. Painted and scribed TCP panels previously subjected to 10 days of humidity and 120 days of cyclic salt fog were subjected to 78 days of cyclic sulfur dioxide and salt fog and paint were still largely intact with only moderate scribe corrosion and paint blistering near the scribe.[18]

Oxsilan 9810/2 is an organic-inorganic pretreatment that is used for steel and most metals prior to the application of organic coatings. The organic component of the Oxsilan is based on silane chemistry. The inorganic component is based on zirconium and other non-regulated metals. Both of these primary components have been used in pretreatment processes for many years. Silanes have been used with increasing frequency since 1988 when Oakite, now Chemetall, launched their industry leading silane-based final seal. For decades, zirconium has been used with increasing frequency since the gradual phase-out of hexavalent chromium use on aluminum, especially on automotive wheels and with the advent of non-phosphorous pretreatments throughout the past 10 years. Oxsilan 9810/2 is the latest generation of silane-based products using an industry-unique silane/zirconium complex that optimizes paint performance for adhesion and corrosion resistance

Oxsilan 9810/2 is currently sold to approximately 400 manufacturers world-wide. Some key global users include PSA Peugeot-Citroen (7 automobile plants), Daimler (Mercedes Benz body parts), JCB (JC Bamford Excavators), and CNH (Case New Holland). In the US, some key users include Alo Tennessee, Hardi North America, Husqvarna Outdoor Products, E-Z-Go Textron, Jacobsen Textron, Caterpillar, Emerson Climate Technologies, and Tesla Motors in California.

Zircobond 4200 is a zirconate based pretreatment developed by PPG and first commercialized in 2008. PPG developed its first Zr based pretreatment for use on aluminum in 1997. Several IIIB and IVB elements were considered, but zirconium was found to provide the best performance as a pretreatment for multi-metal applications. The development of Zircobond was initially targeted at the automotive industry, and is now being adapted as a pretreatment for armor steel in the defense industry. The Zircobond 4200 process is more efficient and minimizes or eliminates the phosphate sludge associated with zinc phosphate lines. Zirconate films develop on a considerably smaller scale relative to zinc phosphate crystals. High quality phosphate films produce individual phosphate crystal sizes in the 2-7 μm range, while individual deposits of zirconium oxide may be hundreds of times smaller. Phosphates are porous and are typically require a chromic acid rinse for corrosion resistance. The following image in Figure 2-7 shows SEM comparisons of zirconium oxide and zinc phosphate at 5000x and 25,000x magnification. Zirconium-based pretreatment SEM image at 5,000x magnification: (a). Zinc phosphate pretreatment SEM image at 5,000x magnification (b), Zirconium-based pretreatment SEM image at 25,000x magnification (c). Zinc phosphate pretreatment SEM image at 25,000x magnification (d).

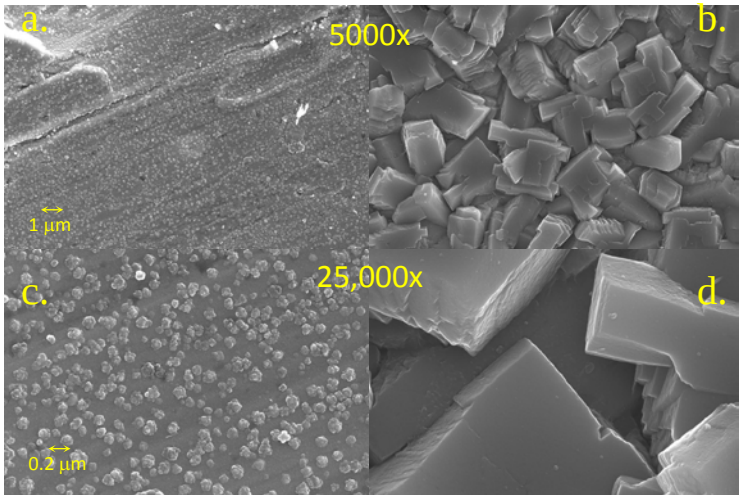


Figure 2-7: Comparison of zirconium based pretreatment and zinc phosphate at 5000x and 25,000x

The reduced physical size of zirconium oxide deposits provides two additional benefits. First, the film is developed from a very dilute bath, reducing both the quantity of raw materials tied up in inventory and the chemical aggressiveness of the bath from an EH&S perspective. Second, the thinner film and smaller crystals result in significantly lower consumption of chemicals, further reducing overall application costs.

2.5 ADVANTAGES AND LIMITATIONS OF THE TECHNOLGY

In this section, the advantages and limitations of the demonstrated technology are listed as compared to the painting process currently employed on the Stryker and MRAP vehicles. The primary material used in the construction of these platforms is MIL-A-46100 high hard armor steel, with material hardness in excess of 50HRC. The material hardness, coupled with the possible existence of residual stresses induced during manufacturing, makes this material

susceptible to stress corrosion cracking (SCC) under certain conditions. Therefore, because of SCC concerns associated with some pretreatments such as phosphate and wash primer, these platforms have been painted without the benefits of a pretreatment. The current processes for both platforms are described in later in section 5.0 . Only a flash rust inhibitor is currently used and, overall, the application processes of the alternative technologies demonstrated are very similar to the current process. `For simplification, the advantages of each product demonstrated will be compared to the current product used on Stryker; Cheminhib 420.

SurTec 650 (TCP)

Advantages (Technical):

- The addition of a true chemical pretreatment/conversion coating provides a complete CARC system as defined in MIL-DTL-53072 for armor steel platforms.
- TCP proven effective as a conversion coating on aluminum
- Adds another layer of corrosion protection while improving coating adhesion
- Added flash rust inhibition
- Easy to apply, drop-in replacement.
- Low process risk of stress corrosion cracking
- Provides a more robust process that will protect against deficiencies in the inorganic coating process

Advantages (Safety and Environmental):

- No hexavalent chromium
- Non-irritant to skin or eyes.
- No HAPs and low VOC

Limitations:

- Little historical data for use on steel
- Little color change to substrate surface to indicate full coverage
- Chrome, even trivalent, makes product less desirable

Chemetall Oxsilan (Silane)

Advantages (Technical)

- The addition of a true chemical pretreatment/conversion coating provides a complete CARC system as defined in MIL-DTL-53072 for armor steel platforms.
- Provides flash rust inhibition
- Best laboratory corrosion performance. As good as or better than hexavalent chrome baselines.
- Improves performance of organic coatings by providing better adhesion of the primer.
- Easy spray application, drop-in replacement.
- Low process risk of stress corrosion cracking
- Inexpensive

Advantages (Safety and Environmental)

- No hexavalent chromium

- No HAPs and low VOC

Limitations:

- Little color change to substrate surface making full coverage difficult to detect
- Sensitive to steel surface contamination
- Product flow rate is critical for reaction to take place

PPG Zircobond 4200

Advantages (Technical)

- The addition of a true chemical pretreatment/conversion coating provides a complete CARC system as defined in MIL-DTL-53072 for armor steel platforms.
- Improves performance of organic coatings by providing better adhesion of the primer.
- Easy to apply drop-in replacement.
- Low process risk of stress corrosion cracking

Advantages (Safety and Environmental)

- No hexavalent chromium
- No HAPs and low VOC

Limitations:

- Product is more sensitive to process conditions
- Variations in color across surface of substrate make it difficult to determine consistent coverage

3.0 PERFORMANCE OBJECTIVES

The performance objectives with success criteria for the demonstrated technologies were evaluated in accordance with the tests delineated in the JTP provided in Appendix A. The functional performance objectives are summarized in Table 3-1. The primary material used in the construction of these platforms is MIL-A-46100 (HHA) steel. Performance objectives derived using HHA as the base metal. The existing process currently used on Stryker (Cheminhib 420) and similar material on MRAP is considered the baseline process. The hardness of HHA is typically in excess of 50HRC. This hardness is associated with the possible existence of residual stresses induced during manufacturing, and when coupled with aggressive environments can make this material susceptible to environmentally assisted cracking (EAC). For this reason, the fracture toughness in a corrosive environment (K_{1EAC}) was evaluated.

Table 3-1 Performance objectives for alternative pretreatments

Performance Objective	Data Requirements	Success Criteria	Results		
Quantitative Performance Objectives			**SurTec 650**	**Oxsilan 9810/2**	**Zircobond 4200**
Humidity Testing*	Comparative test for flash rust inhibition	No flash rust after 24 hours of exposure to ambient temperature and 90% relative humidity	Met	Met	Not Met
Adhesion Test*	ASTM-4541 Pull-off Adhesion	Minimum average 30 events rating of 1200 PSI on 1.5 mil profile surface	Met	Met	Met
	ASTM- D3359 Dry Adhesion	Adhesion rating (steel) > 4B; adhesion rating	Met	Met	Met
	ASTM- D3359 Wet Adhesion	Scribed area rating (steel) ≥ 3A after 24 hours at ambient;	Met	Met	Met
Chip Resistance	SAE-J400	After one cycle, chip rating NLT 5B for steel	Met	Met	Met
Accelerated corrosion	ASTM-B117 Salt Fog	After 500 hours of exposure: steel substrate rating ≥6 scribed	Met	Met	Met
	GM-9540P Cyclic Corrosion ASTM D 1654	After 60 cycles: steel substrate rating ≥ 4	Met	Met	Met
Outdoor Exposure*	Tropical climate exposure at Cape Canaveral Air Force Base FL ASTM D 1654 ASTM G50	Three years of exposure: specimen has a minimum of 25% less creep from scribe than current corrosion protection system	N/A	N/A	N/A
Hydrogen Embrittlement	ASTM E 399-97	No detrimental effect to K1c of substrate. High Hard K1c @ 48-51Rc shall maintain $K_{1EAC} \geq 19$ (ksi√in)	Met	Met	Met
Toxicity Clearance	Toxicity clearances and full disclosure from CHPPM	Approved by processing facility	Met	Met	Met

Processing time	TT-C-490	Equivalent or less than existing process	Met	Met	Met
Field Testing	TT-C-490	Equivalent or less than existing process	Met	Met	Met
Qualitative Performance Objectives					
Ease of use	Feedback from field technician on usability of technology and time required during demonstration	Minimal operator training required	Met	Met	Met

* Additional notes and clarification of success criteria Table 3-1:

- In humidity testing, Zircobond 4200 did not meet requirements because of uneven coloring of substrate that pulled off with pressure sensitive tape.

- The dry tape adhesion is considered Met overall for SurTec 650. The pretreatment ratings for dry tape adhesion were slightly below 4.0 only on samples coated with the MIL-DTL-53022/MIL-DTL-64159 coating system.

- All of the alternatives met the 24 hour requirement for wet tape adhesion. All of the alternatives also rated above a 3.0 even after 96 hours of immersion in DI water.

- Outdoor exposure performance has not been fully assessed because it has not yet been 3 years.

4.0 SITES/PLATFORM DESCRIPTION

4.1 TEST PLATFORMS/FACILITIES

There are two parts to this demonstration of pretreatments for HHA. The first was carried out at Anniston Army Depot (ANAD) during an ongoing Reset of Stryker DRCF-3 vehicles. This Reset presented ARL with a window of opportunity to use some major components on actual Stryker Combat Vehicles to validate the performance of the candidate pretreatments. SBCT agreed to allow ARL to demonstrate the pretreatments on the hatches of 3 Stryker vehicles (PEP hatch, front access hatch, and side egress hatch). The Reset of these vehicles was set to end on or about October 15, 2010.

Figure 4-1: Stryker Combat Vehicle similar to those being Reset at Anniston Army Depot

The Anniston site was selected for three reasons: 1) It was the location performing the Reset on a major combat vehicle constructed of high hard steel, 2) Program Managers Office (PMO) Stryker Brigade Combat Team and ARL have a written Memorandum of Agreement for environmental compliance, enhanced materials, advanced coatings, improved processes at OEM and depot facilities, and finally 3) ARL, through the Sustainable Painting Operations for Total Army (SPOTA) program has enjoyed a long standing productive working relationship with ANAD which included elimination of methylene chloride at the on-site depainting operations . These factors will provide the program with the best chance for success. All of the necessary work was performed on site at ANAD. The parts (hatches) were removed from each vehicle by the Stryker Reset team and tagged in order to stay mated with their specific vehicles. The hatches were then transported by ARL personnel to the ANAD department of Engineering Quality production area where they were abrasive blasted, pretreated, primered and CARC topcoated. ARL returned the parts to the Stryker Reset for reinstallation. All of this was documented in order to track each part and vehicle in the field for periodic inspections.

The pictures below in Figure 4-2 are of one of the actual vehicles used for the demonstration. The picture on the left shows two of the hatches; the larger Side Egress Door and smaller Power Entry Panel located on the left side of the vehicle. The photo on the right is of the Front Access Panel located on the front/topside of the vehicle.

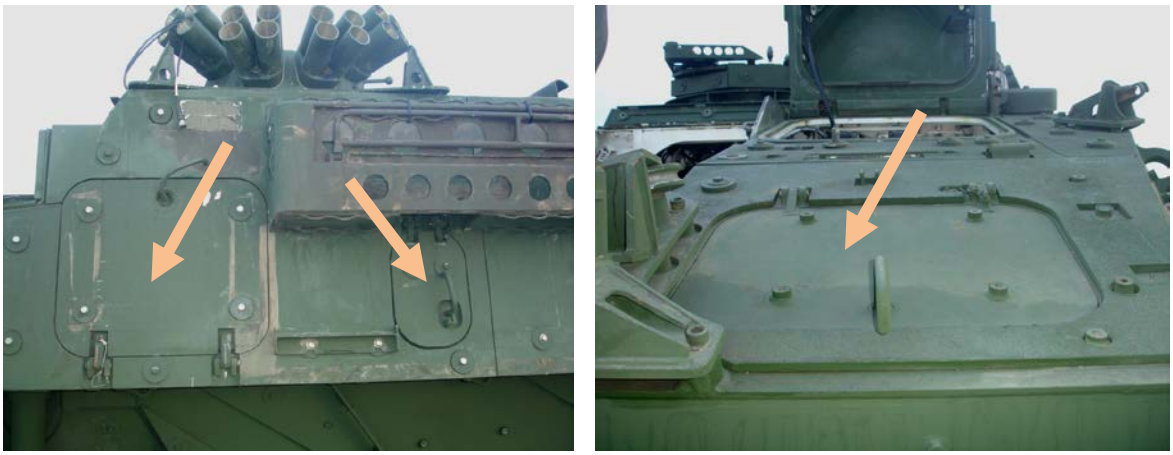


Figure 4-2: One of the Stryker vehicles and hatches used in the demonstration.

The second part of the demonstration of pretreatments for HHA steel was initiated at Camp Lejeune, NC on MRAPs returning from theater. Below in Figure 4-3 is a picture of a similar variant used in the demonstration. Camp Lejeune was selected for this demonstration for three reasons: 1) MRAPs would be returning from theater at approximately the same timeframe the demonstrations would begin 2) ARL received early support from the USMC, Corrosion Prevention and Control (CPAC) Program Support to MRAP II Acquisition and from the MRAP JPO 3) Camp Lejeune has all of the capabilities necessary to process the vehicles as required for the pretreatments.

Figure 4-3: MRAP FPI variant similar to those in the demonstration at Camp Lejeune

All of the necessary work was performed on site at Camp Lejeune. Two MRAP vehicles were selected from a lot of 33 returning from theater. Every effort was taken to ensure the vehicles were as similar as possible to remove as many variables as possible. Once identified, the entire exterior of each vehicle was completely abrasive blasted down to near-white metal prior to pretreatment and paint.

4.2 PRESENT OPERATIONS

As mentioned in the above introduction, a true CARC system as defined in MIL-DTL-53072 consists of a 4-part process: cleaning, a conversion coating or pretreatment in direct contact with a properly prepared substrate, followed by an epoxy primer, and finally polyurethane based topcoat. A coating exception/waiver was granted to Stryker and MRAP manufacturers to allow the omission of the pretreatment/conversion coating step which necessitates the primer to be directly applied to the high hard steel substrate prior to topcoating. Figure 4-4 and 4-5 are flow diagrams for the painting process for Stryker and MRAP respectively. Note that there are interim steps in both cases that involve the application of a flash rust suppressor which is a temporary corrosion inhibitor and not meant to assist in the long term corrosion protection or adhesion of the CARC system.

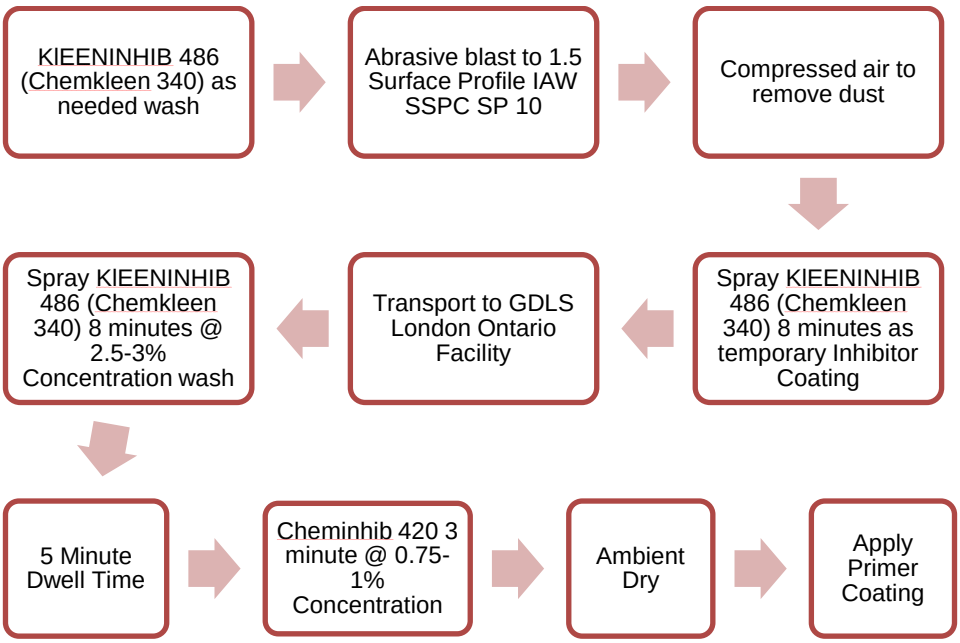


Figure 4-4: Typical flow diagram of the current painting process for Stryker vehicles

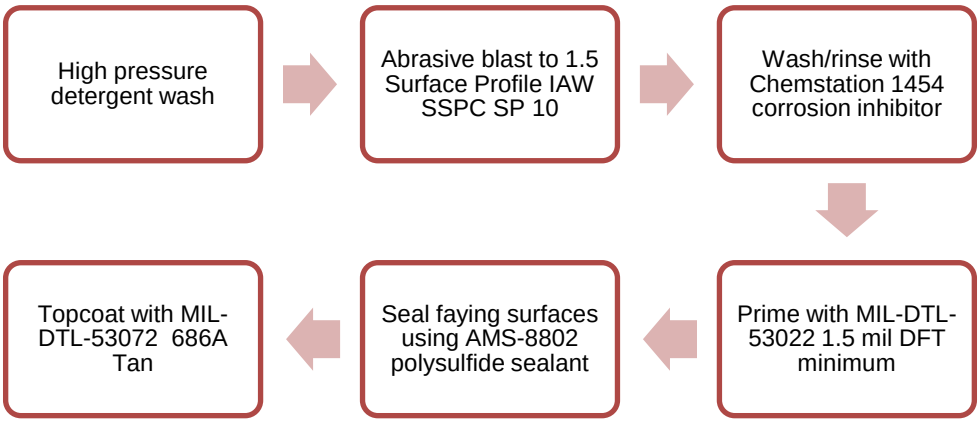


Figure 4-5: Typical flow diagram of the current painting process for MRAP vehicles

The demonstrated technology was intended to replace the temporary flash rust suppressor step in the process and thus will not require additional steps to the current process. In fact, in some cases it is expected to save time overall. Moreover, the demonstrated technology provided additional corrosion protection for the CARC system.

4.3 SITE-RELATED PERMITS AND REGULATIONS

Additional site related permits or regulations were not required for the demonstration to be conducted at ANAD and Camp Lejeune. These facilities have the capability to process and apply pretreatments including hexavalent chrome pretreatments, and hold the necessary documentation to perform the demonstrated chemical pretreatments and dispose of any waste if necessary.

At Camp Lejeune, the Oxsilan 9810/2 was selected as a pretreatment for the MRAP demonstration because it does not contain a chromium component. The lack of chromium in the product made it easier to gain consent from Camp Lejeune due to the chromium environmental regulation restrictions.

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The details of the laboratory testing are provided in the JTP (appendix A). Although significant testing and evaluation of trivalent chrome pretreatments (SurTec 650) on steel substrates was performed as part of SERDP project WP1521, MIL-A-46100 high hard armor steel substrates were not part of the matrix. In fact, many of the alternative pretreatments available have not been evaluated on HHA. For this reason, it is crucial to test these alternative steel pretreatments on high hard armor steel. These three pretreatments; SurTec 650 TCP, Chemetall Oxsilan 9810/2 (Silane), and PPG Zircobond 4200 (ZrOx) will be laboratory validated and field tested on high hard armor test panels according to the JTP provided in Appendix A. In addition to the laboratory validation described in the JTP, field testing on Stryker and MRAP components was conducted.

5.2 Laboratory Experimental Procedure

Sample Preparation

The experiments were conducted using 4 inch x 6 inch x 3/16 inch steel test panels fabricated from HHA steel MIL-A-46100. All of the HHA test panels were abrasive blasted to a 1.5 mil surface finish using aluminum oxide blast media. All of the pretreatments were applied by the vendors in order to eliminate inconsistencies in the processes. All primer and topcoats were applied by the Army Research Laboratory. The coatings used were MIL-DTL-53022 Type II primer, solvent borne MIL-DTL-53039 Type III topcoat, and water borne MIL-DTL-64159 Type II topcoat all manufactured by Hentzen. The test matrix is shown below in Table 5-1.

Table 5-1: Test Matrix for Armor Steel Pretreatments

		Control	Baseline	Alternatives		
Coating system	Tests	Abrasive Blast	DOD-P-15328 (Chromated Wash Primer)	SurTec 650 (TCP)	Chemetall Oxsilan 9810/2	PPG Zircobond 4200
Low-VOC MIL-DTL-53022 / MIL-DTL-53039	Humidity	1	1	1	1	1
	Pull-off Adhesion	3	3	3	3	3
	ASTM- D3359	1	1	1	1	1
	Wet Adhesion	2	2	2	2	2
	SAE-J400	1	1	1	1	1
	ASTM B 117	5	5	5	5	5
	GM 9540P	3	3	3	3	3
Low-VOC MIL-DTL-53022 / MIL-DTL-64159	Humidity	1	1	1	1	1
	Pull-off Adhesion	3	3	3	3	3
	ASTM- D3359	1	1	1	1	1
	Wet Adhesion	2	2	2	2	2
	SAE-J400	1	1	1	1	1
	GM 9540P	3	3	3	3	3

Humidity Testing

Flash rusting on freshly abrasive blasted surfaces prior to the application of the epoxy primer is a concern for HHA. For this reason, the ability of the pretreatments to inhibit flash rust was assessed using a modified version of ASTM D 1735. Pretreatment candidates were applied to freshly abrasive blasted HHA test panels and left unpainted (pretreatment only). These panels along with a freshly abrasive blasted control panel were placed in a $4ft^3$, Blue-M electric environmental chamber, model: CFR-7552C-4, (Figure 5-1), conditioned to a continuous static environment of 100°F chamber temperature and at a high relative humidity level of 90% RH. Samples were periodically removed for evaluation using 3M pressure sensitive tape to capture any existing surface corrosion after 24 hours and 48 hours intervals.

Figure 5-1: Blue M humidity chamber used for evaluating flash rust inhibition

Wet Tape Adhesion:

Wet tape adhesion test evaluates the coating's ability to resist penetration by water. This test was performed in accordance to Method 6301 of FED-STD-141 (Paint, Varnish, Lacquer and Related Materials; Methods of Inspection Sampling and Testing) and rated per ASTM D 3359. An "X" scribe was required on all test panels. The high hard armor steel and low carbon steel panels were evaluated in the 24 and 96 hour wet tape adhesion test. The samples were immersed in distilled water for 24 and 96 hours at room temperature and 120 degree F, respectively. The panels were then removed from the water and dried by wiping with a soft cloth. Two parallel lines were scribed approximately one inch apart with an "X" scribed between the two parallel lines making sure that the coating had been scribed all the way through. A piece of tape was placed over the scribes and smoothed out by rolling with a 3-lb roller. The tape was then removed at an angle of approximately 180-degrees (parallel) to the surface. The areas around the

scribes were inspected for peel-away/delamination and the unscribed immersed area for blisters. Each panel was rated IAW ASTM D3359 and photo-documented.

Dry Tape Adhesion

Tests were conducted at room temperature as defined in ASTM D 3924. An area of the panel free of blemishes was selected. Using a sharp cutting tool, 6 parallel cuts @2mm spacing through the paint film to the metal substrate were made. A second series of cuts at 90 degrees to the initial set were then made. Both cuts were made ensuring that they were sufficiently long enough to make a complete set of 6x6 grid lines. The grids were repeated in two other areas on test coupons in order to obtain 3 data points per coupon. The grid lines were then brushed lightly with a stiff brush to remove any detached flakes or ribbons of coating. A piece of 3M 396 tape was used to further clean off the area by lightly touching it to the grid lines to remove any detritus that would interfere with the full application of the test tape. A complete lap of tape was removed from the roll and discarded prior to removing the length of tape used for the test. A length of tape was removed at a steady rate and cut about 75 mm (3 in.) long. The center of the tape was placed over the grid and the area of the grid smoothed into place by a fingernail. To ensure good contact with the film, the tape was rubbed firmly with the eraser on the end of a pencil. The tape was removed by seizing the free end and rapidly pulling (not jerked) back upon itself at as close to an angle of 180° as possible. Following the tape pull off, each grid was rated using the classification in ASTM D 3359 shown below in Figure 5-2.

Surface of cross-cut area from which flaking has occured. (Example for 6 parallel cuts).	None					Greater than 65%
Classification	**5**	**4**	**3**	**2**	**1**	**0**

Figure 5-2: Cross-cut area ratings

Pull-off Adhesion (ASTM D 4541)

An Elcometer Model 108 Hydraulic Adhesion Test Equipment (HATE) was used to obtain the pull-off adhesion strength in pound per in^2 (psi). The apparatus included a loading fixture commonly referred to as a "dolly" which was secured to the coating normal to the coating surface using Instabond™ S-100 cyanoacrylate adhesive. After allowing the adhesive to cure for 24 hours at 25ºC at 50% RH, the attached dolly was inserted into the test apparatus. The load applied by the apparatus was gradually increased and monitored on the gauge until a plug of coating was detached. The failure tension in pounds per square inch was recorded and the failure mode and location within the coating system was recorded. The pull-off test apparatus and dolly configuration are illustrated in Figure 5-3.

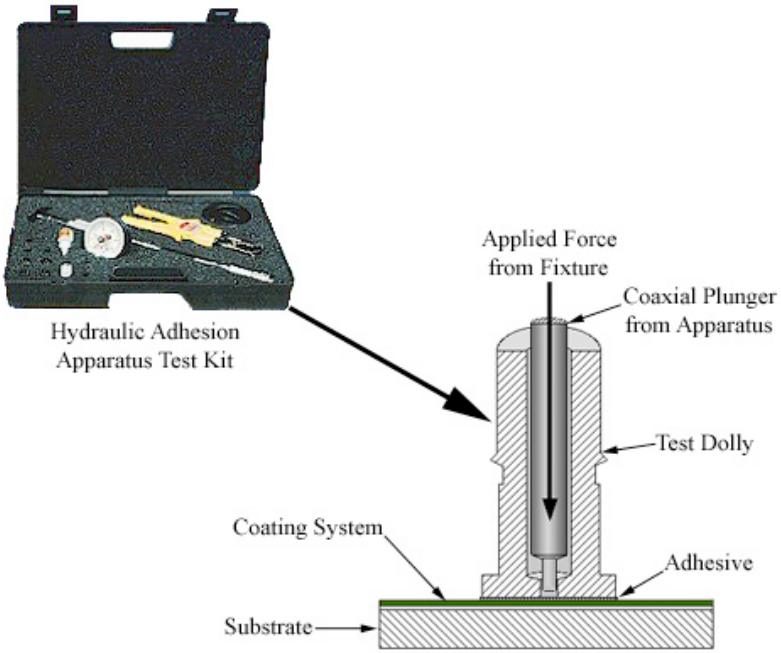


Figure 5-3: Elcometer Model 108 Hydraulic Adhesion Test Equipment (HATE) Pull-off Test Apparatus.

IAW SAE-J400 Chip resistance test

Prior to beginning the tests, each panel was digitally photo documented. The panels were then subjected to chip resistance testing IAW SAE J400 at ambient temperature using a Q-Lab Gravelometer (Figure 5-4). The panels were held in a 45° angle specimen holder and air pressure was used to propel gravel at the sample. The test sample was then removed and gently wiped off with a clean cloth. Tape (3M #898 filament strapping tape as specified in SAE J400) was then applied to the entire tested surface in order to remove any loose fragments of the coating. The tested panel was then compared to standard SAE transparencies to determine a chipping rating.

Panels were again digitally photographed following tests and rated using IAW SAE J400 and ratings for each panel was recorded. The total number of chips inside a 4”x4” grid (16 in^2 area) using a transparency overlay was counted and the rating obtained using Table 5-2. The average size of the chips was measured and rated using Table 5-3. For panels without a dominant chip size, the second most prevalent chip size was included (for example, a “$^{B}/_{A}$” rating had at least $^{2}/_{3}$ chips of size “B” and $^{1}/_{3}$ chips of size “A”).

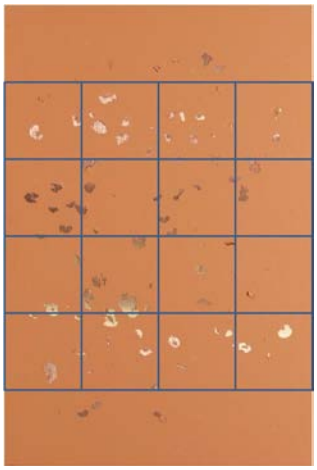


Figure 5-4: Example of the Q-Lab Gravelometer used to measure chip resistance per SAE J400 and the area of a panel evaluated.

Table 5-2: SAE J400 Ratings for number of chips in a 4 inch x 4 inch area

SAE J400 Rating	10	9	8	7	6	5	4	3	2	1	0
Number of Chipps in 4"x 4" Grid	0	1	2-4	5-9	10-24	25-49	50-74	75-99	100-149	150-250	>250

Table 5-3: SAE J400 Ratings for size of chips in a 4 inch x 4 inch area

A	< 1mm	(approximately < 0.03")
B	1-3mm	(approximately 0.03-0.12")
C	3-6mm	(approximately 0.12-0.25")
D	> 6mm	(approximately > 0.25")

Accelerated Corrosion

Two accelerated corrosion test chambers were used to evaluate the steel test panels. The Harshaw Model 22 for standard neutral salt fog and an Atotech Model CCT-NC-30 for cyclic corrosion using GM9540P shows both test chambers in the laboratory where the testing was carried out. The test panels evaluated in neutral salt fog had a single diagonal scribe while the test panels exposed to GM9540P were "X" scribed. In each case, the panels were scribed completely through the coating making sure that the substrate was exposed. The samples were then placed in their respective chambers, tilted at an angle between no more than 15º from the vertical with the scribed surface facing upwards.

The ASTM B 117 neutral salt fog conditions are 95°F with saturated humidity and an atomized fog of 5% NaCl solution. The GM 9540P test consists of 18 separate stages per cycle that include the following: saltwater spray, humidity, , ambient, and heated drying. The environmental conditions and duration of each stage for one complete 9540P cycle are provided in Table 5-4. The standard 0.9% NaCl, 0.1% CaCl2, 0.25% NaHCO3 test solution was used. In addition, the cyclic chamber was calibrated with standard steel mass-loss calibration coupons as described in the GM 9540P test specification.

Table 5-4: Cycle details for the GM 9540P cyclic corrosion test[19].

Interval	Description	Time (min)	Temperature (±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

All of the chemicals for the demonstration were provided by the manufacturers along with specific instructions on the application process. These can be seen in the process flow diagrams in section 2.0.

Outdoor Exposure Testing:

Test panels were prepared as described above. The 4x6” coupons of both HHA and LCS were transferred to Cape Canaveral Air Force Station in Florida. These coupons were X-scribed with a carbide scribe all the way through the coating to the substrate as described in ASTM D1654. These panels were mounted to racks using Teflon fixtures, scribed side up on a 30º angle to the vertical. The racks are set parallel to the Atlantic Ocean and are approximately 100 yards inland from the ocean. The coupons are being inspected and evaluated biannually in June and December in accordance with ASTM D1654 for both corrosion creep from the scribe as well as blistering in the field. Weather data is collected utilizing a data-logging weather station and downloaded annually. Mass loss coupons placed with the test coupons are analyzed annually.

Stress Corrosion Cracking Evaluation:
The resistance to environmentally assisted cracking was assessed using the rising step load method for determination of K_{1EAC}. For this procedure, CV2 Charpy specimens of MIL-A-46100D were machined in the longitudinal-transverse (L-T) orientation IAW ASTM E 399-97. These pretreatments were evaluated to determine if they would have any detrimental effect on the K_{1EAC} of the HHA steel. The specific procedure and specimen fatigue pre-cracking of each of the samples is described in the JTP and elsewhere [18].

5.3 STRYKER COMPONENT DEMONSTRATION

The demonstration on Stryker vehicles was initiated on September 28, 2010. All of the necessary work was performed on site at ANAD. The parts (hatches) were removed from each vehicle by the Stryker Reset team and tagged in order to stay mated with their specific vehicles. The hatches were transported by ARL personnel to the ANAD department of Engineering Quality production area where they were abrasive blasted, pretreated, primed and painted. ARL returned the parts to the Stryker Reset staff for reinstallation.

All hatches were first pressure washed to remove dirt, grease and grime prior to abrasive blasting. The hatches were then abrasive blasted to a surface profile of 1.5 mils in accordance with Steel Structures Painting Council (SSPC) standards. Visual cleanliness was determined using SSPC VIS1, Standard for Abrasive Blasting. A water break test was performed to determine the presence of any contaminants prior to pretreatment.

Each of the candidate pretreatments were applied to major components of each platform according to the manufacturer's required procedure described in section 4.0. Below (figure 5-5) is a photograph of the some of the parts being treated.

Figure 5-5: Actual application of the steel conversion coating on high-hard Stryker hatches.

Once pretreated, all of the hatches were stored over night for 19 hours in ambient shop conditions (60%-70% RH) to duplicate actual coating process lines and to evaluate flash rust

inhibition. According to section 3.5.4 of TT-C-490[20], the organic coating shall be applied to thoroughly dried surfaces within 24 hours after pretreatment. All hatches were primed within 23 hours of pretreatment and topcoated the following morning (20 hours later). After the hatches were painted, they were all returned to the Stryker RESET Team to be reinstalled on their respective vehicles. Table 5-5 lists the actual vehicle identifications and the pretreatments used for each hatch on the vehicles.

Table 5-5: Pretreatments used to treat specific components.

Component	Stryker Demonstration Vehicles Identification		
	MEV-76	**MGS-25**	**ICV-382**
Power Entry Panel (PEP) Hatch	SurTec 650 (TCP)	PPG Zircobond 4200	Chemetall Oxsilan
Front Access Hatch	PPG Zircobond 4200	Chemetall Oxsilan	SurTec 650 (TCP)
Side Egress Hatch	Chemetall Oxsilan	SurTec 650 (TCP)	PPG Zircobond 4200

For the initial demonstration of the Stryker components, no major capital investment was necessary. Only an approved suitable location to apply the candidate pretreatments was needed and miscellaneous supplies and spray equipment were purchased. The manufacturers were consulted in order to obtain their recommended specifications for the application of their products. Step-by-step instructions were supplied to ARL prior to initiating the demonstration. These specifications were used to control the application process. A person with a stop-watch was designated to monitor the required time intervals. Deionized water was used in all steps of the process except the pressure washing of the parts. The air lines were inspected and were deemed relatively new, with proper oil and water traps. In addition, all workers wore gloves to avoid surface contamination. Notes were taken throughout the process. Figure 5-6 shows the applicator and hatches during the pretreatment process. The applicator is force air drying the parts after the required rinse.

SurTec 650 TCP (RTU-Ready To Use)

1. Pressure wash all parts to remove dirt and grime
2. Abrasive blast to 1.5 mils Surface Profile using Al oxide (or equivalent) 54-60 grit.
3. Spray clean with mild/neutral cleaner containing slight rust inhibitor (Surtec 011 or 101)
4. Rinse clean with deionized DI Water.
5. Spray with SurTec 650 RTU keeping surface area moist for 5-6 minutes.
6. Rinse with DI water and blow dry.
7. Apply CARC system after complete dry.

Chemetall Oxsilan

1. Pressure wash all parts to remove dirt and grime
2. Abrasive blast to 1.5 Surface Profile IAW SSPC SP 10
3. Blow-down dust
4. Apply Oxsilan 9810/2 solution (IAW Chemetall TDS) @ 70 - 80 degrees F for 60 - 90 seconds contact time.
5. Rinse with clean with DI water and blow dry.
6. Apply CARC system after complete dry.

PPG Zircobond 4200

1. Pressure wash all parts to remove dirt and grime
2. Abrasive blast to 1.5 mils Surface Profile using Al oxide (or equivalent) 54-60 grit
3. Blow off dust
4. Chemkleen254LF (2% by volume) 60 second spray at 125 F
5. Ambient DI water rinse
6. Zicrobond4200 (3% by volume) 120 second spray at 80 F
7. DI Rinse
8. Forced Air Dry
9. Apply CARC system after complete dry.

Figure 5-6: Applicator shown forced air drying parts with shop air.

5.3.1 Performance Validation on Stryker Parts

As discussed earlier, the metrics for evaluating the candidate pretreatments are contained in the JTP. Depending on the accessibility of each vehicle, periodic inspections were planned during the field testing. Only the hatches indentified earlier were treated and installed on the specific vehicles. The Stryker demonstrations were coordinated through the Stryker PMO. Permission was granted to ARL to discuss opportunities for demonstration candidate pretreatments with the

Stryker Reset Team at Anniston Army Depot. Multiple Resets were being conducted at that location, but it was advised by Mr. James Swann that the Reset of the DRCF-3 vehicles was more conducive to this demonstration plan. This Reset provided ARL with more opportunities because of the slower pace of the Reset. ARL met with Mr. Swann at Anniston on August 11, 2010 and discussed available opportunities. Mr Swann suggested the hatches described in section 1.2 were not likely to be changed out because each is fitted to the vehicle. Once the demonstration vehicles and parts were identified, the following steps for the Stryker demonstrations were carried out:

1. Screened pretreatments for minimum performance using criteria in Table 6-1
2. Acquired pretreatment chemicals and accompanying Material Safety Data Sheets (MSDS), Toxicity Clearances and gain site approval for processing parts.
3. All hatches abrasive blasted to near-white metal as seen in figure 5-7, and pretreated according to the manufacturers recommended guidance outline in section 2.0.

Figure 5-7: All hatches shown here were abrasive blasted prior to pretreatment and paint.

4. According to section 3.5.4 of TT-C-490[21], the organic coating shall be applied to thoroughly dried surfaces within 24 hours after pretreatment. All bare surfaces of the vehicles were primed within 24 hours of pretreatment and topcoated after the primer has sufficiently cured.
5. Once hatches are reinstalled, ARL tracked the vehicle locations for subsequent inspections. It was determined that these vehicles were sent to Joint Base Lewis-McChord Fort Lewis Washington and our POC through Catherine Doherty
   catherine.doherty@us.army.mil
   office: 586-282-2157
   DSN: 782-2157, BB: 586-770-8721

As described in the demonstration plan, depending on the location and availability of each vehicle, periodic inspections would be performed. The metric for evaluating the hatches during periodic inspections are visual comparison with the base vehicle using the Society for Protective Coatings SSPC-VIS 2 “Standard Method for Evaluating the Degree of Rusting on Painted Steel

Surfaces". The success criterion for the fielded hatches was determined as performance greater than or equal to the base vehicle (baseline). SSPC-VIS 2 quantified the degree of rusting on painted steel surfaces with a zero to ten scale based on percentage of visible rust present on the surface. Visible rust includes rust blisters and undercutting of the coating. Table 5-7 lists the SSPC-VIS 2 ratings for percent visual surface corrosion.

Table 5-6: SSPC-VIS 2 Ratings for Percent Corrosion of Painted Surfaces.

Rust Grade	Percent of Surface Rusted	Photographic Standard		
		Spot	General	Pinpoint
10	Less than or equalt to 0.01 percent	NONE		
9	Greater than 0.01 percent to 0.03 percent	9-S	9-G	9-P
8	Greater than 0.03 percent to 0.1 percent	8-S	8-G	8-P
7	Greater than 0.1 percent to 0.3 percent	7-S	7-G	7-P
6	Greater than 0.3 percent to 1 percent	6-S	6-G	6-P
5	Greater than 1 percent to 3 percent	5-S	5-G	5-P
4	Greater than 3 percent to 10 percent	4-S	4-G	4-P
3	Greater than 10 percent to 16 percent	3-S	3-G	3-P
2	Greater than 16 percent to 33 percent	2-S	2-G	2-P
1	Greater than 33 percent to 50 percent	1-S	1-G	1-P
0	Greater than 50 percent	NONE		

5.4 MRAP AND MRAP COMPONENT DEMONSTRATION

The MRAP demonstrations were coordinated through the MRAP PMO and the USMC, Corrosion Prevention and Control (CPAC) Program Support to MRAP II Acquisition. Permission was granted to ARL to discuss opportunities for demonstration of a candidate pretreatment with the USMC Base at Camp Lejeune. Camp Lejeune is a major repair facility for the Marine Corps. ARL met with CWO5 Mark Schmidt and Mr. Daniel Cooper CWO-5 USMC (ret) Senior Logistics Support Coordinator for the II MEF LNO office to discuss the needs of the demonstration and determine the capabilities at Camp Lejeune. A total of 2 trucks (MRAPs) were offered for the demonstration and Mr. Cooper indicated that removing all paint on the exterior of the truck would be no problem. Once each vehicle has been completely processed and fielded, Mr. Cooper would provide the destination of each demonstration vehicle to ARL. The following is his contact information: daniel.cooper@usmc.mil, Office (910) 451-8151 (DSN 751), BB/Cell (910) 581-8644

Every attempt was made to select two variants that are as similar as possible to maximize variable reduction. To simplify processing, only the exterior of each vehicle was used as the test area for this study. The demonstration team arrived at Camp Lejeune on the morning of June 20, 2011. Two vehicles were presented for the demonstration. Upon arrival, MRAP#1 (USMC VIN 634590) was fully abrasive blasted using 60-grit garnet blast media on the previous Friday, June 17, 2011. MRAP #2 (USMC VIN 633359) was approximately 80% abrasive blasted and would not be finished until the following day. Application commenced on MRAP#1 at approximately 1300 hours in a covered outdoor environment outside the blast booth. Environmental conditions were sunny and clear with a temperature of 85°F and 55% RH at the beginning of the application. A full account of the weather conditions from June 17 to June 20, 2011 are shown below in Table 5-7[22] .

Table 5-7: Conditions during demonstration at Camp Lejeune

	Vehicle Abrasive Blasted Friday, June 17, 2011.	Saturday, June 18, 2011	Sunday, June 19, 2011	Monday, June 20, 2011 Day of Demonstration
Mean Temperature	82 °F	82 °F	82 °F	84 °F
Max Temperature	91 °F	93 °F	95 °F	93 °F
Min Temperature	73 °F	72 °F	70 °F	75 °F
Dew Point	71 °F	71 °F	70 °F	70 °F
Average Humidity	75	74	71	73
Maximum Humidity	94	94	93	100
Minimum Humidity	42	39	41	36
Precipitation	0.00 in	0.16 in	0.00 in	0.16 in
Sea Level Pressure	29.96 in	29.94 in	29.87 in	29.85 in
Wind Speed	7 mph (SW)	7 mph (SSW)	8 mph (WSW)	8 mph (WNW)
Max Wind Speed	17 mph	28 mph	20 mph	21 mph
Max Gust Speed	21 mph	34 mph	29 mph	26 mph
Visibility	9 miles	8 miles	9 miles	8 miles
Events	T-storm	Rain , T-storm	---	Rain , T-storm

The application procedure recommended by Gary Nelson, Product Manager, Chemetall, NJ is shown in Figure 2-4. The following is a summary of the procedure for MRAP that was outlined in the demonstration plan:

1. Abrasive blasting: All surfaces were first pressure washed to remove dirt, grease and grime prior to abrasive blasting. Each vehicle was then abrasive blasted to a surface profile of 1.5 mils using garnet blast media in accordance with SSPC-SP 10 Society for Protective Coatings standards.

2. Surface Cleanliness: Visual cleanliness was determined using SSPC1VIS 1, Standard for Abrasive Blasting. A water-break test was performed to determine the presence of any contaminants prior to pretreatment.

3. The Oxsilan 9810/2 RTU conversion coating was then applied to the surface of the vehicles according to the manufacturer's recommended directions described in section 4.0 using the equipment described in section 2.0.

4. Once pretreated, the vehicles would be stored overnight for no more than 20 hours in ambient shop conditions to duplicate actual coating process lines and to evaluate flash rust inhibition. A pull-off tape test would be performed prior to applying the primer to determine if any flash rust had formed.

5. According to section 3.5.4 of TT-C-490, the organic coating shall be applied to thoroughly dried surfaces within 24 hours after pretreatment. All bare surfaces of the vehicles would be primed within 24 hours of pretreatment and topcoated after the primer has sufficiently cured.

In addition, a person with a stop-watch is designated to monitor the required time intervals. DI water was used in all steps of the process. Notes would be taken throughout the process. A representative from the manufacturer was there to monitor the processing of the vehicles and guide ARL and Camp Lejeune through the pretreatment process.

As discussed earlier, the metrics for evaluating the candidate pretreatment are contained in the JTP. Depending on the accessibility of each vehicle, periodic inspections were planned during the field testing. The metric for evaluating each vehicle during periodic inspections are visual comparison with the baseline components using the Society for Protective Coatings SSPC-VIS 2 "Standard Method for Evaluating the Degree of Rusting on Painted Steel Surfaces". The success criteria on the fielded vehicles will be performance greater than or equal to the baseline components and/or panels. The exact locations of evaluated areas and baseline components on the vehicle will be recorded at the time of the inspections.

ARL or a contracted representative will inspect each vehicle at the predetermined inspection time. However, this will depend on the location of each vehicle and the ability to gain access to each for inspections.

5.4.1 Supplemental MRAP Demonstration:

ARL gained additional support from the MRAP Team at the Aberdeen Proving Ground for a limited scope demonstration of the Oxsilan 9810/2 pretreatment. The MRAP Team located an MRAP vehicle from the local APG "boneyard" and assisted in preparing, pretreating and painting the major components of the vehicle for outdoor exposure. The components selected consisted of a set of 2 rear doors. The doors came from the same MRAP vehicle for consistency.

During the week of August 20, 2012, the supplemental demonstration was initiated on two MRAP rear armor steel doors. The two HHA steel doors were blasted with Jetmag Synthetic Olivine grit supplied by Olimag Sands. Jetmag is a sand replacement with low free silica for improved worker safety. The blasting removed more than 99% of the old paint. Oxsilan 9810/2 RTU was applied to both sides of one door with a portable sprayer recommended by Chemetall. The sprayer was a Yamada NDP-15 BPT pump with an 80 degree nozzle with a 4.0 gpm rating. At 10 psi estimated nozzle pressure, the flow calculates to about 2 gpm. There was no pressure gauge on the pump discharge line. Air pressure was 25 psi. Seven gallons of Oxsilan 9810/2 RTU was used over the course of approximately 3 minutes of spraying. The door was rinsed with approximately 4 gallons of DI water using the sprayer and then dried with pressurized air.

The door was allowed to air dry an additional 1.5 hours to ensure no moisture remained on the substrate. Door temperature, air temperature and dew point were measured to make sure there was a wide enough spread to ensure drying and that no condensation would form when painting. The door that was not coated with Oxsilan 9810/2 was coated with DOD-P-15328 wash primer according to standard procedure. Both doors were then primed with a MIL-DTL-53022 primer and MIL-DTL-53039 CARC topcoat. When fully dry, the coated doors were placed on a rack at an angle of ~30º outdoors in back lot of the ARL Rodman Building at Aberdeen Proving Ground and subjected to environmental exposure testing.

6.0 PERFORMANCE ASSESSMENT

Some of the initial testing is described in section 2.2 technology development. However, to fully evaluate the steel pretreatments on armor steel, initial screening tests were performed to gage the relative performance of the alternatives versus the baseline Cheminhib 420 and control. Because of the very small window of opportunity for access to Stryker vehicles during the Reset of the former 1/25 SBCT vehicles (Depot Repair Cycle Float (DRCF-3) vehicles), a full battery of tests could not be completed prior to initiating the demonstration. Some screening tests were performed on the candidate pretreatments including adhesion and ASTM B117 neutral salt fog testing which were compared to the currently used process. Table 6-1 lists the success criteria which were used in screening the candidate pretreatments demonstrated on Stryker. Much of the laboratory testing was completed prior to initiating the demonstration on MRAP at Camp Lejeune NC. These results are presented later in this section.

Table 6-1: Screening requirements for demonstrations on Stryker

Test	Acceptance Criteria	Test Method References	Results
Adhesion (Pull-Off)	Meets or exceeds adhesion strength of DoD-P-15328 on similarly prepared abrasive blasted surface of 1.5 mil profile or 1200 psi	ASTM-4541 Pull-off Adhesion	Met
Corrosion Resistance (Neutral Salt Spray (Fog))	After 336 hours of exposure: Steel substrate rating $\geq$ 7 scribed	ASTM B117 ASTM D1654	Met
Toxicity Clearances	Obtain Toxicity Clearances and site approval	none	Met

For all of the other demonstrations (MRAP, Supplemental MRAP doors), most of the laboratory testing outlined in the Performance Objectives in table 3-1was completed. Only the outdoor exposure tests are ongoing. At the time of the writing of this report, all samples have reached two years of the three years needed to assess performance. This section will discuss the laboratory test results along with the assessment of the demonstrations.

6.1 Laboratory Results

The candidate pretreatments were assessed for flash rust inhibition using the procedure described in section 5.0. Flash rust inhibitors such as the Cheminhib 420 are used on both Stryker and MRAP to prevent corrosion prior to painting. Figure 6-1 clearly indicates that there is less corrosion on the Oxsilan 9810/2 and the SurTec 650 coated panels than on the baseline 1% Cheminhib 420 solution and the control bare HHA. This is consistent for both 24 and 48 hours in the humidity chamber. The 50% Cheminhib solution is not a recommended concentration because it would likely cause poor coating adhesion. It was included for comparison for flash rust inhibition only on bare unpainted substrates. The tape pulled from the Zircobond 4200 panels showed a corrosion like product captured by the tape adhesive. It wasn't clear if it was

corrosion or just the pretreatment itself. In any case, this type of discoloration would make it difficult to assess the quality of the coating to the user. For this reason, the criterion for flash rust inhibition was not met by Zircobond 4200.

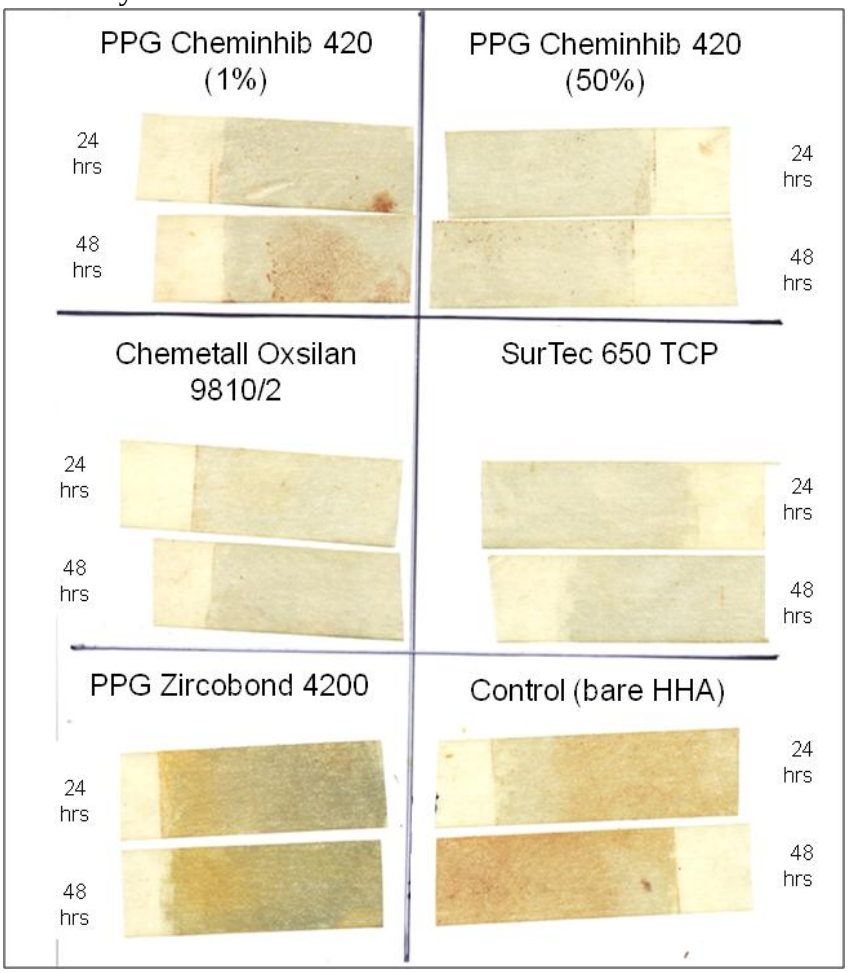


Figure 6-1: flash rust captured with pressure sensitive tape following 24 and 48 hours in humidity chamber set at 90% relative humidity (RH) and 100 degrees Fahrenheit (^{o}F)

The adhesion of the primer and topcoat to the substrate as enhanced by the pretreatments is an important consideration. Figures 6-2, 6-3 and Table 6-2 are indicators of adhesion strength of all the pretreatment/coating combinations in varying conditions. Figure 6-2 contains both pull-off strength and dry tape adhesion ratings. The success criteria for pull-off adhesion were set at 1200 psi or greater. The 1200 psi threshold represents the average pull-off strength achieved for DOD-P-15328 wash primer on low carbon steel with a milled finish (63-125µ inch) and is considered to be ample pull off strength for an organic coating. All of the pretreatments shown in figure 6-2 meet the pull off strength criteria; therefore we consider the dry adhesion tape test results overlaying the pull off results. The success criteria for dry tape adhesion is 4B or greater. All of the alternatives met the 4B rating with the exception of SurTec 650 with the MIL-DTL-53022/ MIL-DTL-64159 paint system. Note that of the baselines and control, Cheminhib with MIL-DTL-53022/ MIL-DTL-64159 was the only one to meet the dry tape test rating requirement. All

of the pretreatments and baseline have comparable dry adhesion when compared with the control (abrasive blasted-no pretreatment).

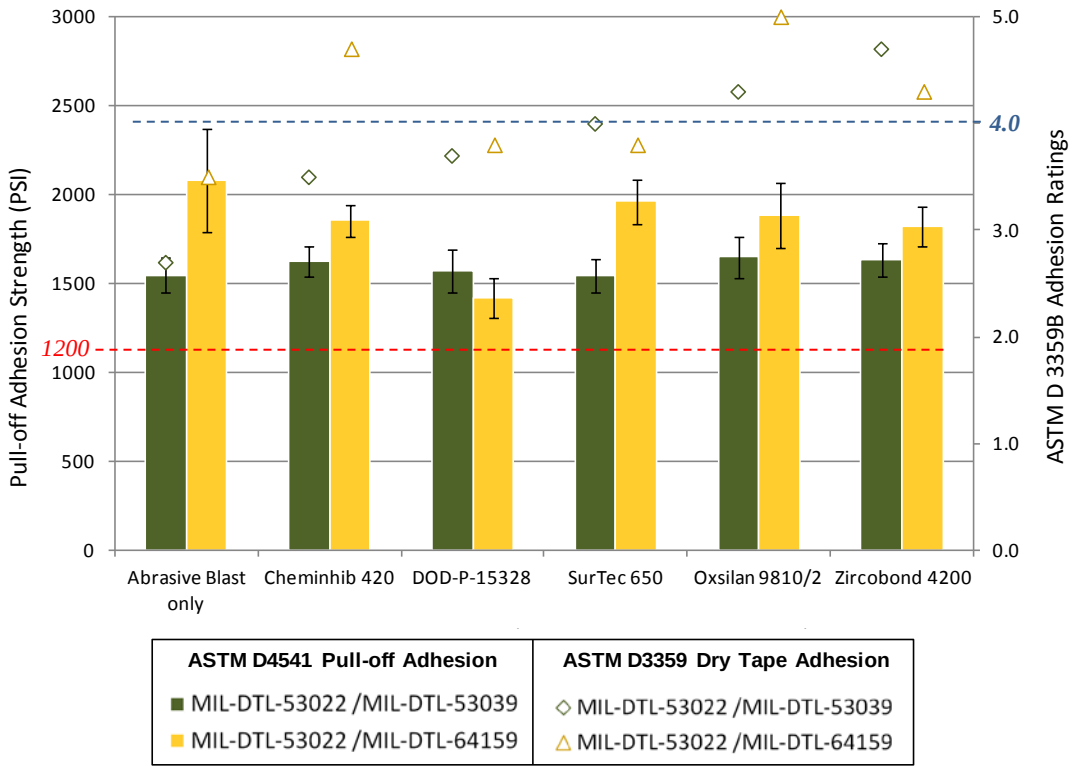


Figure 6-2: ASTM D 4541 adhesion strength on abrasive blasted HHA steel

Wet adhesion tests were carried out according to ADTM-3359 method A scribing technique with this caveat: The specification does not prescribe water, temperature or duration. The success criteria for the pretreatments were derived using NAVAIR requirements. The wet tape adhesion test results are shown in Figure 6-3. The success criteria is 3A or greater after 24 hours immersed in ambient DI water. All of the samples tested met the minimum 3A with the exception of DOD-P-15328 wash primer with MIL-DTL-53022/ MIL-DTL-64159 coating system. Under these conditions, the SurTec 650 and the Oxsilan 9810/2 with ratings of 5A performed satisfactorily.

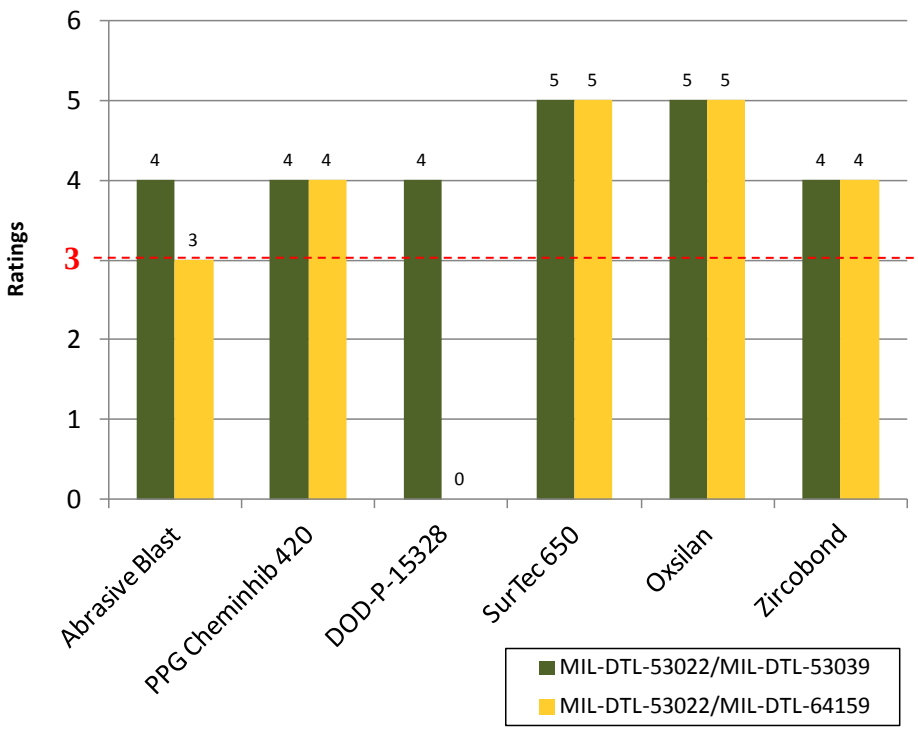


Figure 6-3: ASTM-D3359A ratings for wet tape adhesion at 96 hours on abrasive blasted HHA steel test panels

Another indication of adhesion is the ability of the coating system to resist chipping. This is particularly important for military ground vehicles that navigate in rough terrain. Table 6-2 shows the measure of chip resistance using the SAE J400 gravelometer. The test samples are pretreated and coated with two different primer/topcoat combinations. The success for chip resistance is a rating of 5B. The DOD-P-15328 did not pass with either coating system. Of the alternatives, the SurTec 650 was only able to achieve a 4B/A rating, meaning the size of chips are acceptable, but the 4 ratings suggests that it is more susceptible to chipping. As compared to the baseline, the SurTec 650, in this case, is as good as the wash primer with the MIL-DTL-53022/MIL-DTL-64159 system. All other alternatives met or exceeded the success criteria.

Table 6-2: Chip resistance of pretreatments on abrasive blasted HHA steel

Abrasive Blasted High Hard Armor				
Pretreatment	**MIL-DTL-53022 / MIL-DTL-53039**		**MIL-DTL-53022 / MIL-DTL-64159**	
Abrasive Blasted only	6	A/B	5	B/A
DOD-P-15328	4	B/A	4	B
PPG Chem Inhib 420	5	B	5	B
SurTec 650	5	A	4	B/A
Chemetall Oxsilan	5	B	5	B
PPG ZircoBond 4200	5	B/A	5	B

Accelerated Corrosion:
Only test panels coated with CARC system MIL-DTL-53022/MIL-DTL-53039 were tested in ASTM B117. The primary mode of failure for all of the test panels was creep from the scribe. The ratings of five replicates of each pretreatment were averaged and presented in Figure 6-4. Beyond 500 hours of exposure, the alternatives displayed less creep from the scribe and met the success criteria of a ≥ 6 scribed. After all samples completed 1000 hours, they were scraped clean of all loose coating and corrosion products using a 2” putty knife before the final ratings were made. All three of the alternatives are showed improved performance over the control and all of the baselines including the chromate wash primer DOD-P-15328. In fact, all were very close to meeting the 6.0 rating even after 1000 hours. As previously mentioned, the Cheminhib 420 is the baseline the alternatives are being evaluated against. It proved to be the least satisfactory of all the test panels measured in ASTM B117 salt fog. Representative panels from each set of replicates are shown in Figure 6-5. Each panel is captioned with the pretreatment name and average rating. These panels were selected because they best represent the average of the set. A visual comparison between the alternatives and baseline shows a noticeable improvement when using the alternative pretreatments. The baselines and controls show significantly more corrosion along the scribe than that visible on the alternative pretreatment systems.

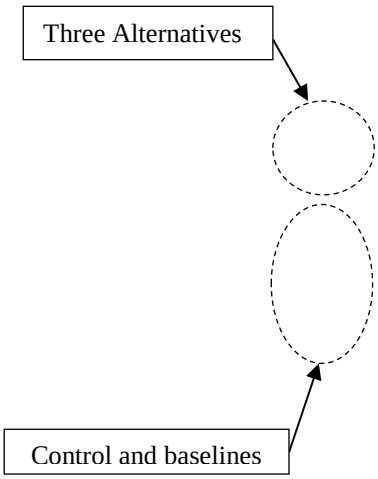


Figure 6-4: ASTM D 1654 rating for abrasive blasted high hard armor panels through 1000 hours of ASTM B117 salt fog exposure

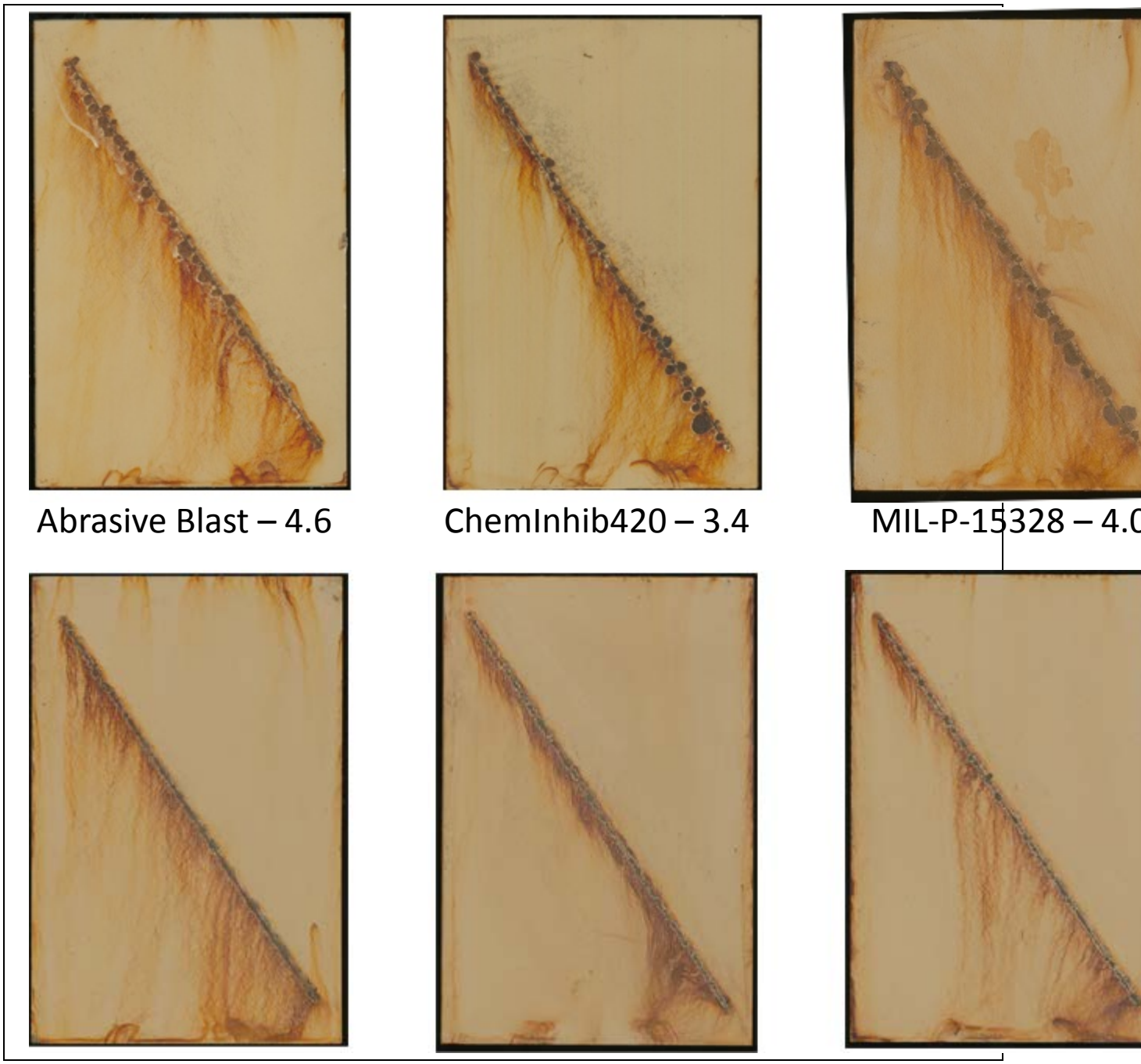


Figure 6-7: Abrasive blasted HHA with MIL-DTL-53022/MIL-DTL-53039 scraped after 1000 hrs B117 exposure. Performance determined by creep-back from scribe.

Sets of panels with two CARC coating systems, MIL-DTL-53022 / MIL-DTL-53039 and MIL-DTL-53022 / MIL-DTL-64159 were tested in GM 9540P cyclic corrosion. Replicates of 3 were used for the GM 9540P tests for each pretreatment and baseline. Figures (6-6 and 6-7) lists the actual ratings for each test panel (not averaged). The success criteria here is an average ASTM 1654 rating of ≥ 4 for "X" scribed panels. The test was carried out to 80 cycles before scraping the panels clean of loose coatings and corrosion products with a 2" putty knife for a final rating, however the acceptance criteria was determined at 60 cycles. Similar to the ASTM B117 results,

only the alternative pretreatments were able to achieve ratings of ≥ 4 after 60 cycles. The only exception was in the Zircobond 4200 coating with DTL-53022 / MIL-DTL-64159 sample set, where one of the 3 panels in the set rated a 3. The average of this set was 3.7, still much higher than baselines regardless of coating system. When the test reached 80 cycles and the panels were scraped and measured, all of the controls (abrasive blast only), and nearly all baselines rated a zero. Photographs of representative panels are in Figure 6-8 and 6-9. The three alternatives displayed enhanced corrosion resistance along the scribe, however there is some secondary blistering seen in the field away from the scribe on the SurTec 650. Overall, there was no real difference between pretreatments coated with MIL-DTL-53022 / MIL-DTL-53039 or MIL-DTL-53022 / MIL-DTL-64159. The similar performance of the two coating systems is likely because MIL-DTL-53022 was used for the primer in both cases.

ASTM-D1654 Ratings for High Hard Armor (HHA) with 53022/53039						
		GM 9540P Cycles				
Panel	Pretreatment	10	20	40	60	80
1	Abrasive Blast Only	7	6	4	2	0
2		8	7	4	0	0
3		8	6	5	2	0
1	PPG Cheminhib 420	8	5	2	0	0
2		7	5	3	2	0
3		5	5	4	1	0
1	DOD-P-15328	8	7	4	3	1
2		7	5	4	2	0
3		7	7	5	2	0
1	SurTec 650 (TCP)	7	7	5	4	2
2		7	7	5	5	3
3		7	7	5	4	2
1	Chemetall Oxsilan	7	7	4	4	2
2		7	7	5	4	2
3		7	7	5	5	4
1	PPG Zircobond 4200	7	7	5	5	2
2		7	7	5	5	4
3		7	7	6	6	4

Figure 6-6: GM 9540P results for low carbon steel and high hard armor substrates pretreated and coated with MIL-DTL-53022 / MIL-DTL-53039 CARC system

ASTM-D1654 Ratings for High Hard Armor (HHA) with 53022/64159						
		GM 9540P Cycles				
Panel	Pretreatment	10	20	40	60	80
1		7	5	5	2	0
2		8	7	5	3	0
3	Abrasive Blast Only	7	7	4	1	0
1		7	3	2	0	0
2		5	3	2	0	0
3	PPG Cheminhib 420	6	5	3	1	0
1		7	5	4	3	3
2		7	5	4	2	0
3	DOD-P-15328	8	7	4	3	0
1		7	7	6	4	2
2		7	7	7	6	5
3	SurTec 650 (TCP)	7	7	5	4	3
1		7	7	5	4	2
2		7	7	5	4	3
3	Chemetall Oxsilan	7	7	5	4	3
1		7	6	6	4	3
2		7	7	5	3	0
3	PPG Zircobond 4200	6	6	5	4	3

Figure 6-7: GM 9540P results for low carbon steel and high hard armor substrates pretreated and coated with MIL-DTL-53022 / MIL-DTL-64159 CARC system

Figure 16: Abrasive blasted HHA with MIL-DTL-53022/MIL-DTL-53039 scraped after 80 cycles of GM 9540P exposure

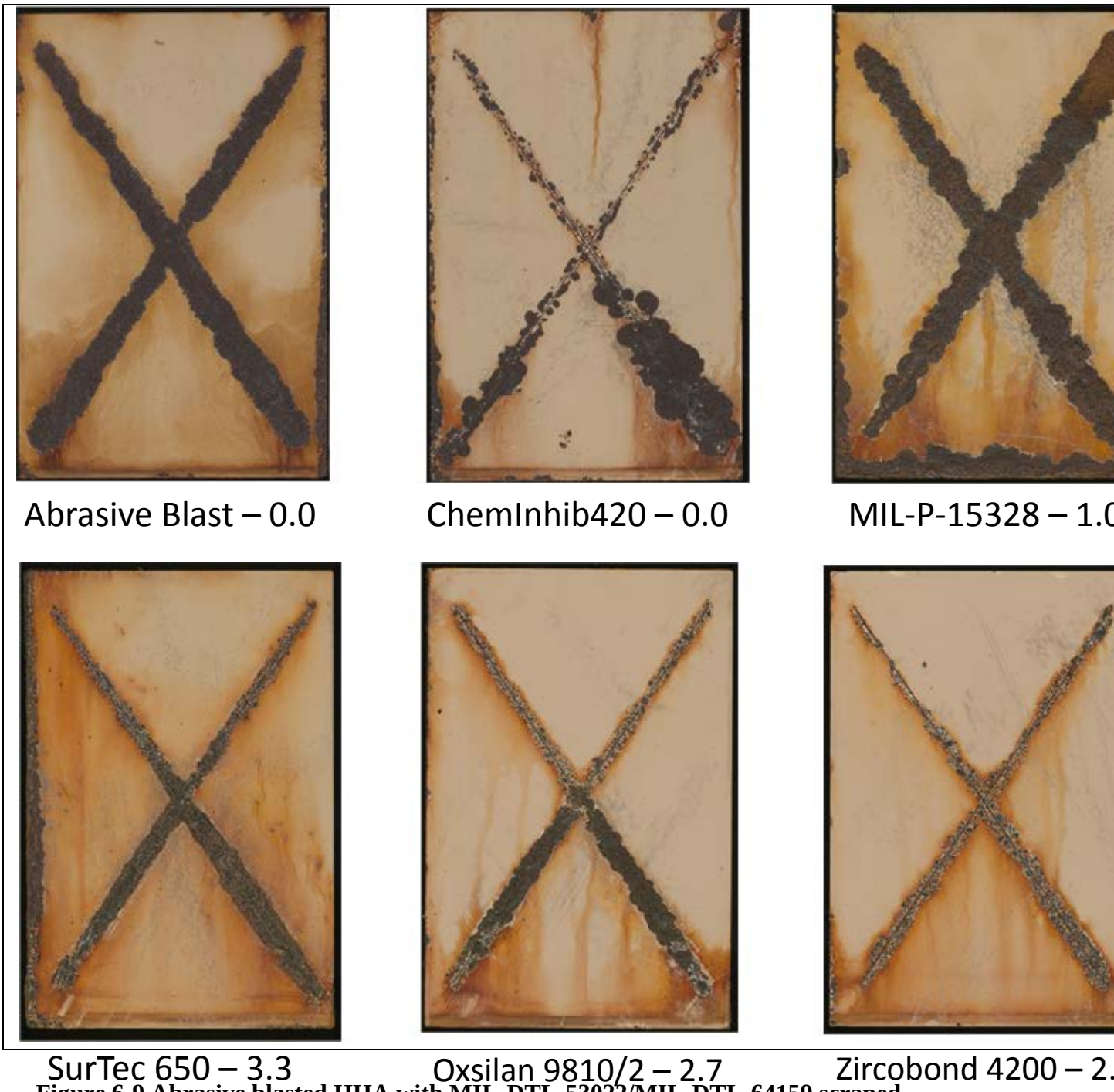


Figure 6-9 Abrasive blasted HHA with MIL-DTL-53022/MIL-DTL-64159 scraped after 80 cycles of GM 9540P exposure

Outdoor Exposure at Cape Canaveral:

The success criteria of 25% less creep from the scribe than the Cheminhib 420 baseline will not be evaluated until after three years of outdoor exposure has been completed. However, inspections were conducted at 2 years and those results presented in Figures 6-10 through 6-13. The data presented in Figure 6-10 and 6-11 represent the average ASTM-1654 ratings vs. time of

exposure. The actual measurement for creep from the scribe will be determined after three years exposure when the test panels are to be scraped and measured.

As expected, the abrasive blasted only (control- no pretreatment) panels have shown the greatest creep from the scribe as well as the most secondary blistering in areas away from the scribe. For these panels the average ratings are 4.33 and 4.67 with MIL-DTL-53022 / MIL-DTL-53039 and MIL-DTL-53022 / MIL-DTL-64159 respectively. The Cheminhib 420 is the baseline system the alternative pretreatments will be measured against. The Cheminhib 420 has performed slightly better than control, but only with an average of 6.0 rating thus far with only one coating combination, MIL-DTL-53022/ MIL-DTL-64159. The DOD-P-15328 wash primer is currently at a 6.0 and 7.33 with, MIL-DTL-53022/MIL-DTL-53039, and DTL-53022/ MIL-DTL-64159 combinations respectively.

All three of the alternatives; SurTec 650, Oxsilan 9810/2 and Zircobond 4200 are outperforming the baselines and control at 2 years with MIL-DTL-53022 / MIL-DTL-53039. For the MIL-DTL-53022 / MIL-DTL-64159 dataset, the grouping is much closer with Oxsilan 9810/2 and SurTec 650 rating above 7.0. These ratings are likely higher than the MIL-DTL-53022 / MIL-DTL-53039 dataset in outdoor exposure because the waterborne CARC topcoat tends to have better UV resistance. These two year outdoor exposure results are remarkably similar to the B117 results presented in Figure 6-4. Chemetall's Oxsilan 9810/2 is currently rated at 7.0 on each of the Army CARCs. SurTec 650 TCP is also holding up well with ratings at 7.0 and the Zircobond 4200 just under a 7.0.

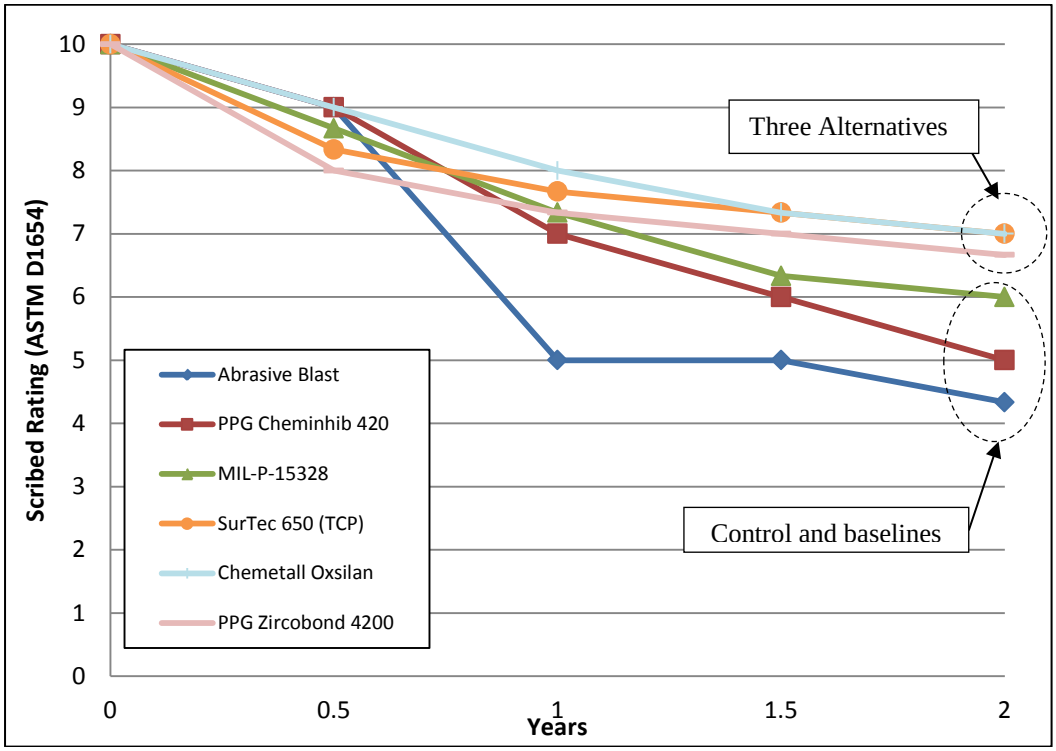


Figure 6-10: ASTM D 1654 ratings for abrasive blasted high hard armor panels with MIL-DTL-53039 after 2 years outdoor exposure

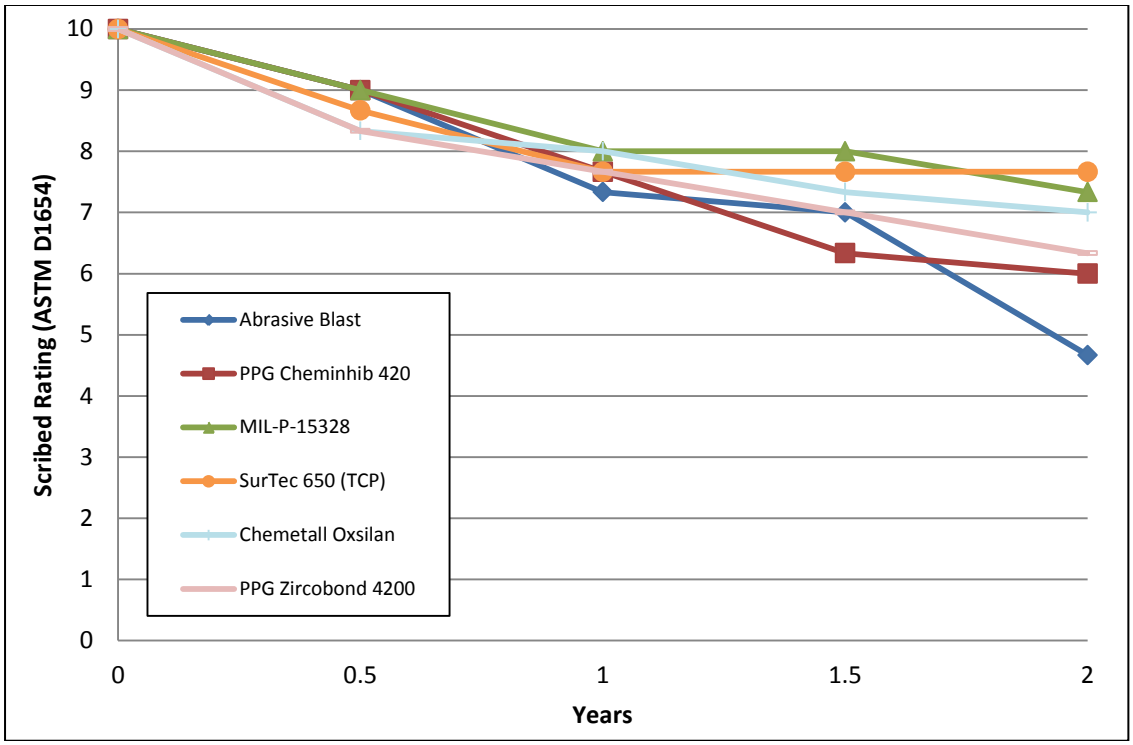


Figure 6-11: ASTM D 1654 ratings for abrasive blasted high hard armor panels with MIL-DTL-64159 after 2 years outdoor exposure

Representative test panels for each pretreatment, baselines and control are shown in Figures 6-12 and 6-13. Each photograph is identified with the pretreatment name and the average ASTM-1654 rating after 2 years of outdoor exposure. Visual inspections indicate that each of the alternatives is performing better than the Cheminhib baseline. All appear to enhance the corrosion performance of the coating system versus abrasive blasting alone. To date, this suggests that a direct-to-metal process alone may not be a sufficient method for preparing HHA for paint.

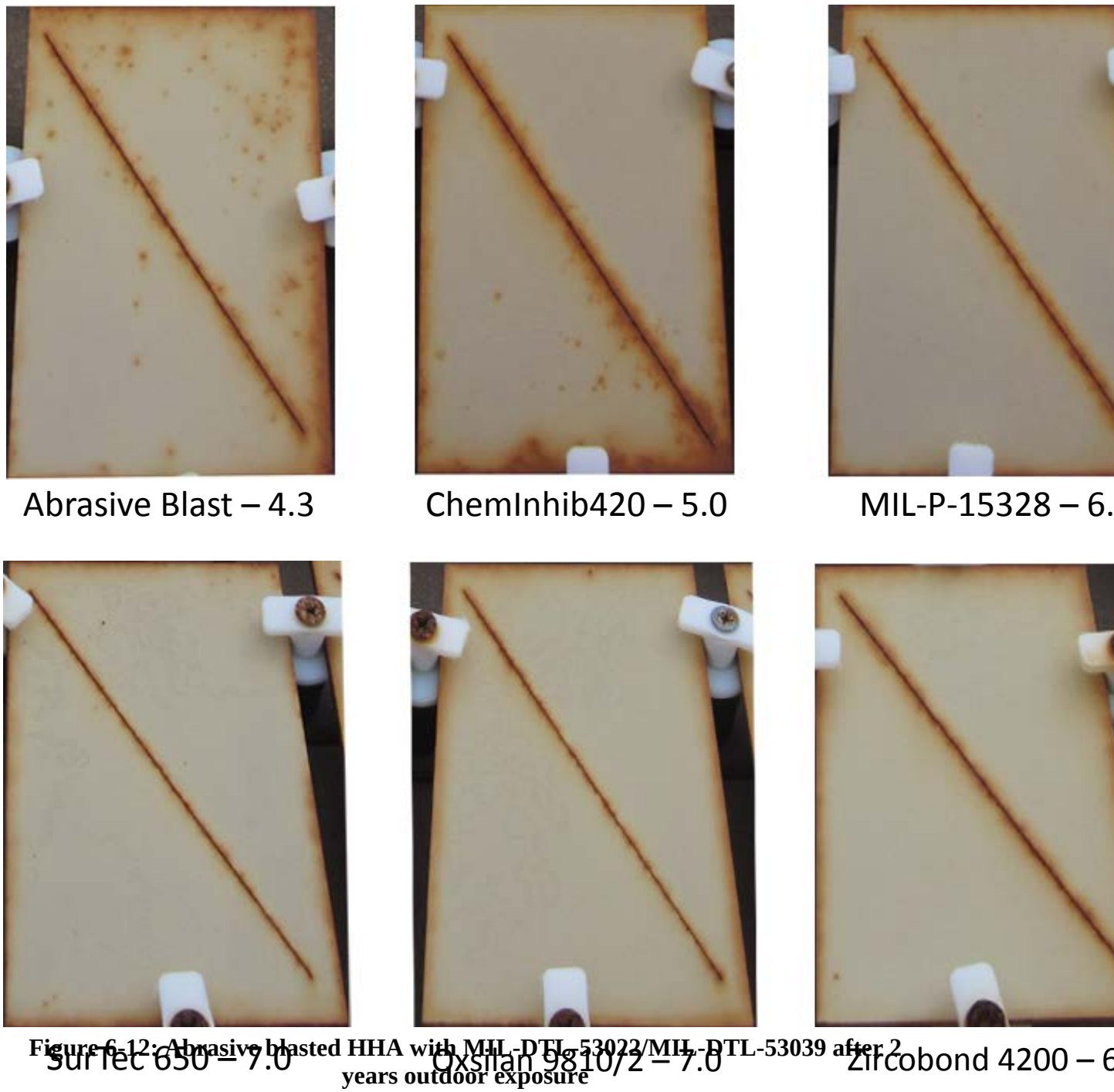


Figure 6-12: Abrasive blasted HHA with MIL-DTL-53022/MIL-DTL-53039 after 2 years outdoor exposure

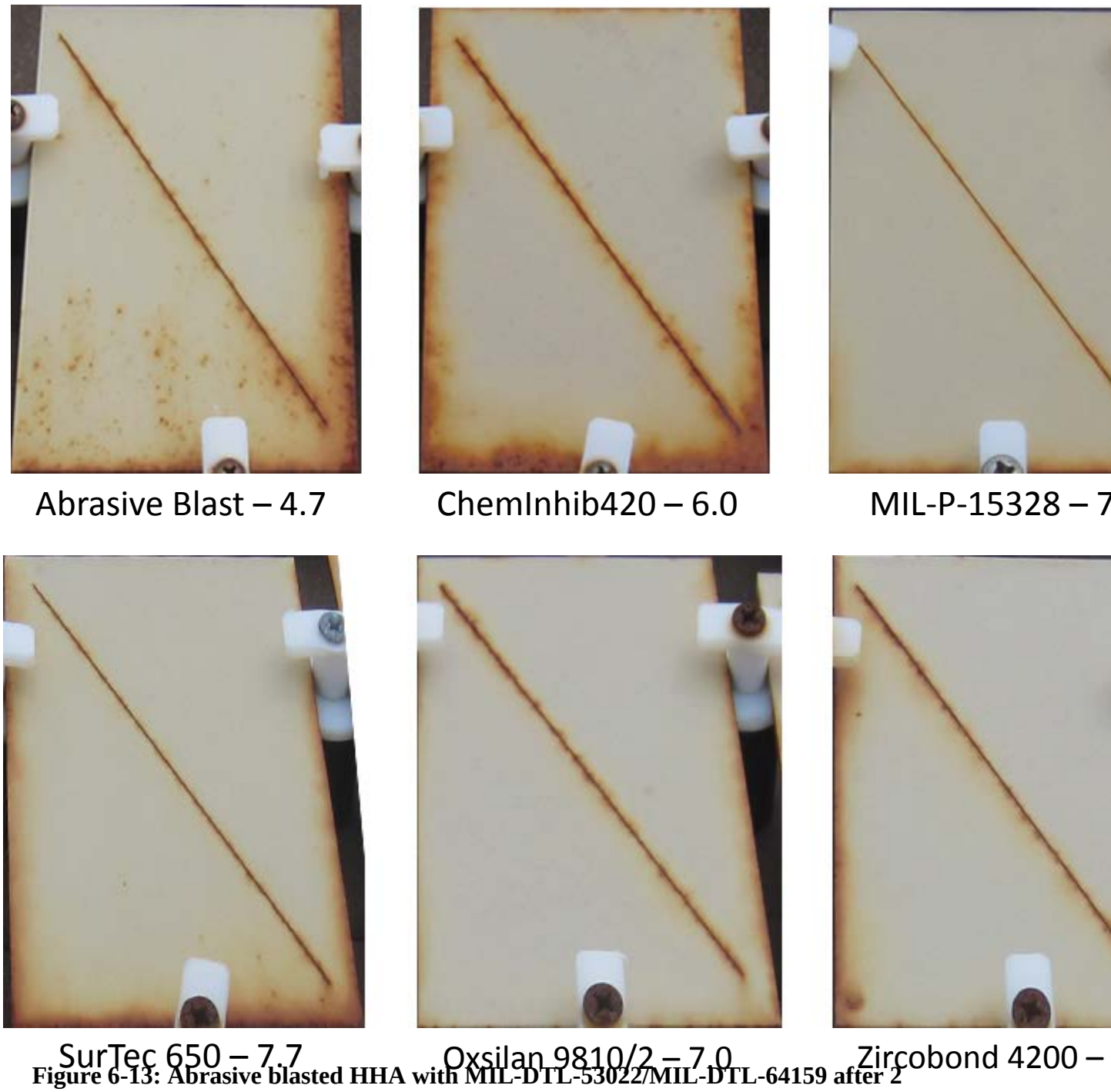


Figure 6-13: Abrasive blasted HHA with MIL-DTL-53022/MIL-DTL-64159 after 2 years outdoor exposure

It was important to determine if any of the proposed pretreatments would have a detrimental effect on the HHA resistance to environmentally assisted cracking. Figure 6-14 shows the K_{1EAC} results that were measured using the rising step load method. When the empirical data for K_{1EAC} is compared with that found in the literature, it is clear that none of the alternatives had any influence on the MIL-A-46100 resistance to environmentally assisted cracking[23],[24].

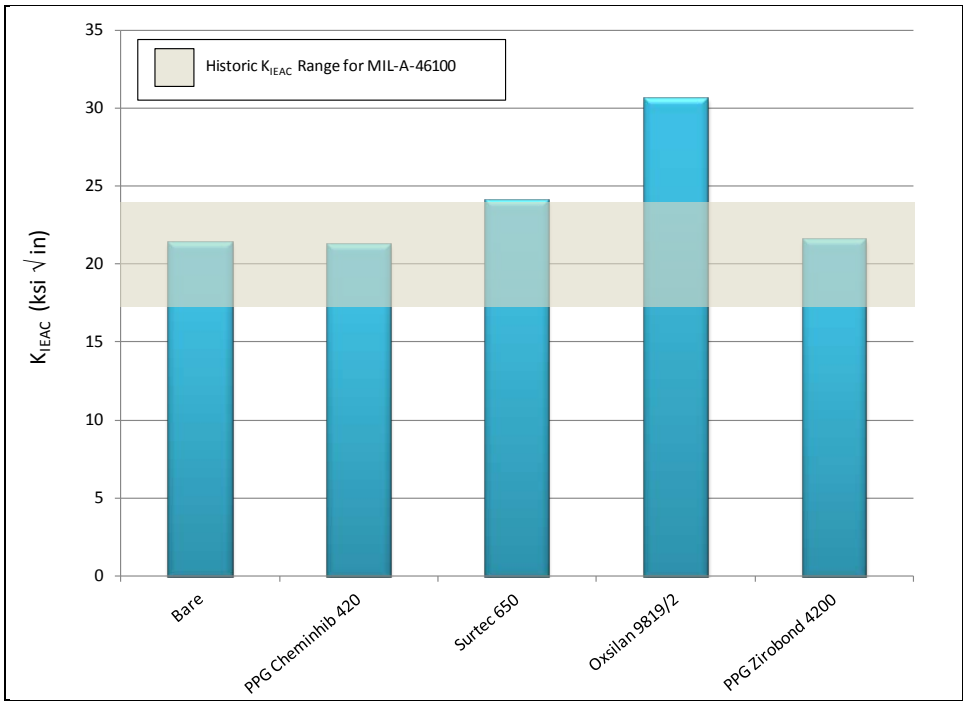


Figure 6-14: Average K_{1EAC} values for pretreated MIL-A-46100

6.2 Stryker Demonstration Results:

Figure 6-15 shows 3 hatches 19 hours after the application of the pretreatments. Only the Zircobond showed noticeable discoloration of the steel. The blotchy color change initially appeared as a pinkish rose color almost immediately after application and turned yellowish as it dried as seen in the picture below. It was not clear whether it was flash rust or an expected result from the reaction of the Zircobond and the steel. The Oxsilan 9810/2 and SurTec 650 showed no significant discoloration. Only slight darkening was observed with these two pretreatments. The lack of color or some type of indicator however makes it a challenge to detect if proper coverage was achieved.

Oxsilan 9810/2	SurTec 650	Zircobond 4200

Figure 6-15: Front Access Hatches after approx 19 hours ambient indoor exposure

Two of the three Strykers (MGS-25 and ICV-382) were photographed and the results examined in April 2013 (after 2 years. 7 months in service). The third (MEV-76) was unavailable because it was deployed to Afghanistan earlier that year. Table 6-3 below shows the vehicle identifications and how each of the hatches was pretreated (shaded area are the vehicles that were inspected). The subsequent photographs show the condition of the hatches from each vehicle. It is important to note that these hatches are mated with bolt-on composite armor sandwiched on top of the HHA. Some wearing of the topcoat that occurs from vehicle vibration is typical.

Table 6-3: Stryker vehicle identifications and hatch pretreatments

Component	Stryker Demonstration Vehicles Identification		
	MEV-76	**MGS-25**	**ICV-382**
Power Entry Panel (PEP) Hatch	SurTec 650 (TCP)	**PPG Zircobond 4200**	**Chemetall Oxsilan**
Front Access Hatch	PPG Zircobond 4200	**Chemetall Oxsilan**	**SurTec 650 (TCP)**
Side Egress Hatch	Chemetall Oxsilan	**SurTec 650 (TCP)**	**PPG Zircobond 4200**

The primary and secondary performance criteria being evaluated in a production setting during the demonstration are listed in Table 6-4. As discussed earlier in this section, all of the products exceeded the performance of the baseline Cheminhib 420 without exception. None of the alternatives contain hexavalent chrome and thus meet the hazardous materials requirement. The waste disposal metric is easily met because the process is similar to the baseline Cheminhib 420. Therefore, identical waste procedures to the baseline, if any, would apply. In either case, they do not require the extensive reporting requirements needed for hexavalent chrome processes. For comparing the alternatives in identical operating conditions as the baseline, we examine the flowcharts for the alternatives in section 2.0 are compared them with the baseline process flowchart in section 4.0. There was little or no difference in the application methods employed. Both are spray-applied technologies that dry-in-place.

With the exception of the scale up capability, all the secondary performance criteria were met. Each of the alternatives can be used in a similar fashion as the baseline Cheminhib 420. No significant training is required. Also, because the Stryker parts that were treated are considered relatively small, there was no issue with flow rates of the products. Provided the proper equipment is available, only the manufacturer's instructions and a representative on site to monitor the implementation are necessary. This is not unique to the implementation of any drop-in-replacement. Storage and recordkeeping for any of the alternatives will depend on how it is purchased. They are mixed with DI water at a concentration ranging from 3-5% by volume. Therefore, the alternatives can be purchased and stored as a concentrate in smaller quantities

which will reduce the amount of record keeping. All are also water cleanup. No different than the baseline.

The issues that have been identified with scale up are discussed further in the next section concerning the MRAP demonstration. For the Stryker demonstration, the parts were relatively small and scale up requirements could not fully be assessed. However, the primary concern in this demonstration was with the Zircobond 4200. The blotchy surface finish (Figure 6-15) will be a challenge for quality assurance engineers to determine if the resulting film is acceptable. SurTec 650 and Oxsilan 9810/2 had no color change on Stryker which is similar to the appearance of the baseline Cheminhib 420. The challenge here is to ensure that a large complex structure is completely and adequately wet for the required duration. It is believed that this is a challenge that can be overcome with proper equipment that produces adequate flow of the product and capture and recycle the run-off.

Table 6-4 Validation methods and performance metrics for demonstration on Stryker

Performance Criteria	Expected Performance Metric (Pre-Demonstration)	Performance Evaluation Method	Actual Performance (Post-Demonstration)		
Primary Performance Criteria			**SurTec 650**	**Oxsilan 9810/2**	**Zircobond 4200**
Product Testing	The performance of the alternative technology will meet or exceed the current process employed on Stryker during manufacturing as defined in the JTP in Appendix A.	Laboratory analysis and field testing	Met	Met	Met
Hazardous Materials	Maintains a hex-chrome free platform	Assessment of product constituents and previous studies	Met	Met	Met
Hazardous Waste	Meets or exceeds current process used in Stryker manufacturing	Operating experience and assessments	Met	Met	Met
Factors Affecting Technology Performance	Comparison of alternatives in identical operating conditions	Operating Experience	Met	Met	Met
Secondary Performance Criteria					

Ease of Use	Man hours, training, and quality assurance methods shall be equivalent to current process used in Stryker and MRAP manufacturing	Operating experience	Met	Met	Met
Maintenance	Requirements for record keeping for storage, and clean up shall be equivalent to current process	Compare records	Met	Met	Met
Scale up capability	Identify additional equipment, if any, necessary to scale up process for full vehicle treatment.	Operating experience and investigation	N/A	N/A	N/A

The Strykers that participated in the demonstration at ANAD in September of 2010 were eventually sent to Joint Base Lewis McCord (JBLM). ARL made numerous inquiries and requests through Ms Catherine Doherty (section 5-4) to locate and allow access to the vehicles for inspection. Our attempts to locate and access the vehicles were unsuccessful because Ms Doherty was: a) unable to locate the exact location of the vehicles, and b) was not able to give permission to inspect them. Eventually, ARL was able to secure the cooperation of Ms Terry L. Austin, Pollution Prevention Program Manager, Installation Sustainability Coordinator, DPW-Env Div, JBLM. Through Ms Austin, we were able to identify the POC of each vehicle:

MGS-0025 :
POC: Mr. Douglas Saunders, Stryker Fielding Office, JBLM Logistics Support,
Vehicle is deployed with 1-38 in Afghanistan.
GDLS will photograph treated parts at the first opportunity.

ICV-0382 and *MEV-0076*:
POC: MSG Sanders, 7ID; 7ID has all SBCT at JBLM.
SFC Jackson will locate vehicles and photograph treated parts.

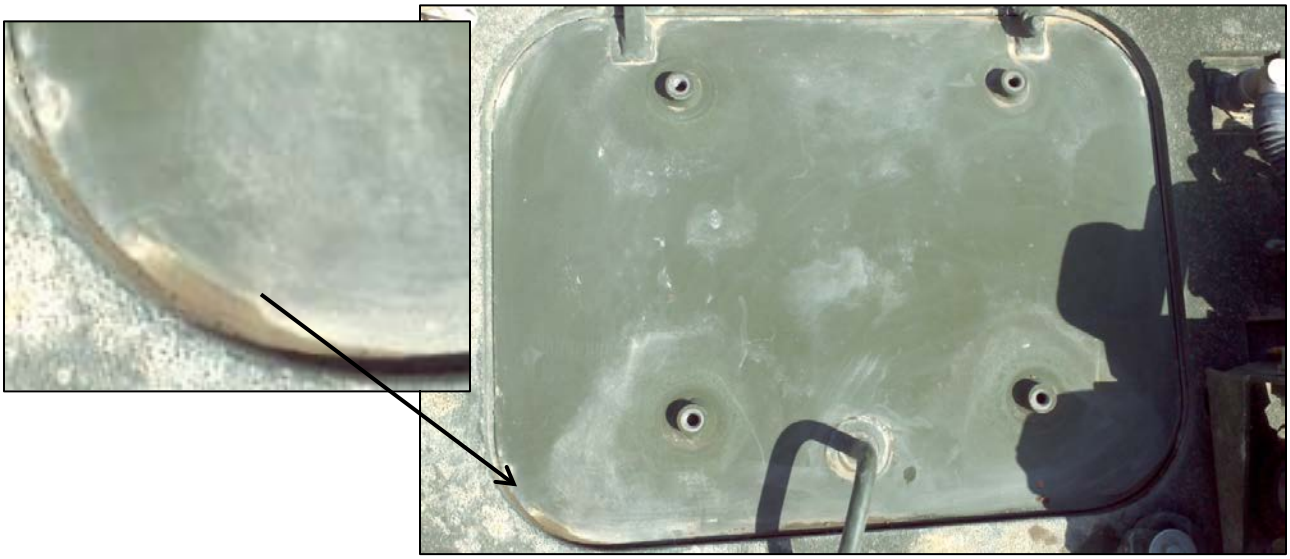
ARL contacted each of the POC and gained their cooperation. MGS-0025 and ICV-0382 were still located at JBLM however, MEV-0076 was deployed to Afghanistan and is unavailable for inspection or photographing. The photographs of the hatches on MGS-0025 and ICV-0382 are shown in Figures 6-16 and 6-17. Because of travel restrictions ARL was unable to physically inspect the hatches, and therefore the photographs were provided by SFC Jackson-Smith, Sylbert D. 7th ID G4, Armament Maintenance Joint Base Lewis-McChord. Upon examination of 6-16, very little corrosion can be seen. Even when zooming in on the high resolution photos, only the front access hatch shows some indication of wear that may have been caused by rubbing of the composite armor. Other than that, no evidence of corrosion or paint delamination of the coating exists.

SFC Jackson-Smith provided his opinion on the condition of the hatches on ICV-0382 in figure 6-17.

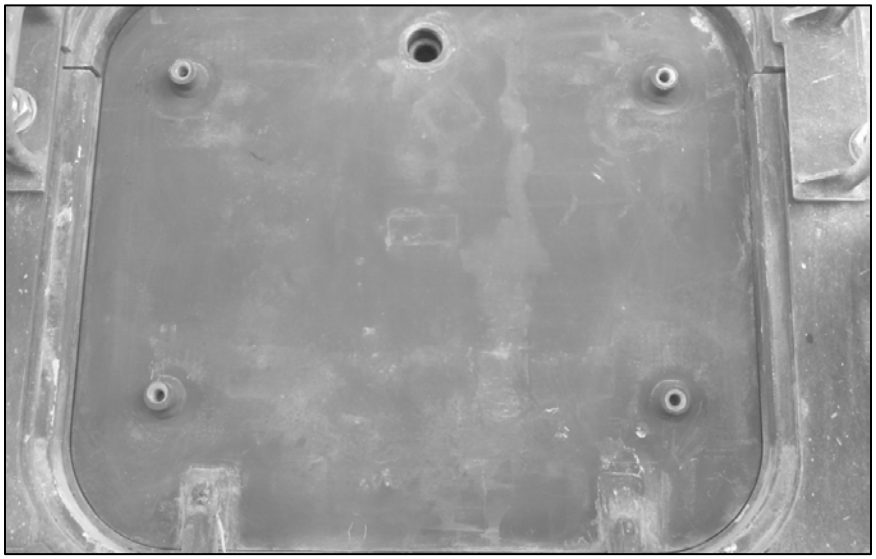
SFC Jackson-Smith:
“I didn't see any paint peeling on any of the hatches, There was a few small red rust areas on the side egress hatch up towards the top that appeared to me to be just light surface rust.”

Although one of the hatches, Figure 6-17b appears to have some red rust near the edges, SFC Jackson-Smith do not seem to mention that. It is thought that the darker areas around the edge of that hatch may be dirt or clay that darkens when wet. The right side of that hatch, (dry side) is a light brown/tan color, not red. It’s possible the darker brown/red is in fact mud that collected under the composite armor outer. It appears that all of the hatches on both vehicles have some type of dirt/sand that collected under the composite armor. The only corrosion damage recognizable from the photographs in Figure 6-17 is the spot in 6-17c. This can be rated using SSPC-VIS-2 as “rust grade 9-S (spot) less than 0.03 percent. At this time, the hatches are considered comparable to the base vehicle.

a) MGS-25 Power Entry Panel (PEP) hatch, pretreated with PPG Zircobond 4200



b) MGS-25 Front Access Hatch, pretreated with Chemetall Oxsilan 9810/2

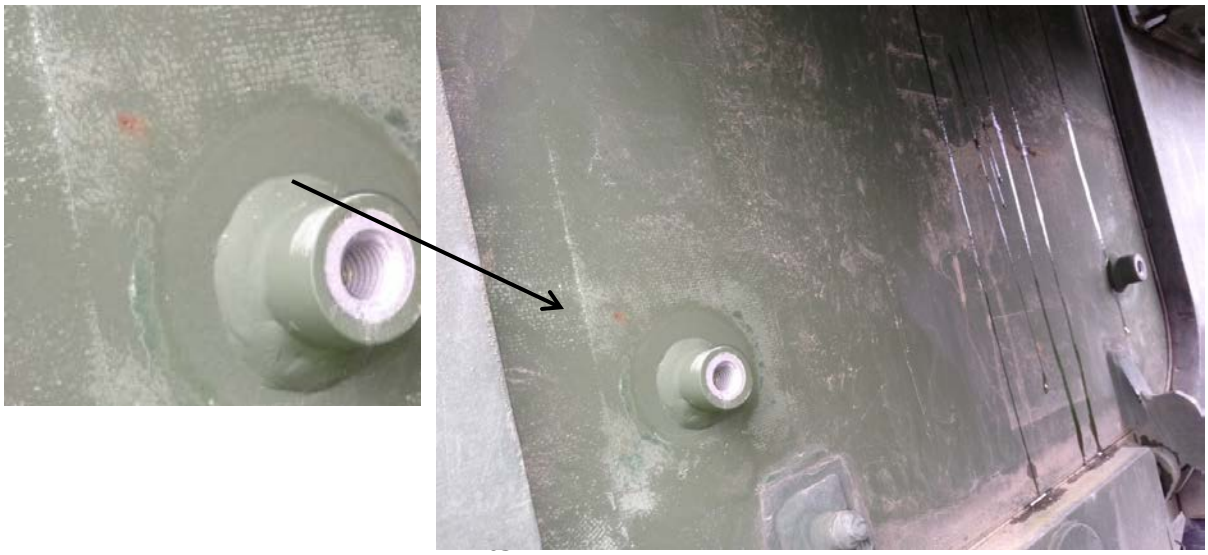


c) MGS-25 Side Egress Hatch, pretreated with SurTec 650 (TCP)

Figure 6-16: Photographs of hatches from Stryker vehicle MGS-25 located at Joint Base Lewis McChord (JBLM) after 31 months in service[25].

a) ICV-382 Power Entry Panel (PEP), pretreated with Chemetall Oxsilan 9810/2

b) ICV-382 Front access hatch, pretreated with SurTec 650 (TCP)



c) ICV-382 Side Egress Hatch, pretreated with PPG Zircobond 4200

Figure 6-17: Photographs of hatches from Stryker vehicle ICV-382 located at Joint Base Lewis McChord (JBLM) after 31 months in service.

6.3: MRAP Full Scale Demonstration:

Two electric pumps (depicted in the demonstration plan and Figure 2-5) were used to apply the Oxsilan 9810/2 and DI rinse water. The flow rate of each of the pumps was measured to be 1.1 gallons per minute. The process called for wetting the MRAP with the Oxsilan 9810/2, allowing it to dwell for 60-90 seconds, and rinsing with clean DI water. The process was carried out as close as practical with 2 applicators and 1 person blow-drying with compressed air. However, during the application of the pretreatment, the color of MRAP#1 began to change to a reddish hue within 1 minute. As the application progressed into the rinse and dry phase, a darker reddish-brown color appeared which looked similar to flash rusting on the steel surface. We estimated that about 90% of the vehicle was covered with this reddish-brown product. After some of the areas on the vehicle were fully dry, pull-off tape tests were conducted to determine the stability of the reddish-brown surface finish. Tape adhesion was very tight, comparable to taping a blasted steel surface, with little or no reddish-brown product pulled off with the tape. In fact, in some cases the backing adhesive was pulled off of the test tape.

Figure 6-18 shows MRAP#1 after the application of the Oxsilan 9810/2. These results were completely unexpected and bear no resemblance to the surface finish that was achieved on earlier test panels and the Stryker hatches treated Oxsilan 9810/2 during the earlier Stryker demonstration at Anniston (see Figure 6-15).

Figure 6-18: MRAP #1 After application of with Oxsilan 9810/2 RTU from drums June 20, 2011.

During a meeting and conference call with Chemetall America's Product Manager on the evening of June 20, 2011, several possibilities for the unexpected results were discussed: 1) improper solution chemistry, 2) application rate [not enough flow], 3) surface contamination

likely because MRAP #1 was not abrasive blasted within the required 24 hours prior to pretreatment, but rather 72 hours prior to treatment; and/ or blast media was contaminated.

A sample of the Oxsilan 9810/2 was taken from the drums and sent to the Chemetall laboratories for analysis. Chemetall laboratory determined that the solution chemistry was within their acceptable range. As a result, further tests by ARL were conducted to attempt to duplicate the (desired) results from earlier tests using the batch of Oxsilan from the drums at Camp Lejeune, as well as replicate the (undesirable) results obtained at Camp Lejeune.

Follow up Tests:
HHA test panels (4in x 6in x 3/16in) were abrasive blasted with 60-grit aluminum oxide to SSPC-SP 5 to provide a clean surface prior to spray applying Oxsilan 9810/2. Beyond the initial abrasive blasted finish, the test panels were prepared as described below to mimic different scenarios.

1) Mimic the "best case scenario" panels were sprayed using maximum flow and maximum dwell time recommended by the manufacture. In the first case a panel is sprayed (essentially bathed) in Oxsilan for 90 seconds prior to rinsing with DI water to represent an ideal condition of maximum flow and dwell.

2) Mimic worst case for flow rate and dwell time are test panels sprayed with minimum flow allowable to keep the panel wet for 30 seconds and subsequently rinsed with DI water.

3) The role of contaminants on the surface of the HHA prior to treatment with Oxsilan was examined. Two different sets of panels were deliberately contaminated using two methods:
    a) NaCl Spray: Test panels were deliberately contaminated by spraying down with 3.5% sodium chloride (NaCl) solution and allowed to dry prior to applying Oxsilan 9810/2 at various application rates.

    b) Pre-exposed: Freshly abrasive blasted HHA panels were pre-exposed to a covered outdoor environment for 72 hours prior to applying the Oxsilan 9810/2 to mimic events at Camp Lejeune.

A significant change in the color was evident in the panels with surface contaminants. Figure 6-19 shows a comparison of a freshly blasted HHA panel (left), with panels that were treated with Oxsilan 9810/2 following 72 hours in an outside environment. The center panel was treated using minimal flow for 30 seconds, and right panel bathed for 90 seconds.. The color is of the center panel is very similar to what was seen on the MRAP during the demonstration at Camp Lejeune (Figure 6-18). Unique to these test panels vs. all the others was the spotting and streaking of the panel that was only allowed 30 seconds of dwell for the Oxsilan 9810/2; again, similar to the MRAP. The surface is clearly contaminated, and it appears that the contamination is having an effect on the consistency and ability of the Oxsilan 9810/2 to react with the steel substrate. Although there was also a color change with the panel treated for 90 seconds, it did not resemble the MRAP results. The color change in the 90 second dwell panel was far less

dramatic. In some respects, it resembled the earlier “best case scenario”. The results of this experiment indicates that more than one factor may have affected the MRAP results.

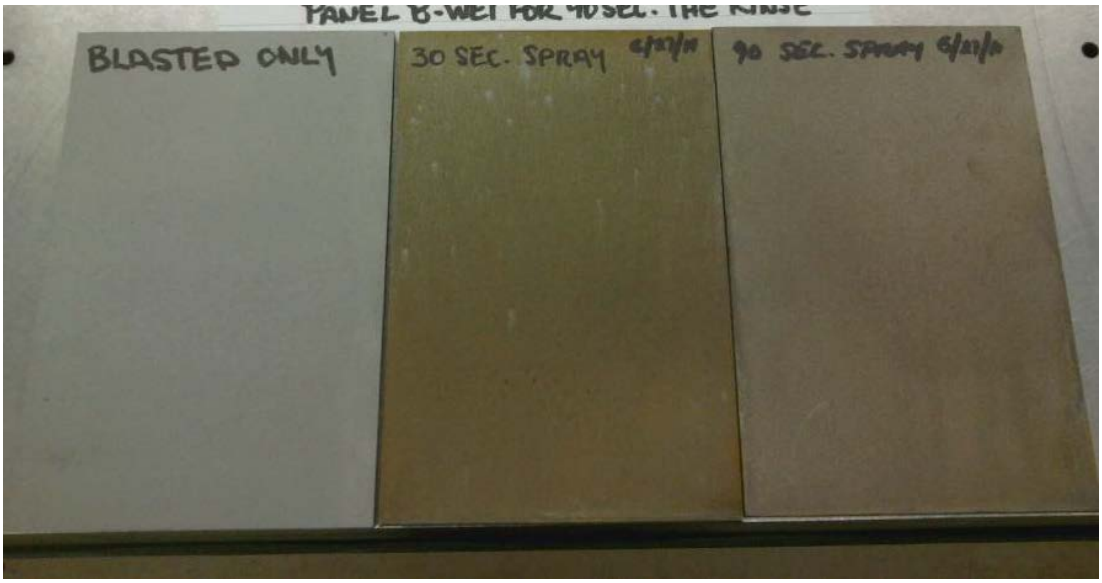


Figure 6-19: Comparison of HHA test panels that were weathered then pretreated with Oxsilan 9810/2

These results indicate that a combination of events contributed to the corrosion-like appearance of the MRAP. The scale-up from laboratory sized and smaller hatch sized parts to a full sized, the scope of the MRAP was underestimated, resulting in inadequate flow of the applied Oxsilan 9810/2. We also believe that the 72 hours the bare surface of the vehicle was exposed to the environment led to some surface contamination which likely would affect the reaction of the Oxsilan 9810/2 with the steel surface. We cannot rule out the possibility that the grit used for abrasive blasting the vehicles may have contained chlorides or other salts that would have also served to contaminate the steel surface. The laboratory tests and the previous demonstration of Strykers indicate that the Oxsilan 9810/2 must be applied to a freshly cleaned, abrasive blasted surface as soon as practical. Preferably within 2-4 hours of abrasive blasting. The flow rate used for the Oxsilan 9810/2 must be sufficient enough to keep the vehicle wet throughout the treatment. Rinsing with clean water should be done using adequate flow rate to thoroughly remove the un-reacted Oxsilan 9810/2. We are confident that the desired results can be achieved by following these recommendations[26].

To prove our hypothesis, ARL worked closely with the MRAP-PMO to secure another demonstration of a limited scope. The MRAP-PMO agreed to provide one set of two rear doors from an MRAP variant for pretreatment using Oxsilan 9810/2. During this demonstration, we were very cognizant of the mistakes made at Camp Lejeune. Therefore, two improvements were made over the process used at Camp Lejeune: 1) the freshly abrasive blasted doors were pretreated with Oxsilan 9810/2 within 2 hours of blasting, and 2) adequate flow of the pretreatment solution was achieved by using a Yamada NDP-15 BPT pump with a 4.0 gpm rating. The Oxsilan treated surfaces of the door looked similar to the results seen at Anniston

during the Stryker hatch demonstration. As can be seen in Figure 6-20, they appeared light grayish blue. No reddish/brown discoloration occurred anywhere on the door. The application of the Oxsilan was carried out similar to the Stryker hatches at Anniston. The surfaces were treated with Oxsilan less than 2 hours after abrasive blasting using a pump sprayer with adequate flow to keep the surfaces wet throughout the pretreatment process. This is added evidence that the undesirable results from the MRAP demonstration at Camp Lejeune was a result of 1) surface contamination, and/or 2) inadequate flow rate of the Oxsilan 9810/2.

Freshly Abrasive Blasted | During application of Oxsilan 9810/2 | Drying process

Figure 6-20: MRAP rear doors in pretreatment process.

The other of the two doors was pretreated with the DOD-P-15328 wash primer and both doors were then primed with MIL-DTL-53022, and topcoated with MIL-DTL-53039. An “X” was scribed near the bottom of each door and both doors were subjected to outdoor exposure at the Aberdeen Proving Ground (see figure 6-21).

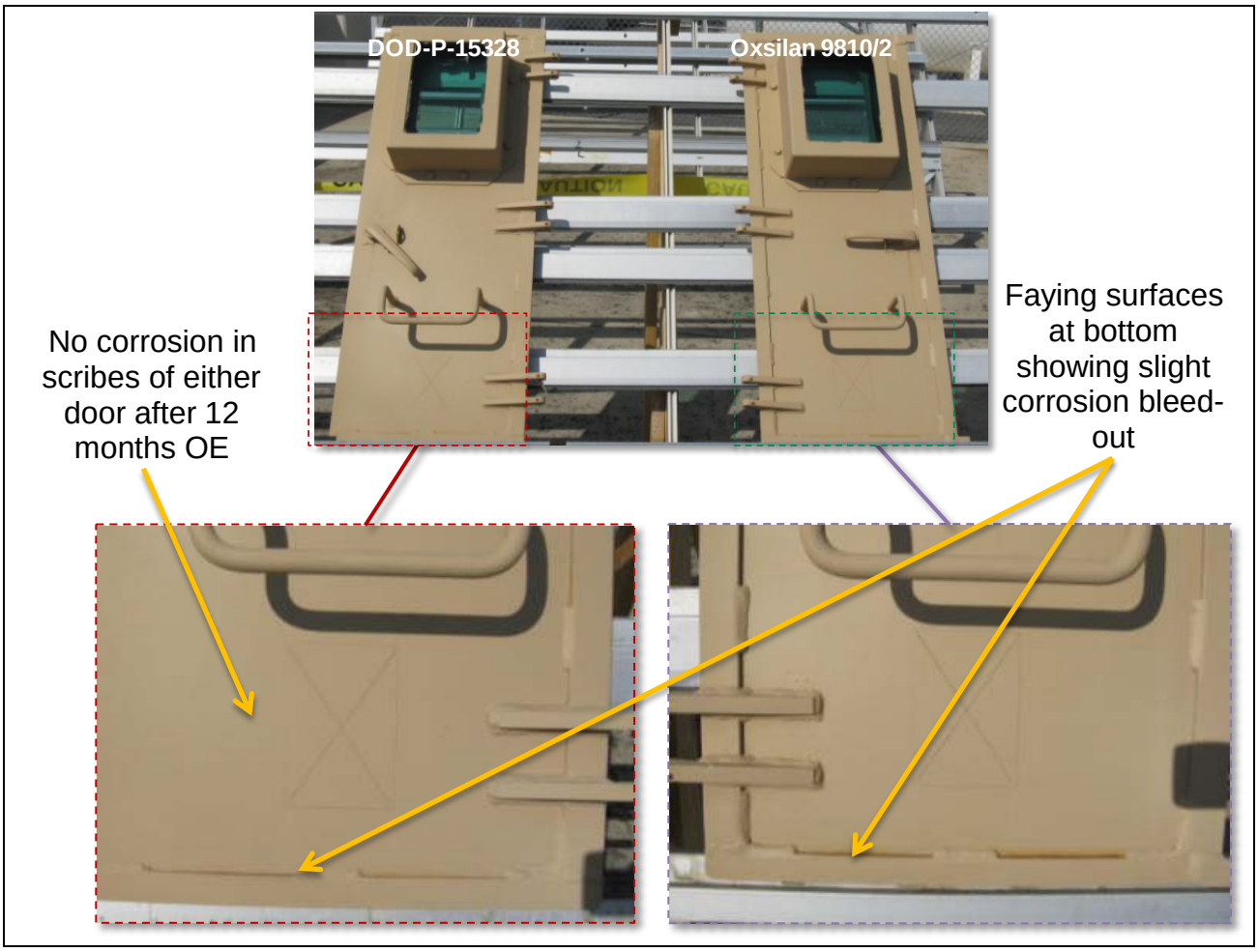


Figure 6-21: MRAP rear doors after 1 year in outdoor exposure at APG.

After 12 month of exposure, there is no noticeable difference between the Oxsilan 9810/2 treated door and the door pretreated with wash primer. Only slight corrosion "bleed out" exists in the faying surfaces at the bottom of each door. The performance after 1 year is considered comparable thus far. The doors will remain in outdoor exposure at least until the scribed areas are rated a failure.

Only the Oxsilan 9810/2 was assessed on MRAP and MRAP components. Table 6-5 presents the results of the demonstration assessments. For the same reasons given in Section 6.2 Demonstration on Stryker, Oxsilan 9810/2 met all of the primary performance criteria when tested on the MRAP doors. The demonstration on the full MRAP was not carried out to the point where field testing was conducted and therefore the field performance was not assessed. The application of the product on the large MRAP platform was a challenge and may be more complicated to apply than the baseline Cheminhib 420. However, the superior performance validated in laboratory tests and on smaller components would be worth the added effort.

The ease-of-use criterion was considered not met because the Oxsilan 9810/2 process appears to be more sensitive to flow rates and substrate surface conditions than applying a simple flash rust inhibitor such as the baseline Cheminhib 420. There were clearly issues with the application of

the product to a large structure such as the MRAP. Although it's been shown that surface contamination played a role, we also know that adequate flow rate of the Oxsilan 9810/2 is essential. We believe that optimum efficiency can be achieved by using a halo type sprayer with recirculation system similar to the one in Figure 6-22 for applying Oxsilan 9810/2. However, application can be performed using multiple high volume (4 gpm) spray equipment in a catch basin. This would be particularly useful for installations that perform rework of Armor vehicles.

Table 6-5: Validation methods and expected performance metrics for demonstrating Oxsilan 9810/2 on MRAP and MRAP doors

Performance Criteria	Expected Performance Metric (Pre-Demonstration)	Performance Evaluation Method	Actual Performance (Post-Demonstration)	
Primary Performance Criteria			**Vehicle**	**Doors**
Product Testing	The performance of the alternative technology will meet or exceed the current process employed on MRAP during manufacturing as defined in the JTP in Appendix A.	Laboratory analysis and field testing	N/A	Met
Hazardous Materials	Maintains a hex-chrome free platform	Assessment of product constituents and previous studies	Met	Met
Hazardous Waste	Meets or exceeds current process used in MRAP manufacturing	Operating experience and assessments	Met	Met
Factors Affecting Technology Performance	Comparison of alternatives in identical operating conditions	Operating Experience	Not Met	Met
Secondary Performance Criteria				
Ease of Use	Man hours and training shall be equivalent to current process used in MRAP manufacturing	Operating experience	Not Met	Met
Maintenance	Requirements for record keeping for storage, and clean up shall be equivalent to current process	Compare records	Met	Met
Scale up capability	Identify additional equipment, if any, necessary to scale up process for full vehicle treatment.	Operating experience and investigation	Met	Met

Figure 6-22: Example of a Halo type wash/rinse system with collection basin

6.4: Summary and Recommendations

The demonstrations of the Oxsilan 9810/2 revealed that the surface conditions of the steel substrate and application rate of the pretreatment must be diligently controlled similar to any other pretreatment process. When properly applied to HHA, the SurTec 650, Oxsilan 9810/2, and Zircobond 4200 provide very good adhesion for the subsequent primer and topcoat, and performed better in all of the corrosion tests than the baseline product Cheminhib 420, including 2 years in outdoor exposure. The Oxsilan 9810/2 and SurTec 650 also inhibited flash rust beyond the TT-C-490 requirement of 24 hours.

Although from the beginning the baseline process that the alternative pretreatments were measured against was the Cheminhib 420, we discovered that in some cases they may be viable alternatives for DOD-P-15328 chromated wash primer. All three candidates performed better than the wash primer in all corrosion and laboratory adhesion test and are showing comparable performance after 2 years in outdoor exposure.

The synergy of this project and the revision of Federal Specification TT-C-490 has provided a pathway for the implementation of these and other new pretreatment technologies. All three pretreatments evaluated in WP200906 met the minimum requirements of TT-C-490 Revision F and were assigned a QPD number making them available to any OEM, or Depot for use on abrasive blasted steel. This is especially useful on contracts issued that must be free of hexavalent chromium.

7.0 COST ASSESSMENT

This project is unique in that it has three technology areas being demonstrated and would have been expensive and time consuming to conduct a comprehensive cost assessment on each. An attempt was made to conduct the cost analysis during the MRAP demonstration at Camp Lejeune, but events occurring during that demonstration prevented us from making a reasonable

cost and performance assessment. Therefore, an actual economic and environmental impact study will be included in the third of three Final Reports which will be on Non-Hexavalent Chrome Sealers for Zinc Phosphate. For this report we offer the estimations made in the demonstration plan with some modifications.

A cost assessment was performed for this project as it related to MRAP, but it is believed that the assumptions made will apply to Stryker. Stryker and MRAP are similarly sized vehicles and both are constructed mainly with High Hard armor steel.

The work time required to prepare and paint an MRAP is approximately 16 hours. This includes abrasive blasting, pressure washing, prepping, and painting. The man-hours consumed for disassembly steps needed prior to surface coating tasks (breakdown, etc.) take several times that. Based upon a conversation with an OEM source, a conservative 5:1 ratio of disassembly hours to painting hours exists. Therefore, the total cost to disassemble or "breakdown" for hull strip and painting operations is conservatively estimated to be five times the number of hours as the actual surface prepping and painting stages. When totaled, the work-hours add up to approximately 96 hours per vehicle at a cost of $13,440. The total paint used is estimated to be 4.9 gallons of MIL-DTL-0053022 primer at cost of $56.00/gallon and five gallons of MIL-DTL-53039 topcoat at a cost of $50.52/gallon resulting in a total cost of paint of $527 per vehicle. The total cost for repainting an MRAP is calculated at $13,967.00.

The preparation steps and associated costs such as labor will all remain as stated above to implement any of the pretreatments. A modest additional cost per vehicle will be added as a result of the pretreatment step. Although, as mentioned earlier, <u>a flash rust inhibitor step exists in the current process and therefore this assumption is considered conservative</u>.

Taking into account complex shapes and geometries, a conservative estimated surface area for an MRAP vehicle is 600 square feet. For the Oxsilan 9810/2 pretreatment, the cost depends on the type of system used for application and how the product is purchased. It can be spray applied with the runoff collected and disposed (Spray-to-drain), or by conventional recirculating spray system. Oxsilan 9810/2 can be purchased either as a concentrate or as ready-to-use (RTU) premixed drums. The most cost effective approach is using a conventional recirculating spray system. In this case, the product cost is reduced to approximately $6.00 per vehicle when the Oxsilan is purchased as a concentrate and $12.00 per vehicle when the Oxsilan is purchased RTU. The most costly scenario is when Oxsilan 9810/2 is applied Spray-to-drain. In this example, the cost per vehicle increases dramatically. Using the concentrate, the cost is $250.00-$400.00 per vehicle, and $1600.00-$2300.00 per vehicle for RTU. The pretreatment discussed here would increase the total cost of repainting the vehicle ($13.967.00) from 0.5% (recycling spray system) to 16% (spray-to-drain) depending on the pretreatment application process used.

The current coating system used for MRAPs has shown obvious deficiencies and as such each MRAP will likely need to be completely repainted on an average of every three years if the current processes remain in place. If improved coating systems that include a pretreatment are fully utilized from this demonstration, it is expected that the repaint interval will increase by a factor of two over the current baseline. For the following chart, using the current coating system, the entire fleet of 15,500 will require repainting every three years. This schedule assumes that a

third of the fleet will be repainted every year to maintain a consistent processing cycle. By implementing the new pretreatment system, the repaint cycle will likely double, thereby reducing the annual recoating costs by 50%. This reduction means that beginning after year four, only 1/6th of the MRAP fleet will need to be repainted, at a cost of $14,692/vehicle.

Table 7-1: Return on investment calculation of demonstrated technology on MRAP

				Investment Required			1,500,000
				Return on Investment Ratio	132.43	Percent	13243%
				Net Present Value of Costs and Benefits/Savings	308,185,811	506,828,441	198,642,630
A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	72,162,833					67,443,384	67,443,384
2	72,162,833		72,162,833		63,027,018	63,027,018	
3	72,162,833		72,162,833		58,906,521	58,906,521	
4	72,162,833		72,162,833		55,053,025	55,053,025	
5	72,162,833		36,081,417		25,726,050	51,452,100	25,726,050
6	72,162,833		36,081,417		24,041,048	48,082,096	24,041,048
7	72,162,833		36,081,417		22,467,898	44,935,796	22,467,898
8	72,162,833		36,081,417		20,999,384	41,998,769	20,999,384
9	72,162,833		36,081,417		19,624,682	39,249,365	19,624,682
10	72,162,833		36,081,417		18,340,184	36,680,368	18,340,184

This table shows only the costs and savings associated with complete re-painting of each vehicle. Note that no savings or benefits are realized until year four. Based on the assumption that the initial painting of 15,500 vehicles with the enhanced (longer service life) coating requires repainting of only 1/6th of the fleet after year four, the 50% reduction in "new system Costs (column D) only occurs during year four. Additional benefits from using the enhanced (longer service life) coating system with pretreatment include reduced unit level corrosion maintenance efforts as well as benefits to other platforms. These additional benefits are not quantified here but would likely be substantial.

7.0 IMPLEMENTATION

The implementation of non-hexavalent chrome steel pretreatments will be expedited by the recent publication of the reconstructed Federal specification TT-C-490F. This specification has been the overarching document referenced in dozens of military coating specifications and tens of thousands of military drawings for the cleaning and pretreatment of (only) ferrous substrates prior to the application of organic finishes such as CARC. It has been the primary reference preferred by engineers to specify cleaning, pretreatment, and subsequent testing. It is widely used by all OEMS and Services for finishing steel. However, technical major gaps existed in this specification that motivated the significant changes. First, previous versions of TT-C-490 continued to specify the use of hexavalent chromium in surface finishing although hex chromium has been targeted for elimination for years. With many other specifications that continue to require hexavalent chrome usage, there was no official mechanism to validate, approve and implement alternative surface finishing operations except through contract waivers, drawing changes and engineering change notices, which can be an expensive and a cumbersome process. Also, no comprehensive specification existed governing the cleaning and pretreatment of DoD relevant metallic and multimetal substrates.

The U.S. Army Research Laboratory recognized the synergy that existed between the TT-C-490 reconstructions in the ESTCP funded project WP200906 to examine alternative steel pretreatments. Several of the candidates evaluated were found to at least achieve the performance requirements and in some cases exceed the performance of existing hexavalent chrome pretreatments. The reconstruction of TT-C-490 adopted much of the JTP and success criteria developed under WP200906 as a basis for the performance specification.
With this improved testing regimen, ARL can transition pretreatment materials that meet ARL's established performance criteria into use through the Qualified Product Database in a seamless structure that will eliminate the costly time consuming and expense of waivers and engineering change notices. This procedure will encourage innovation because of a well-defined path to approval for qualified products.

Details of TT-C-490 Revision F can be seen in the specification in Appendix C. The revisions enable many improvements to multiple alloy finishing operations within industry and the DoD. These improvements include:

1. Provides new commercially available technologies, such as those used by the automotive industry, a pathway for implementation and use on military systems and reduces bureaucracy.
2. ARL provides stewardship of TT-C-490F and monitors approval process.
3. Includes a plan for Objective Quality Evidence that will improve overall quality of new and existing technologies.
4. Governs pretreatments for aluminum and multi-metal applications, [TT-C-490 no longer limited to steel].
5. Establishes a qualified products database (QPD) that will include new Types and Classes.
6. Updates and provides better detail cleaning requirements.
7. Encourages innovation and promotes low-energy and green technologies.

The revised TT-C-490 includes new Types and Classes and ties them to specific cleaning Methods to accommodate steel, aluminum and multi-metal substrates as well as corrosion resistant metal-rich coatings.

The revised document is being adopted by entire DoD and beyond (i.e.: industry) for surface finishing of alloys – TACOM has adopted the language and principles of Objective Quality Evidence in the new TT-C-490F specification and has begun placing it in their Procurement Automated Data and Document System (PADDS clause) for pretreatments and CARC on all new contract requirements that requires all DoD and DoD contractors to follow the doctrine of the newly revised TT-C-490F specification.

The QPD has been populated by two of the products evaluated in WP200906: SurTec 650 and Oxsilan 9810/2. These two spray applied pretreatments have been approved for abrasive blasted steel substrates. Currently there are two more WP200906 candidates in the QPD approval pipeline: SurTec 580 and Zircobond 4200. The SurTec 580 is a non-hexavalent sealer for zinc phosphate and the Zircobond 4200 is another spray applied pretreatment for steel. Both have met or exceeded the success criteria and are in the application process for inclusion on the QPD.

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Appendix A: Joint Test Protocol, Validation of Pretreatments for Steel Armor

DRAFT

Joint Test Protocol

Validation of Pretreatments for Steel Armor

Draft

October 17, 2010

Distribution Statement "A" applies.
Approved for public release; distribution is unlimited.

Prepared and Submitted by the
U.S. Army Research Laboratory,
Corrosion Science and Engineering Team,
Aberdeen, Md.

Format and context of this report were developed using
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J-01-GV-002-P2
Validation of Corrosion Protection for
Ground Vehicle Frame Structures
Draft
July 20, 2007

JTP Approved & Authorized By: _____

Name, Organization, Date

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APPENDIX

APPENDIX: List of Stakeholders and List of Contributors A-1

ACRONYM LIST

A2LA	American Association for Laboratory Accreditation
ACDT	Accelerated Corrosion Durability Test
AISI	American Iron and Steel Institute
ANSI	American National Standards Institute
ARDEC	U.S. Army Armament Research, Development and Engineering Center
ARL	U.S. Army Research Laboratory
ASTM	American Society for Testing and Materials
ATC	U.S. Army Aberdeen Test Center
BP	Best Performance
CARC	Chemical Agent Resistant Coating
cfm	Cubic Feet per Minute
COTS	Commercial Off-the-Shelf
CPC	Corrosion Preventive Compound
CTC	Concurrent Technologies Corporation
DoD	Department of Defense
VPSA	Validation of Pretreatments for Armor Steel
HSLA	High-Strength Low-Alloy
IP	Improved Performance
JG-PP	Joint Group on Pollution Prevention
JTP	Joint Test Protocol
JTR	Joint Test Report
kPa	Kilopascal
lb	Pound
mg	Milligram
mm	Millimeter
MMC	Metal-Matrix Composite
MP	Minimum Performance
NLT	Not Less Than
NSS	Neutral Salt Spray
NVLAP	National Voluntary Laboratory Accreditation Program
PFL	Product Failure Laboratory
psi	Pounds per Square Inch
QPL	Qualified Products List
SAE	Society of Automotive Engineers
SS	Salt Spray
TACOM	U.S. Army Tank-automotive and Armaments Command
TDPMD	Technology Demonstration for Prevention of Material Degradation
U.S.	United States
VOC	Volatile Organic Compound

PREFACE

This Joint Test Protocol (JTP) was prepared by the Army Research Laboratory Corrosion Science and Engineering Team. The objective of this JTP is to select and implement the most appropriate approaches for the improvement of the control of material degradation on Army materiel and assets, thereby reducing life cycle operational costs and maximizing equipment sustainability for the warfighter.

Format and context of this report were developed using Joint Test Protocol J-01-GV-002-P2 Validation of Corrosion Protection for Ground Vehicle Frame Structures (Draft), July 20, 2007. The depth of technical content of this JTP was determined by technical associates, pertinent United States (U.S.) Army personnel, government contractors, and other government and commercial technical representatives (hereafter referred to as "stakeholders") who are participants in the Integrated Product Team (IPT) of the ESTCP funded project for Non-Chromate Zero-VOC Coatings for Army and Navy Ground Vehicles.

JTP REVISIONS HISTORY

This section will serve as a means to document revisions and discussions regarding this JTP only. It is intended to help the reader identify updated versions of the JTP, and to organize periodic updates of the JTP as new materials and techniques become available. If the latest entry on the JTP Revisions History is more than two (2) years old, the entry "No revisions have been made for the year 20xy" will be entered where appropriate.

Letter	Pages Changed	Pages Added	Description	Date	Approved by (Signature/Division)

1.0 INTRODUCTION

This JTP contains the critical requirements and tests necessary to evaluate pretreatment technologies for use on U.S. military steel armor. The JTP provides a standard set of tests and test conditions that the manufacturers, the U.S. military, and third-party testing organizations may use to fairly gauge how the technology compares to existing technologies. With the test results presented in a Joint Test Report (JTR), the manufacturer and military can make an informed decision with regard to subjecting the technology to qualification testing for inclusion on the Qualified Products List (QPL). This document is a protocol for testing and assessing the performance of any potential corrosion prevention pretreatment, or any repair process or maintenance process involving steel armor. The potential technologies for consideration will hereafter be referred to simply as "candidates." Candidate steel pretreatment processes shall not exceed 160°C in order to qualify for testing.

1.1 Scope

This JTP establishes the corrosion-resistance performance requirements that must be met for a candidate to be considered for use on military steel armor. Military steel armor is considered that which meets the specifications described in MIL-A-46100. Other properties of potential candidates will also be considered (see Feasibility Study discussion in the next section). However, evaluations of these properties are specific to the application, and will be considered acceptable based only upon equal or improved performance when compared to the corrosion protection system currently being used.

It must be emphasized that this JTP document is not a process, material, or product specification, nor is it intended to address ongoing quality issues. The testing outlined in this document confirms the technical capabilities of the candidate for the particular application with respect to corrosion resistance, and qualifies the candidate for consideration for military use by the relevant armed services' Corrosion Office invoking the JTP (e.g., the Army Corrosion Manager) or the relevant Program Manager (hereafter referred to as the "invoking authority"). ***It should also be emphasized that successful completion of the procedures outlined in this JTP does not obligate the U.S. Army or any other DoD organization to procure or use the candidate.***

1.2 Execution

This document is organized in such a manner to aid the user during the corrosion study planning stage, through the testing activity, and during the data reporting and interpretation phases. This section describes the use of this document by outlining the steps that will guide the user through the process of extracting and utilizing the corrosion data. Section 2.0 describes a logical flow to the process of evaluating the results of the corrosion tests and comparing the properties of the candidate with the established criteria necessary to qualify the candidate for potential military use. Section 2.0 also provides a test flow diagram and examples of situations in which the JTP could be used. Section 3.0 discusses application scenarios, the test method matrix, and methodology. Section 4.0

describes test requirements (acceptance criteria) and procedures. Section 5.0 discusses failure analysis. Finally, Section 6.0 provides a list of reference documents that were utilized in the preparation of this JTP.

The corrosion-resistance performance of candidates evaluated using this JTP will be determined through a series of tests. These tests have been derived from engineering, performance, and operational impact (supportability) standards defined by a consensus of government and industry participants. The tests in this document are based upon recognized commercial and military test standards that are currently in use by established test facilities. In instances where the JTP test method conflicts with the reference standard on which it is based, the JTP test method will take precedence. This JTP also provides guidelines for the screening of candidates (Screening Tests), in cases where initial viability must be assessed before conducting the Performance and Special Tests or for urgent short-run applications.

Prior to conducting the required tests, a candidate must undergo a preliminary Feasibility Study, in which the following considerations shall be addressed:

- The candidate must be evaluated using those tests that define the performance levels of Chemical Agent Resistant Coatings (CARCs), per MIL-DTL-53072, Chemical Agent Resistant Coating CARC) System Application Procedures And Quality Control Inspection, and Federal Specification TT-C-490, Chemical Conversion Coatings and Pretreatments for Metallic Substrates (Base for Organic Coatings). The candidate must demonstrate compatibility with the existing CARC system, with no adverse effects on the CARC properties. Relevant test methods and military standards are defined in MIL-C-53072. . Since CARC compatibility testing involves the use of chemical agents, the U.S. Army Research Laboratory (ARL) will conduct these tests on test specimens supplied by the vendor, at the vendor's expense.
- The candidate must conform to current military environmental regulations and concerns, such as atmospheric and groundwater impact, volatile organic compound (VOC) content, waste disposal, etc.
- Procurement of the candidate must be compatible with standard military business procedures. Considerations include, but are not limited to: distribution status (domestic/offshore), product cost analysis, and vendor capability, reputation, and reliability.

The Feasibility Study shall be conducted prior to the execution of the test program contained in this JTP. The business issues assessment shall be conducted again at the completion of the JTP testing if business issues have changed as a result of product and/or financial changes. The actual implementation of the Feasibility Study shall be conducted under the authority of the invoking authority, and is outside the scope of this JTP.

The tests outlined in this JTP are organized into three general areas, Screening, Performance, and Special Testing. Screening Testing involves those tests the vendor may

decide to perform if limited data exists to determine the candidate's ability to pass the Performance Tests, or tests that the invoking authority may require for urgent short-run applications. Performance Testing involves those tests required for evaluating any pretreatment candidate for use on steel armor. Special Testing includes those tests identified by some (but not all) stakeholders for evaluating any pretreatment candidate for use on steel armor in special applications, such as exposure to particularly unusual environments. The candidate must meet both Performance and applicable Special Testing requirements to be considered for special applications.

A JTR will document the testing conducted on each candidate in accordance with this JTP. The JTR will provide a record of test specifics, such as candidate test specimen and substrate preparation, application process, test equipment model and calibration, laboratory environmental conditions, and test results. If planned execution of the tests varies from that described in this JTP, test procedure modifications must be approved by the stakeholders and the invoking authority in advance and documented in the JTR. The JTR will be used as a reference for future corrosion-prevention endeavors by other DoD and commercial users to minimize duplication of effort.

1.3 Document Maintenance

Annual updates and general maintenance of this document will be the responsibility of a committee chaired by the Army Corrosion Office or designee. The document will be reviewed and updated on an annual basis with changes being noted on the "JTP Revisions History" page. If no changes have been made, the entry "no revision has been made for the year 20xy" will be entered where appropriate. This document is considered to be obsolete if the latest entry on the JTP Revisions History is more than two years old. In this case, contact the Army Corrosion Office or designee for the most recent revisions before conducting testing in accordance with this JTP.

2.0 JTP DOCUMENT GUIDE

This section of the JTP facilitates the use of this document by providing a logical implementation flow process as well as examples of JTP evaluations for several candidates. Use of this document for military consideration of a candidate utilizing the Performance and Special Testing sections, and the preliminary screening of untried candidates using the Screening Tests, is described and demonstrated.

Figure 1 illustrates the process flow for conducting Screening, Performance, and Special Tests, as well as the retesting of candidates that have failed one of the aforementioned tests. The evaluation process begins with the Feasibility Study. If the candidate conforms to current military environmental regulations, and procurement of the candidate is compatible with standard military business procedures, the testing required is determined via the Test Method Matrix (presented later in Table 1).

The Screening Tests have been established so that preliminary screening of newer, unproven candidates can be conducted. The decision of whether or not to utilize Screening Tests before conducting Performance and Special Tests lies solely with the invoking authority. Successful completion of the Screening Tests qualifies a candidate for continued testing under the Performance Tests or evaluates the performance for qualitative purposes only. Screening Tests can also be used in instances where a small production run is required, and/or where expedited use is required for a limited application. However, consideration of a candidate for generalized military use, as defined in this JTP, can be accomplished only by successful completion of the Performance Tests, and Special Tests for special applications.

Any candidate that is to be considered technically acceptable must meet at least the Minimum Performance (MP) criteria for each Performance or Special Test, as established in Section 4.0, Testing Requirements, Descriptions and Procedures.

A failure analysis can be performed on any test specimen that fails Screening, Performance, or Special Tests to determine the cause of failure (see Section 5.0). Failure in any test does not necessarily disqualify a candidate for use in all possible applications; however, use of a candidate that has failed Screening, Performance, or Special Tests is at the discretion of the invoking authority, and is outside the scope of this document. Following completion of testing and/or failure analysis, the JTR is forwarded to the vendor for transmittal to the invoking authority for review.

Note that, in Figure 1, there are potential "infinite loops" that might occur due to continual testing failures. To resolve this, the following procedure is to be followed. If failure is still occurring after the third cycle for any of the Screening Tests, the testing process is to end, the failures are to be documented in the JTR, and the JTR is to be forwarded to the vendor for transmittal to the invoking authority for review and response. This procedure is likewise applicable for the Performance and Special Tests.

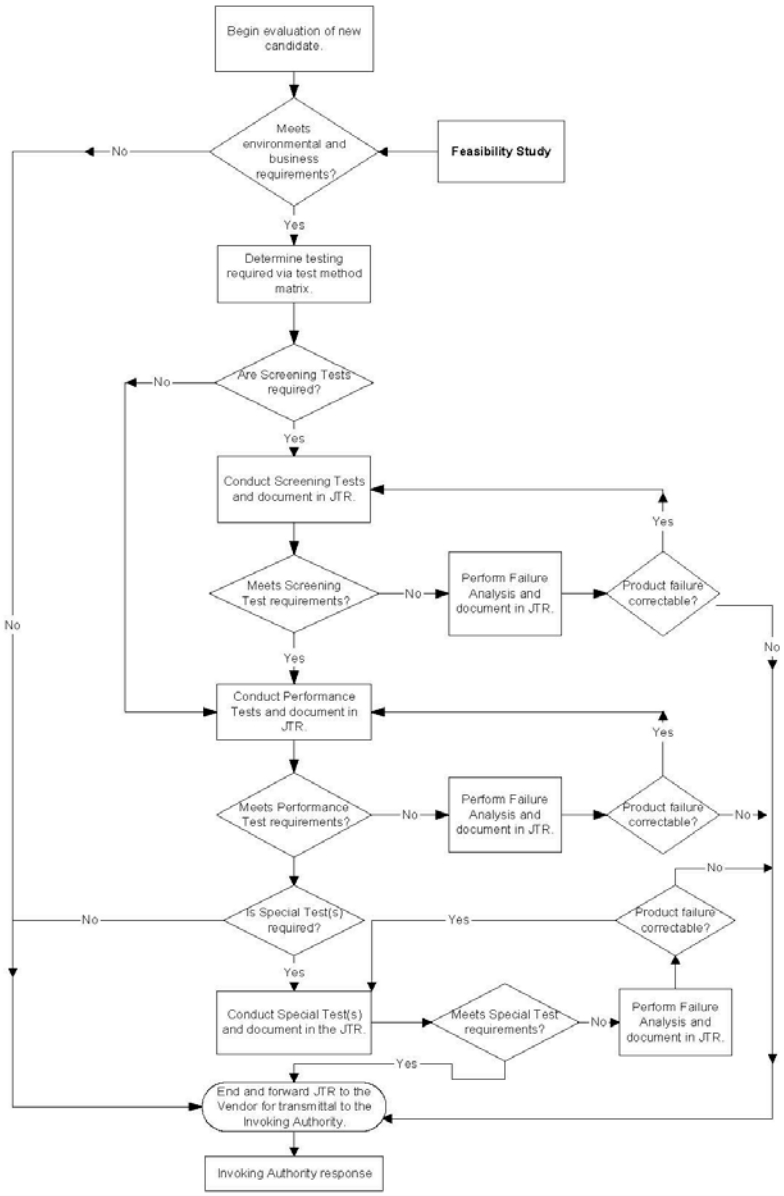

Figure 1. Test Flow Diagram

The following three examples are provided to demonstrate how this JTP can be used for Screening, Performance, and Special Testing situations.

Example # 1

SITUATION: A vendor has developed a new conversion coating system to be considered for use on only steel armor for a special urgent short-run application.

EVALUATION:

1. The VPSA JTP directs the users to the JTP Test Flow Diagram (Figure 1). The Feasibility Study is conducted, and initial assessments regarding CARC compatibility, environmental concerns, and overall business risk are determined.
2. The invoking authority determines that Screening Tests only will be necessary for this system, and that, if the outcome is positive, qualification will be via a waiver (which is beyond the scope of this document). The JTP Test Flow Diagram leads the users to the Test Method Matrix (Table 1) to determine the testing required for screening.
3. The relevant test lab personnel begin the screening evaluation of the conversion coating.
4. A JTR is written documenting the results of the Screening Tests.
5. Screening Test results demonstrate acceptable performance relative to the other approved coating systems.
6. The JTR is submitted to the vendor for transmittal to the invoking authority for review. The invoking authority, if satisfied, issues a waiver/deviation (which is outside the scope of this JTP) to authorize the new conversion coating for this limited special short-run application.

RESULT: The JTP provides guidelines regarding testing and performance levels for preliminary risk reduction for this urgent short-run requirement.

Example # 2

SITUATION: A vendor proposes a new pretreatment / conversion coating, an inhibitor spray, to be considered for use on steel armor.

EVALUATION:

1. The VPSA JTP directs the users to the JTP Test Flow Diagram. The Feasibility Study is conducted, and initial assessments are made regarding CARC compatibility, environmental concerns, and overall business risk.
2. The vendor decides that, since the candidate is new, the candidate will be subjected to Screening Tests prior to the initiation of the Performance Tests. The JTP Test Flow Diagram leads the users to the Test Methods Matrix to determine the testing required for effective screening.

3. The relevant test lab personnel begin the screening evaluation of the pretreatment spray.
4. A JTR is written documenting the results of the Screening Tests and is forwarded to the vendor.
5. Screening Test results indicate that the pretreatment shows promise, as the corrosion performance level improved significantly as compared to the current corrosion protection system.
6. The relevant test lab personnel conduct Performance Tests per the Test Method Matrix.
7. A JTR is written documenting the results of the Performance Tests and is forwarded to the vendor for transmittal to the invoking authority for review.

RESULT: The JTP establishes the requirements for consideration, as well as guidelines for preliminary testing (Screening Tests), and provides the methodology for documenting the relative performance of the candidate compared to current corrosion protection systems.

3.0 APPLICATION SCENARIOS

3.1 Guidelines

This section establishes the guidelines for testing a potential candidate for corrosion protection of steel armor, given various application scenarios.

A generic model of a candidate and the various layers of materials that may be applied to the substrate to establish a corrosion protection system are shown in Figure 2.

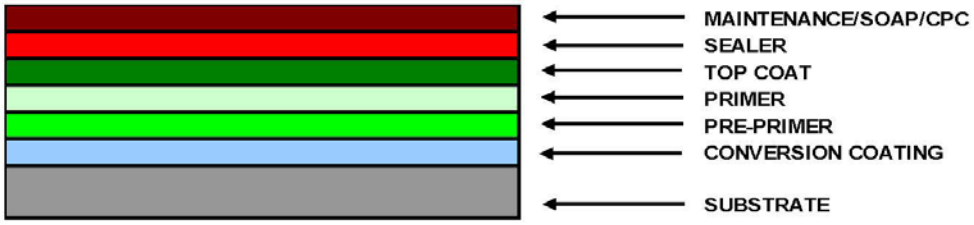

Figure 2. Generic Substrate and Corrosion Protection System Model (not to scale)

The above model represents a generic coating system with numerous layers of constituent materials that may be included as part of a candidate corrosion protection system. Using this approach, guidelines for Screening, Performance, and Special Test procedures can be derived, even if the candidate consists of only some of the constituent layers shown in Figure 2.

Table 1 lists the tests to be applied for Screening, Performance, and Special Tests, as well as the location of the test procedure within the JTP document.

Table 1. Test Method Matrix

SCREENING TESTS (conducted on coupons, about 1 month in duration)	JTP Section
Adhesion (Pull-off)	4.4.3
Corrosion Resistance (Neutral Salt Spray (Fog))	4.4.5
PERFORMANCE TESTS (conducted on actual or simulated parts, about 6 months in duration)	JTP Section
Adhesion (Dry)	4.4.1
Adhesion (Wet)	4.4.2
Adhesion (Pull-off)	4.4.3
Corrosion Resistance (Cyclic)	4.4.4
Corrosion Resistance (Neutral Salt Spray (Fog))	4.4.5
Chip Resistance	4.4.6
Stress-Corrosion Cracking	4.4.7
SPECIAL TESTS (conducted on actual or simulated parts, up to 5 years in duration)	JTP Section
Field Exposure, Static	4.4.8
Field Exposure, On-Vehicle	4.4.9

The guidelines for testing candidates under this JTP are as follows:

1. Select the test specimens or proposed steel armor, or manufactured parts that accurately simulate current production material, for testing of the candidate.
2. Obtain approval for test procedure modification if applicable.
3. Perform appropriate testing and obtain test results.
4. Submit JTR to the vendor for transmittal to the invoking authority for review.

3.2 Methodology

Screening Tests shall be conducted on test panels made from the same material or alloy as the actual steel armor. The actual processes to be used in the preparation of the test panels shall be outlined in the JTR.

Performance and Special Tests shall be conducted on sections of actual steel armor, or manufactured parts that accurately simulate current production material and manufacturing processes. Mechanical conditions such as bends, welds, fasteners,

crevices, etc., shall be incorporated when applicable. The actual processes used in the test specimen preparation shall be outlined in the JTR.

4.0 TESTING REQUIREMENTS, DESCRIPTIONS AND PROCEDURES

The stakeholders have established the requirements necessary to evaluate corrosion-resistant candidates for use on U.S. military steel armor. These requirements have been used to identify test methods, derive test procedures, and establish acceptance criteria.

Screening Test methods are identified along with acceptance criteria in Section 4.1. Performance Test methods are identified along with acceptance criteria in Section 4.2.

Special Test methods are identified along with acceptance criteria in Section 4.3. These are program-specific requirements identified by at least one of the stakeholders. Special Tests are performed on sections of actual armored vehicles or manufactured parts that accurately simulate current production material and manufacturing processes.

It is recommended that different examples of substrates utilizing the candidate, if applicable, be tested concurrently to obtain maximum benefit from the testing effort. Questions regarding the different substrate materials shall be directed to the invoking authority.

The candidate must pass the Performance and applicable Special Tests with at least Minimum Performance (MP) in order to be considered for military use. Acceptance criteria for Improved Performance (IP) and Best Performance (BP) are provided as well, so that improved corrosion resistance with respect to the current corrosion protection system can be quantified.

In instances where the JTP test method conflicts with the reference standard on which it is based, the JTP test method shall take precedence.

All testing shall be performed at the vendor's expense by a government or independent testing laboratory, which shall be agreed upon by the stakeholders. The independent testing laboratory must either be accredited by a recognized governing body (such as the American Association for Laboratory Accreditation (A2LA) or the National Voluntary Laboratory Accreditation Program (NVLAP)), or be an ISO 9001 certified company having its own testing laboratory. **Testimonials shall be used for informational purposes only, and are not to be used in lieu of tests required under this JTP.** Incorporation of previous studies performed on the candidate by an outside laboratory, at the request of the vendor, is at the discretion of the invoking authority.

All tests shall be conducted in a manner that will eliminate duplication and maximize the use of each test specimen. Where possible, more than one test shall be performed on each specimen. The number and types of tests that can be run on any one specimen will be dependant upon the degree of alteration imparted to the sample from previous tests. Failure in any test does not necessarily disqualify a candidate for use in all possible applications; however, acceptance of a candidate that has failed Screening, Performance, or Special Tests is at the discretion of the invoking authority. In this case, use of the

candidate will be justified by a special waiver, which is outside the scope of this document.

The tests described in this JTP may involve the use of hazardous materials, operations, and/or equipment. This JTP does not address all safety issues associated with their use. It is the responsibility of each user of this JTP to establish appropriate safety and health practices, and to determine the applicability of regulatory limitations, prior to the use of such materials, operations, and/or equipment.

The following conditions will apply to all Screening, Performance, and Special Testing, unless otherwise specified in an individual test description:

- It is preferred that all test panels be produced from the same material lot.
- It is suggested that at least three specimens be used for Screening Tests, and at least five specimens be used for Performance and Special Tests.
- Unless otherwise specified, all test specimens shall be cleaned prior to pretreatment to ensure surfaces are free of water breaks in accordance with the latest version of American Society for Testing and Materials (ASTM) G1, "Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens."
- Pretreatment of the test specimens will be dependant upon the candidate under scrutiny, and shall be specified in the JTR.

It is recommended that users of this JTP obtain copies of previous JTRs, if available, from the invoking authority for additional test details or minor modifications that were necessary in the execution of previous testing.

4.1 Screening Testing Requirements

Table 2 lists all Screening Testing requirements identified by stakeholders for evaluating candidates on steel armor.

Table 2. Screening Testing Requirements

JTP Section	Test	Acceptance Criteria	Test Method References
4.4.3	Adhesion (Pull-off)	Meets or exceeds adhesion strength of DoD-P-15328 on similarly prepared abrasive blasted surface of 1.5 mil profile or 1200 psi	ASTM-4541 Pull-off Adhesion
4.4.5	Corrosion Resistance (Neutral Salt Spray (Fog))	After 336 hrs of exposure: Steel substrate rating $\geq$ 7 scribed	ASTM B117 TT-C-490 ASTM D1654

Screening Tests are performed on test panels made from steel armor-representative substrate material. It is preferred that all test panels be produced from the same material lot, and it is desirable that the processing pedigree be well documented in the JTR. The candidate must pass the acceptance criteria of each Screening Test. Results of the Screening Tests are reported in the JTR and submitted to the vendor for transmittal to the invoking authority.

The Screening Tests (identified in Table 2) are further defined in Section 4.4, with test descriptions, scope, and methodology. Also included are any major or unique equipment and instrumentation requirements, reagents, procedures, and acceptance criteria. The procedure identifies the test specimen preparation, test procedure, and method for collecting and reporting test results.

4.2 Performance Testing Requirements

Table 3 lists all Performance Testing requirements identified by stakeholders for evaluating candidates on commonly used steel armor substrates. The tests (listed below) shall be conducted for non-traditional candidate substrates such as high-hardness (greater than Rockwell hardness Rc35), (HHA) steels and high-strength low-alloy (HSLA) steels.

A material/corrosion design review will be conducted by the invoking authority to determine if hydrogen embrittlement, corrosion fatigue, or stress-corrosion cracking could occur based on the material and potential exposure environment. However, shall be known that HHA has hardnesses well over Rc35 and is susceptible to environmentally assisted cracking (EAC) whenever residual stresses are present. The invoking authority will specify the appropriate mechanical stability testing required, and the vendor will contract with an independent, certified lab to perform the required tests.

The criteria for determining a risk candidate for hydrogen embrittlement are as follows:

1. Any ferrous-based alloy exhibiting hardness greater than Rc35 (e.g., high-strength steel) requires testing and heat treatment according to Federal Specification TT-C-490, "Cleaning Methods for Ferrous Surfaces and Pretreatments for Organic

Coatings," . Testing is recommended for materials that will be exposed to an electrochemical environment where hydrogen evolution can occur (e.g., electroplating, pickling).

The basic criteria for determining a risk candidate for stress-corrosion cracking are as follows:

1. Any material that will be exposed to a corrosive environment known to cause stress-corrosion cracking, such as sodium hydroxide for carbon steel or chloride ions for stainless steels, and tensile stress due to applied load or residual stresses such as those produced by welding (e.g., any material that will experience a stress greater than 50% of the yield stress) shall be tested.
2. Any material that is known to be subject to stress-corrosion cracking (determine susceptibility by conducting a literature search or consulting with a corrosion expert) shall be tested.

Table 3. Performance Testing Requirements

JTP Section	Test	Acceptance Criteria, Minimum Performance (MP)	Acceptance Criteria, Improved Performance (IP)	Acceptance Criteria, Best Performance (BP)	Test Method References
4.4.1	Adhesion (Dry)	Adhesion rating (steel) ≥ 4B; adhesion rating	N/A	Adhesion rating (steel) = 5B; adhesion rating	ASTM D3359
4.4.2	Adhesion (Wet)	Scribed area rating (steel) ≥ 3A after 24 hours at ambient;	Scribed area rating (steel) ≥ 3A after 96 hours at 120°F;	Scribed area rating (steel) ≥ 4A after 168 hours at 150°F;	ASTM D3359
4.4.3	Adhesion (Pull-off)	Minimum average 30 events rating of 1200 PSI	Minimum average 30 events rating of 1800 PSI	Minimum average 30 events rating of 2500 PSI	ASTM D 4541
4.4.4	Corrosion Resistance (Cyclic)	After 80 cycles: steel substrate rating ≥ 5 scribed and ≥ 6F unscribed	After 120 cycles: steel substrate rating ≥ 7 scribed and ≥ 6F unscribed	After 120 cycles: steel substrate rating ≥ 9 scribed and ≥ 8F unscribed;	GM 9540 TT-C-490 ASTM D1654
4.4.5	Corrosion Resistance (Neutral Salt Spray (Fog))	After 500 hours of exposure: steel substrate rating ≥ 7 scribed and ≥ 8F unscribed; aluminum substrate rating ≥ 7 scribed and = 10 unscribed	After 750 hours of exposure: steel substrate rating ≥ 7 scribed and ≥ 8F unscribed; aluminum substrate rating ≥ 9 scribed and = 10 unscribed	After 1000 hours of exposure: steel substrate rating ≥ 9 scribed and ≥ 8F unscribed; aluminum substrate rating = 10 scribed and unscribed	ASTM B117 TT-C-490 ASTM D1654

NLT = Not Less Than

Table 3. Performance Testing Requirements (Continued)

JTP Section	Test	Acceptance Criteria, Minimum Performance (MP)	Acceptance Criteria, Improved Performance (IP)	Acceptance Criteria, Best Performance (BP)	Test Method References
4.4.6	Chip Resistance	After one cycle, chip rating NLT 6B for steel, 7C for aluminum	After one cycle, chip rating NLT 8C for steel, 8B for aluminum	After one cycle, chip rating NLT 9C for steel, 9B for aluminum	SAE J400
4.4.7	RSL Stress-Corrosion Cracking	There shall be no detrimental effect to K1c of substrate. High Hard K1c @ 48-51Rc shall maintain K1eac ≥ 19 (ksi√in)			ASTM E 399-97 ASTM G30 ASTM G38 ASTM G39 ASTM G47

NLT = not less than

Performance Tests are performed on sections of actual steel armor or manufactured parts that accurately simulate current production material and manufacturing processes. Results of the Performance Tests are reported in the JTR and submitted to the vendor for transmittal to the invoking authority.

The Performance Tests (identified in Table 3) are further defined in Section 4.4, with test descriptions, scope, and methodology. Also included are any major or unique equipment and instrumentation requirements, reagents, procedures, and acceptance criteria. The procedure identifies the test specimen preparation, test procedure, and method for collecting and reporting test results.

4.3 Special Testing Requirements

Table 4 lists Special Testing requirements identified and required by some (but not all) stakeholders for evaluating candidates.

Table 4. Special Testing Requirements

JTP Section	Test	Acceptance Criteria, Minimum Performance (MP)	Acceptance Criteria, Improved Performance (IP)	Acceptance Criteria, Best Performance (BP)	Test Method References	Branch/ Stakeholders/ Service Requiring Test
4.4.8	Field Exposure, Static	Three years of exposure: specimen has a minimum of 25% less creepage from scribe than current corrosion protection system	Four years of exposure: specimen has a minimum of 50% less creepage from scribe than current corrosion protection system	Five years of exposure: specimen has a minimum of 75% less creepage from scribe than current corrosion protection system	Approved test site standard practice ASTM G50 ASTM G7 ASTM D1654	As required by the invoking authority
4.4.9	Field Exposure, On-Vehicle	Three years of exposure: steel substrate rating ≥ 5 scribed and ≥ 5M unscribed; aluminum substrate rating = 10 scribed and unscribed	Four years of exposure: steel substrate rating ≥ 5 scribed and ≥ 5M unscribed; aluminum substrate rating = 10 scribed and unscribed	Five years of exposure: steel substrate rating ≥ 5 scribed and ≥ 5M unscribed; aluminum substrate rating = 10 scribed and unscribed	ASTM D1654 TT-C-490	As required by the invoking authority

NLT = not less than

Unless otherwise noted, Special Testing shall be performed on sections of actual steel armor or manufactured parts that accurately simulate current production material and manufacturing processes. Results of the Special Tests are reported in the JTR and submitted to the vendor for transmittal to the invoking authority.

The Special Tests (identified in Table 4) are further defined in Section 4.4, with test descriptions, scope, and methodology. Also included are any major or unique equipment and instrumentation requirements, reagents, procedures, and acceptance criteria. The procedure identifies the test specimen preparation, test procedure, and method for collecting and reporting test results.

4.4 Test Descriptions

4.4.1 Adhesion (Dry) (ASTM D3359)

4.4.1.1 Scope

This test method assesses the adhesion of coatings to substrates by applying and removing pressure-sensitive tape over cuts made in the coating.

4.4.1.2 Equipment

Cutting Tool. A very sharp razor blade, scalpel, knife, or other cutting device having a cutting edge (tip) angle between 15 and 30 degrees.
Cutting Guide. Steel or other hard metal straightedge to ensure straight cuts.
Rule. A steel rule graduated in 0.5-millimeter (mm) (0.02") increments for measuring individual cuts.
Tape 1"-wide 3M 250 Flatback Masking Tape, 3M Corporation or LA-26 Testing Tape, Intertape Polymer Corporation. Other tapes may be used provided they demonstrate a minimum tensile pull of 80 oz/inch on the coating being tested in accordance with ASTM D 3330 and have a minimum shelf life of 12 months.
Pencil eraser or plastic spoonIllumination. A light source to determine whether the cuts have been made through the coating into the substrate.
Dry Film Thickness Gage. A device to measure the thickness of the applied coating.

4.4.1.3 Reagents

None.

4.4.1.4 Procedure

Test Specimens. Prepare at least three test specimens for Screening Testing and at least five specimens for Performance Testing. For Screening Testing, use 102 x 152 mm) (4" x 6" test panels, composed of the material that is utilized in the end application. For Performance Testing, sections of actual or simulated armor steel parts shall be used (see Section 3.2).
Preparation. Using test specimens incorporating the candidate, measure the dry film thickness in at least five areas. Make cuts in the coating system per the latest version of ASTM D3359, "Standard Test Methods for Measuring Adhesion by Tape Test – Cross-Cut Tape Test." Remove two laps of tape and discard. Remove an additional length of tape and cut a piece approximately 76 mm (3") long. Place the center of the tape over the grid and smooth into place removing all bubbles using a pencil eraser or the convex side of a plastic spoon.
Test Procedure. Within 90 $\pm$ 30 seconds of tape application, remove the tape by holding the free end and rapidly pulling (not jerking) back upon itself at as close to an angle of 180 degrees as possible.
Test Results. Inspect the grid area for removal of coating from the substrate or from a previous coating. Rate the adhesion in accordance with the latest version of ASTM D3359, Test Method B. If ratings differ by more than one rating unit, the results are considered suspect and three additional test specimens for Screening Testing and five additional test specimens for Performance Testing shall be prepared and the tests repeated. If applicable, use these latter ratings in the report.

Report. Report all information per the latest version of ASTM D3359 Test Method B. In addition, report the average of the five dry film thickness measurements (as measured by thickness gauge).

4.4.1.5 Acceptance Criteria

Substrate	Acceptance Criteria, Minimum Performance (MP)	Acceptance Criteria, Improved Performance (IP)	Acceptance Criteria, Best Performance (BP)
Steel	Adhesion rating $\geq$ 4B	N/A	Adhesion rating = 5B

4.4.2 Adhesion (Wet) (ASTM D3359)

4.4.2.1 Scope

This test method describes the procedure and conditions for assessing the wet adhesion of coatings to metallic substrates by applying and removing pressure-sensitive tape over cuts made in the coating.

4.4.2.2 Equipment

Tank and Tank Cover. A tank made from corrosion-resistant materials and large enough to hold the required number of test specimens. The tank cover is required to help maintain water temperature and prevent evaporation.

Heaters. Heaters capable of maintaining the required water temperature (see Section 4.4.2.4, Procedure).
Circulation System. A pump or stirrer required for circulating the water in the water tank, capable of low to moderate agitation speeds.
Test Specimen Supports. Supports constructed of nonconductive and corrosion-resistant materials to hold the coated test specimens 30 mm (1.2") apart and at least 30 mm (1.2") from the bottom and sidewalls of the tank.
Cutting Tool. A very sharp razor blade, scalpel, knife, or other cutting device having a cutting edge (tip) angle between 15 and 30 degrees.
Cutting Guide. Steel or other hard metal straightedge to ensure straight cuts.
Rule. A steel rule graduated in 0.5-mm (0.02") increments for measuring individual cuts.
Tape1"-wide 3M 250 Flatback Masking Tape, 3M Corporation or LA-26 Testing Tape, Intertape Polymer Corporation. Other tapes may be used provided they demonstrate a minimum tensile pull of 80 oz/inch on the coating being tested in accordance with ASTM D 3330 and have a minimum shelf life of 12 months.
Roller. A 4.5-lb rubber-covered roller.
Illumination. A light source to determine whether the cuts have been made through the coating to the substrate.
Dry Film Thickness Gage. A device to measure the thickness of the applied coating.

4.4.2.3 Reagents

Distilled Water. Conforming to Type IV water as described in the latest version of ASTM D1193.

4.4.2.4 Procedure

Test Specimens. At least three test specimens shall be used for Screening Testing and at least five specimens for Performance Testing. For Screening Testing, use 102 x 152 mm (4" x 6") test panels, composed of the material that is utilized in the end application. For Performance Testing, use sections of actual or simulated steel armor (see Section 3.2).
Preparation. Using test specimens incorporating the candidate, measure the dry film thickness in at least five areas.
Test Procedure. For the Screening and Minimum Performance Tests, immerse the test specimens in ambient (room temperature) distilled water for 24 hours. For Improved Performance, immerse the test specimens in distilled water maintained at 49 ± 2°C (120 ± 4°F) for 96 hours. For Best Performance, immerse the test specimens in distilled water maintained at 66 ± 2°C (150 ± 4°F) for 168 hours. Remove the test specimens from the water and wipe dry with a soft cloth. Within 90 ± 30 seconds after removal from the water, make cuts in the coating system with two parallel lines, 19 mm (0.75") apart, and place an "X" scribe within the parallel lines. Make the "X" lines about 38 mm (1.5") long and intersecting at 30–45 degrees in the center of the parallel lines. Remove two laps of tape and discard. Remove an additional length of tape and cut a piece approximately 75 mm (3") long. Place the center of the 25 mm (1") wide tape over the center of the "X" and smooth into place by passing the roller over the area once. Remove the tape by holding the free end and rapidly pulling (not jerking) back upon itself at as close to an angle of 180 degrees as possible.
Test Results. Rate the adhesion in accordance with the latest version of ASTM D3359, Method A "Measuring Adhesion by Tape Test – X-Cut Tape Test."
Report. Report all information per the latest version of ASTM D3359, Method A. In addition, report the average of the five dry film thickness measurements.

4.4.2.5 Acceptance Criteria

Parameter	Acceptance Criteria, Minimum Performance (MP)	Acceptance Criteria, Improved Performance (IP)	Acceptance Criteria, Best Performance (BP)
Scribed Area Rating	≥ 3A	≥ 3A	≥ 4A
Immersion Period	24 hours	96 hours	168 hours
Water Temperature	ambient	49°C (120°F)	66°C (150°F)

4.4.3 Adhesion (Pull off) (ASTM D-4541)

4.4.3.1 Scope

This test method covers a procedure for evaluating the pull-off strength (commonly referred to as adhesion) of a coating by determining either the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached, or whether the surface remains intact at a prescribed force (pass/fail). Failure will occur along the weakest plane within the system comprised of the test fixture, adhesive, coating system, and substrate, and will be exposed by the fracture surface. This test method maximizes tensile stress as compared to shear stress applied by other methods, such as scratch or knife adhesion, and results may not be comparable. Further, pull-off strength measurements depend upon both material and instrumental parameters. Results obtained using different devices or results for the same coatings on substrates having different stiffness may not be comparable.

4.4.3.2 Equipment

Adhesion Tester. Commercially available or comparable apparatus as described in Annex A1-Annex A4 of ASTM D 4541.
Loading Fixtures. Devise having a flat surface on one end that can be adhered to the coating and a means of attachment to the tester on the other end.
Detaching Assembly. (adhesion tester) A central grip for engaging the fixture.
Base. Part of the detaching assembly, or an annular bearing ring if needed for uniformly pressing against the coating surface around the fixture either directly , or by way of an intermediate bearing ring. A means of aligning the base is needed so that so that the resultant force is normal to the surface and a means of moving the grip away from the base in as smooth and continuous manner as possible so that a torsion-free, co-axial (opposing pull of the grip and push of the base along the same axis) force results between them.
Timer. Means of limiting the rate of stress to less than 150 psi/s (1PPa/s) so that the maximum stress is obtained in less than about 100s. A timer is the minimum equipment when used by the operator along with the force indicator.

4.4.3.4 Procedure

Test Specimens. At least 10 test pulls shall be used for the Screening Testing and at least 30 test pulls shall be used for the Performance Testing.
Preparation. There are a few physical restrictions imposed by the general methods and apparatus. The following requirements apply:
The selected test area must be a flat surface large enough to support the test fixture.
The selected area must have enough perpendicular and radial clearance and be rigid enough to support the counter force.
Test Procedure. Clean the loading fixture and the coating surface to be bonded. Use care to select only those solvents which will not attack the coating and/or leave residues on the fixture. Prepare the adhesive in accordance with the adhesive manufacturer's recommendations. Apply the adhesive to the fixture or the surface to be bonded using a procedure recommended by the adhesive manufacturer being certain the entire bonding surface is covered. Based on the manufacturer's recommendations, allow enough time

for the adhesive to cure. Carefully connect the central grip of the detaching assembly to the loading fixture without bumping, bending, or otherwise prestressing the sample and connect the detaching assembly to its control mechanism, if necessary. After setting the force indicator to zero, increase the load to the fixture in as smooth and continuous manner as possible, at a rate of less than 150 psi/s (1 MPa/s) so that failure occurs or the maximum stress is reached in about 100 s or less.
Test Results. Rate the average results of each set of events.

4.4.3.5 Acceptance Criteria (See Table 3)

Substrate	Screening Test	Acceptance Criteria, Minimum Performance (MP)	Acceptance Criteria, Improved Performance (IP)	Acceptance Criteria, Best Performance (BP)
Steel	Minimum average 10 events rating of 1200 PSI	Minimum average 30 events rating of 1200 PSI	Minimum average 30 events rating of 1800 PSI	Minimum average 30 events rating of 2500 PSI

4.4.4 Corrosion Resistance (Cyclic) (GM 9540)

4.4.4.1 Scope

This test method describes a field-correlated, laboratory corrosion test method for determining cosmetic corrosion performance that provides a combination of cyclic conditions (salt solution immersion, temperature, and humidity) to accelerate the corrosion process.

4.4.4.2 Equipment

Test Cabinet. Test cabinet with the ability to obtain and maintain the required environmental conditions as specified in GM9540P.
Scribe Tool. An ANSI B 94.50, style E scriber.
Imaging System. A means of visually recording corrosion effects on all test specimens, such as a camera or scanner/software system.
Air Source. A source of clean, dry compressed air capable of delivering at least 10 cfm at 80 psi.
Scale. A ruler with 1-mm (0.04") divisions.
Balance. A digital electronic balance capable of weighing up to 10,000 mg with an accuracy of ± 1%.
Straightedge. Any straightedge of sufficient length to guide the scribing tool in a straight line.
pH Meter. A meter to measure the pH of the salt solution prior to the start of the test and on a weekly basis thereafter.
Putty Knife. Blunt-edged, 38 mm (1.5") wide.

4.4.4.3 Reagents

Distilled Water. Conforming to Type IV water as described in the latest version of ASTM D1193.
Cleaning Solution. Methanol.
Sodium Chloride. Substantially free of nickel and copper and containing not more than 0.1% sodium iodide and not more than 0.3% total impurities by weight.
Calcium Chloride.
Sodium Bicarbonate.

4.4.4.4 Procedure

Test Specimens. Actual or simulated steel armor shall be used for test specimens (see Section 3.2). The number of test specimens depends on the number of cycles selected for the test exposure duration. Use reference coupons consisting of uncoated 25 x 51 x 3 mm (1" x 2" x 1/8") pieces of any alloy American Iron and Steel Institute (AISI) 1006 through 1010 steel to monitor the average general bare steel corrosion produced by the test environment. The coupon weight in milligrams shall be recorded and retained for future reference. The number of coupons also depends on the number of cycles selected for the test exposure duration. Each test specimen and reference coupon shall be permanently identified by stamping numbers onto the surface.
Preparation. Using test specimens incorporating the candidate, scribe an X scribe through the coating, making sure that the scribed line is all the way through the coating to the substrate. Place the scribed test specimens and reference coupons in the chamber, leaning at an angle of at most 15 degrees from the vertical with the scribed surface facing upwards. Prepare the salt solution per GM9540P and measure the pH prior to the start of the test and on a weekly basis thereafter. Do not attempt to adjust the pH. Clean the reference coupons (bare steel bars) thoroughly with the cleaning solution prior to placing them in the exposure chamber.
Test Procedure. For the MP level, use a test duration of 80 cycles; for the IP and BP levels, use a test duration of 120 cycles. After initially weighing each reference coupon and test specimen, install both the reference coupons and test specimens in the exposure chamber. After every 20 cycles, remove two coupons and two test specimens. Weigh each reference coupon (after removal of the rust layers) and determine the average weight loss for that specific number of cycles. For the test specimens, record the scribe creepback values with respect to average, using ASTM-D1654 and TT-C-490. For the interim creepback measurements, conduct them in a rinsed-only condition. At the final number of cycles, two sets of creepback values will be recorded – one set in a rinsed-only condition and one set after the scrape-and-tape process (see also SAE J2334).
Test Results. At the conclusion of the exposure period (or interim period), remove the test specimens and rinse. Scrape the specimens side-to-side with the putty knife at a 30-degree contact angle. Evaluate the creepage of the test specimens per the latest version of ASTM D1654 and TT-C-490 for scribed and unscribed areas. Rate the corrosion or loss of coating extending from the scribe mark (using the worst case for the rinsed or scraped methods) and evaluate the unscribed areas for corrosion spots, blisters, and any other

types of failure that may occur. Photographically document each of the test specimens and the reference coupons using the imaging system. Clean the reference coupons using a mild sand (or glass bead) blast to remove all corrosion by-products. Once they are clean, wipe the coupons with methanol and weigh to determine weight loss. Corrosion losses may also be expressed in terms of average corrosion rates from the weight loss, coupon area, test duration, and metal density by use of the calculation described in ASTM G1.

Report. Report all information required in TT-C-490, and ASTM D1654, including the photographs from the imaging system, and weight loss and/or corrosion rate of the reference coupons.

4.4.4.5 Acceptance Criteria

Parameter	Acceptance Criteria, Minimum Performance (MP)	Acceptance Criteria, Improved Performance (IP)	Acceptance Criteria, Best Performance (BP)
Scribed Area Rating	≥ 5	≥ 7	≥ 9
Unscribed Area Rating	$\geq$ 6F	$\geq$ 6F	$\geq$ 8F

4.4.5 Corrosion Resistance (Neutral Salt Spray (Fog)) (ASTM B117)

4.4.5.1 Scope

This test method describes the procedure and conditions required to create and maintain the neutral salt spray (NSS) (fog) test environment and the evaluation of specimens incorporating the candidate with respect to corrosion, blistering associated with corrosion, loss of adhesion at a scribe mark, or other corrosive attack.

4.4.5.2 Equipment

NSS (Fog) Chamber. This equipment shall consist of a heated fog chamber, a salt solution reservoir, a supply of conditioned (oil- and contaminant-free) compressed air, atomizing nozzles, and specimen supports.

Imaging System. A means of visually recording corrosion effects on all tested specimens, such as a digital camera or scanner/software system.

Scribe Tool. An American National Standards Institute (ANSI) B 94.50, style E scriber.

Straightedge. Any straightedge of sufficient length to guide the scribing tool in a straight line across the specimen surface.

Air Source. A source of clean, dry compressed air capable of delivering at least 10 cubic feet per minute (cfm) at 80 pounds per square inch (psi).

Air Gun and Guard. An air dusting gun and nozzle combination to meet the specification in ASTM D1654. A guard to protect the operator, such as a sandblasting cabinet.

Scale. A ruler with 1-mm (0.04") divisions.

Putty Knife. Blunt-edged, 38 mm (1.5") wide.

4.4.5.3 Reagents

Distilled Water. Conforming to Type IV water as described in the latest version of ASTM D1193.
Sodium Chloride. Substantially free of nickel and copper and containing not more than 0.1% sodium iodide and not more than 0.3% total impurities by weight.

4.4.5.4 Procedure

Test Specimens. At least three specimens shall be used for Screening Testing, and at least five specimens shall be used for Performance Testing. Screening Testing shall be conducted with 102 x 152 mm (4" x 6") test panels, composed of the material that is utilized in the end application. Actual or simulated frame structures shall be used for Performance Testing (see Section 3.2). Each test specimen shall contain a clear identification mark.
Preparation. Using test specimens incorporating the candidate, scribe a single diagonal line through the coating making sure that the scribed line is all the way through to the substrate. Place the scribed test specimens in the chambers, leaning at an angle between 15 and 30 degrees from the vertical with the scribed surface facing upwards. Prepare the salt solution as specified in ASTM B117 such that when atomized at 35°C (95°F), the collected solution is in the pH range of 6.5–7.2.
Test Procedure. Conduct the NSS (fog) test in accordance with the latest version of ASTM B117, "Standard Practice for Operating Salt Spray (Fog) Apparatus." The NSS (fog) chamber shall be operated continuously for the specified number of hours, as shown in Section 4.4.3.5, Acceptance Criteria.
Test Results. At the conclusion of the exposure period, remove the test specimens and clean them by gently flushing with running tap water and drying them with a stream of clean, dry compressed air. Allow the test specimens to recover for 24 hours. Scrape the test specimens side-to-side with the putty knife at 30-degree contact angle. Evaluate the corrosion resistance and creepage of the test specimens in accordance with the latest version of ASTM D1654, "Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments." and TT-C-490 "Chemical Conversion Coatings and Pretreatments for Metallic Substrates (Base for Organic Coatings). Rate the corrosion or loss of coating extending back from the scribe mark and evaluate the unscribed areas for corrosion spots, blisters, and any other types of failure that may occur. Use the rating system in ASTM D1654 and TT-C-490 for scribed and unscribed areas. Photographically document the surface condition of each of the test specimens using the imaging system.
Report. Report all information required in ASTM B117, D714, and D1654, and include the images from the imaging system.

4.4.5.5 Acceptance Criteria

Parameter	Screening Test	Acceptance Criteria, Minimum Performance (MP)	Acceptance Criteria, Improved Performance (IP)	Acceptance Criteria, Best Performance (BP)
Steel Substrate				
Scribed Area Rating	≥ 7	≥ 7	≥ 7	≥ 9
Unscribed Area Rating	≥ 8F	≥ 8F	≥ 8F	≥ 8F
Exposure Period	336 hours	500 hours	750 hours	1000 hours

4.4.6 Chip Resistance (SAE J400)

4.4.6.1 Scope

The Chip Resistance test is designed to reproduce the effect of gravel or other media striking exposed painted and/or coated surfaces of a vehicle and has been correlated to actual field results. The purpose of this test is to evaluate the chip resistance of flat test specimens incorporating the candidate.

4.4.6.2 Equipment

Gravelometer. As specified in SAE J400 with the test panel at a 45-degree angle.
Test Cabinet. Temperature conditioning (usually run at ambient or lower temperature) with the ability to obtain and maintain the required environmental conditions as specified in SAE J400.
Transparent Grid. Approximately 3.2 x 127 x 127 mm (1/8" x 5" x 5") on which a 101.6 x 101.6 mm (4" x 4") grid of 25.4 mm (1") squares has been etched or scribed.
Paint Removal Tape. 100 mm (3.94") wide or 50 mm (1.97") wide, 3M product # 898 filament strapping tape or equivalent. *NOTE*: Note that the tape has a one-year shelf life. Utilizing the tape after this time may yield inaccurate results.
Gravel. Water-worn road gravel, not crushed limestone or rock. The gravel will pass through 15.86 mm (5/8") space screen when graded, but be retained on 9.53 mm (3/8") space screen. Gravel must be changed in accordance with SAE J400 Section 4.2.

4.4.6.3 Reagents

None.

4.4.6.4 Procedure

Test Specimen. Screening and Performance test specimens shall be panels, composed of the material that is utilized in the end application. The chipped area to be evaluated on the tested panel shall be flat and 101.6 x 101.6 mm (4" x 4") square and must be located about the center of the chipped pattern. SAE recommends that three replicates of each test panel be exposed in the Gravelometer. The composition, surface preparation, and size of panels; the type and thickness of the coating and the number and method of

application; and the aging conditions for the coatings shall be agreed upon between the vendor and invoking authority.

Test Setup/Preparation. Condition the test panels incorporating the candidate at the temperature specified in SAE J400 for a minimum of 15 minutes prior to testing. Fill a 0.473-liter (1-pt) container to the top with grated/screened gravel. Gravel must be changed every 3 runs. Adjust air pressure on the Gravelometer to 483 kilopascals (kPa) (70 psi) +/- 21 kPa (0.30 psi) with the air valve open. Set feed rate so that the hopper empties in 7–10 seconds per pint (s/pt). Other air pressures can be used as agreed upon by the vendor and invoking authority.

Test Procedure for Modular Gravelometer with Electronic Feed Mechanism. Insert the test panel into the specimen holder assembly. Clamp panel and close the specimen holder. Pour gravel from the one-pint container into hopper, then set the test timer.

a. Time Test

Set the test timer to the desired test time (typically < 10 s).

Turn the main power switch to ON.

Flip the control switch to TIME START.

b. Manual Test

See SAE J400 Section 4.2.3.2.

Chipping Rating System. The basic structure of the chipping rating system consists of one or more number-letter combinations in which rating values/numbers 10–0 indicate the number of chips of each size with rating letters A–D designating the sizes of the corresponding chips. Tables 5 and 6 provide guidelines for Rating Criteria as stated in SAE J400. A point of failure notation can also be used if desired (see Table 7).

Table 5. Rating for Number of Chips Within 4" x 4" Grid Lines

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

Table 6. Rating for Size of Chips

Rating Letter	Size of Chips
A	< 1 mm (approximately 0.03")
B	1–3 mm (approximately 0.03–0.12")
C	3–6 mm (approximately 0.12–0.25")
D	> 6 mm (> approximately 0.25")

Table 7. Point of Failure

Notation	Level of Failure	Failure Type

(S/P)	Substrate to Primer	Adhesional
(S/T)	Substrate to Top Coat	Adhesional
(P)	Primer	Cohesional
(P/T)	Primer to Top Coat	Adhesional
(T)	Top Coat	Cohesional

Method 1 – Exact Counting Procedure. This very precise method shall be used where definitive accuracy is required or as the referee method in case differences arise between laboratories.

a) Use the transparent overlay onto which has been etched a 101.6 x 101.6 mm (4" x 4") grid of 25.4 mm (1") squares as a location reference to aid the counting/rating process.

b) Examine all chips that are within each 25.4 mm (1") square, and estimate the size of each chip as encountered; examine all 16 squares and record the summed results.

c) Convert the actual number of chips counted for each size into the number-letter combinations utilizing Tables 5 and 6. Then arrange the number-letter ratings in ascending order (by number then letter). Summarize the number-letter ratings to give a condensed single number rating based on the total number of chips of all sizes followed by all applicable letter ratings to indicate the relative number of chips of each size.

Method 2 – Visual Comparison Procedure. This faster method shall be used for many routine laboratory evaluations where accuracy is not required.

a) Visually compare the area to be rated with the standards (SAE J400, Figure 3).

b) As with Method 1, list the ratings in ascending order. Summarize the number-letter ratings to give a condensed single number rating based on the total number of chips of all sizes followed by all applicable letter ratings to indicate the relative number of chips of each size.

Test Results. Visually evaluate the resistance of the coating surface to chipping by gravel impact using the transparent grid and the rating scheme (Tables 5, 6 and 7, and Method 1 and Method 2).

Reports. Report the summarized number-letter rating and all applicable test conditions. In addition, report the substrate material type and thickness; any preliminary surface treatment of test panels; the type of surface coatings; baking/aging or pertinent processing schedules; and the film thickness of the coating system being evaluated.

4.4.6.5 Acceptance Criteria

Substrate	Acceptance Criteria, Minimum Performance (MP)	Acceptance Criteria, Improved Performance (IP)	Acceptance Criteria, Best Performance (BP)
Steel	After one cycle, chip rating not less than 6B	After one cycle, chip rating not less than 8C	After one cycle, chip rating not less than 9C

4.4.7 Rising Step Load (Stress Corrosion Cracking)

4.4.7.1 Scope

Hydrogen embrittlement testing shall be performed on any candidate that is considered a risk candidate. Resistance to environmentally assisted cracking shall be assessed using the rising step load method for determination of K_{IEAC}. For this procedure, CV2 Charpy specimens of MIL-A-46100D shall be machined in longitudinal-transverse (L-T) and transverse longitudinal (T-L) orientations in accordance with ASTM E 399-97. Unlike the armor test panels, the charpy specimens shall not be abrasive blasted prior to pretreatment.

4.4.7.2 Equipment

The equipment shall be determined by the applicable test method.

4.4.7.3 Reagents

The reagents shall be as described in the applicable test method.

4.4.7.4Procedure

Specimen fatigue precracking shall be carried out using three stages, each consisting of decreasing loading levels. In the first precracking stage, the load was maintained to keep stress intensity values below 80% of the estimated experimental critical stress intensity and the stress ratio ($\sigma_{max}/\sigma_{min}$) was kept between –1 and+0.1. In the intermediate stage, the cycling load shall be reduced to maintain the stress intensity value as crack growth occurred and the intact cross section was reduced. For the final stage of precracking, the load shall be further reduced so the final value of K_{max} will unlikely exceed 60% of the estimated value for K_I during experimentation. Additionally, the final value for K_{max}/E should not exceed 0.0032 $m^{1/2}$, where E is Young's modulus. Precrack length, represented by the dimensionless expression a/W (crack length over specimen width), shall be maintained near 0.5.

Specimens shall be fastened into a double cantilever array test fixture under aqueous conditions with 3.5% NaCl solution at open circuit potential conditions. Specimens shall be loaded by incremental steps in accordance with ASTM F 1624-95 (*26*) using an appropriate load frame apparatus. The specimen load values versus time shall be recorded. The calculation for the onset of environmentally assisted cracking, or KIEAC, is derived as follows for cantilever bending from the four-point bending expression.

$$K_{IEAC} = \left(\frac{6M_{IEAC}\sqrt{\pi a}}{BW^2}\right) \times f(a/W)$$

4.4.8 Field Exposure, Static (ASTM G50)

4.4.8.1 Scope

This test method describes a basic procedure for conducting outdoor testing of specimens incorporating of candidates for GVFSs.

4.4.8.2 Equipment

Standard Racks. See Section 5 of ASTM G50.
Scribe Tool. An ANSI B 94.50, style E scriber.
Straightedge. Any straightedge of sufficient length to guide the scribing tool in a straight line.
Balance. A digital electronic balance capable of weighing up to 10,000 mg with an accuracy of +/- 1%.

4.4.8.3 Reagents

Cleaning Solution. Methanol.

4.4.8.4 Procedure

Test Specimens. Prepare at least 10 specimens consisting of sections of actual GVFSs or manufactured parts that accurately simulate current production material and manufacturing processes, incorporating the candidate, and 10 specimens incorporating the current corrosion protection system. Each test specimen and reference coupon shall contain a clear identification mark. Use reference coupons consisting of uncoated 25 x 51 x 3 mm (1" x 2" x 1/8") pieces of any alloy AISI 1006 through 1010 steel to monitor the average general bare steel corrosion produced by the test track environment. The reference coupons shall be thoroughly cleaned using the cleaning solution. The coupon weight in milligrams shall be recorded and retained for future reference.
Test Sites. Test sites shall be chosen at a number of locations representative of the atmospheric environments where the military vehicle is likely to be used.
Preparation. Using test specimens incorporating the candidate and the current corrosion protection system, scribe a single diagonal line making sure that the scribed line is all the way through the coating into the substrate.
Test Procedure. Attach the test specimens and reference coupons to the racks at the approved test site and test in accordance with the test site standard practice, ASTM G50, "Standard Practice for Conducting Atmospheric Corrosion Tests on Metals". ASTM G50 recommends a multi-year exposure period to minimize the variability of environmental (industrial and natural) factors influencing the atmospheric corrosivity of a test site.

Monitor environmental factors in accordance with ASTM G50. Evaluate the performance of the candidate and current corrosion protection system test specimens, and reference coupons at six-month intervals and at the completion of the exposure period. At the end of the exposure period, clean the reference coupons using a mild sand (or glass bead) blast to remove all corrosion by-products.

Test Results. Inspect the test specimens and reference coupons for any signs of degradation. Measure scribe creep in accordance with ASTM D1654 and TT-C-490. Once clean, wipe coupons with methanol and weigh to determine weight loss. Corrosion losses may also be expressed in terms of average corrosion rates from the weight loss, coupon area, test duration, and metal density by use of the calculation described in ASTM G1.

Report. Report observations in accordance with the test site standard practice, ASTM G50, including environmental factors monitoring, and weight loss and/or corrosion rate of the reference coupons.

4.4.8.5 Acceptance Criteria

Test	Acceptance Criteria, Minimum Performance (MP)	Acceptance Criteria, Improved Performance (IP)	Acceptance Criteria, Best Performance (BP)
Field Exposure, Static	Three years of exposure: specimen has a minimum of 25% less creepage from scribe than current corrosion protection system	Four years of exposure: specimen has a minimum of 50% less creepage from scribe than current corrosion protection system	Five years of exposure: specimen has a minimum of 75% less creepage from scribe than current corrosion protection system

4.4.9 Field Exposure, On-Vehicle (ASTM D 1654, TT-C-490)

4.4.9.1 Scope

This test method describes a basic procedure for conducting on-vehicle testing of candidates. This may be performed by selective replacement or refinishing of an appropriate representative substrate/component on a vehicle incorporating the candidate, or by the use of test specimens incorporating the candidate attached to the military ground vehicle.

4.4.9.2 Equipment

Military Ground Vehicle. A vehicle used for standard deployment.

4.4.9.3 Reagents

Cleaning Solution. Materials required as designated by each candidate supplier.

4.4.9.4 Procedure

At a minimum, the process shall be conducted to replace or refinish a part or section of the vehicle in accordance with the suggested finishing parameters and the controls established by the

CARC applications specification MIL-DTL-53072 and TT-C-490. If using test panel, they shall be prepared in accordance with above G50 for static field testing and evaluated using ASTM-D 1654. _Representative substrates/components will be pretreated in accordance with pretreatment manufacturers recommended specifications finishing parameters and controls established in MIL-DTL-53072 and TT-C-490. Components substrates will be evaluated during periodic inspections by visual comparison with the base vehicle or control samples attached to the vehicle. The Society for Protective Coatings SSPC-VIS-2 "Standard Method for Evaluating the Degree of Rusting on Painted Steel Surfaces" shall be used for evaluating component substrates and control samples. The success criteria for field testing will be performance greater than or equal to the base vehicle (baseline) or control sample.

Report. After a predetermined exposure agreed upon by the stakeholders, the affected vehicles/parts shall be evaluated for coating adhesion, color, and corrosion resistance in accordance with SSPC-VIS-2, MIL-DTL-53072, TT-C-490, and ASTM D 1654.

5.0 FAILURE ANALYSIS

To be considered for use as a replacement for the current corrosion protection system, a candidate must pass all tests. The failure of any Screening, Performance, or Special Test shall be documented in the JTR. At the candidate vendor's request and expense, a failure analysis procedure can be undertaken to determine the failure mechanisms. Such failure analysis can be a useful vendor option to identify and correct failure mechanisms prior to retesting. However, after failing any of the Screening, Performance, or Special Tests for the third time, further iterations of that test are not permitted. Instead, the JTP process shall be ended and the results noted in the JTR. The JTR shall then be forwarded to the vendor for transmittal to the invoking authority for review.

In the event of any testing-related dispute between vendor and tester, such as causes of premature failure, a third-party testing lab will be mutually agreed upon as a credible testing source by the invoking authority. This Product Failure Laboratory (PFL) must have no pre-existing connections to either the vendor of the candidate or the original laboratory that conducted the testing. The process flow is illustrated in Figure 1, which appears in Section 2.0, JTP Document Guide.

Marginal test results must be either overcome by retesting or documented before rejecting/failing the candidate. Failure in any test does not necessarily disqualify a candidate for use in all possible applications.

The initial JTR and all related JTRs (specifically those documenting failure analyses) shall be submitted to the vendor for transmittal to the invoking authority for review.

6.0 REFERENCE DOCUMENTS

The documents listed in Table 8 were referenced in the development of this JTP.

Table 8. Reference Documents

Reference Document	Title	Applicable Section(s) of Reference Document	JTP Test	JTP Section Cross-Reference	Document Source
ASTM B117	Standard Test Method of SS (Fog) Testing	All	Corrosion Resistance NSS (Fog)	4.4.5	ASTM
ASTM D1193	Specification for Reagent Water	All	All	All	ASTM
ASTM D1654	Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments	All	Corrosion Resistance NSS (Fog) Corrosion Resistance (Cyclic) Field Exposure, Static Field Exposure, On-Vehicle	4.4.5 4.4.4 4.4.8 4.4.9	ASTM
ASTM D3359	Standard Test Methods for Measuring Adhesion by Tape Test	All	Adhesion (Dry) Adhesion (Wet)	4.4.1 4.4.2	ASTM
Federal Specification TT-C-490	Cleaning Methods for Ferrous Surfaces and Pretreatments for Organic Coatings Evaluating Degree of Blistering of Paints	3.5.9 3.5.10	Hydrogen Embrittlement Corrosion Resistance NSS (Fog) Corrosion Resistance (Cyclic) Field Exposure, on-Vehicle	4.2 4.4.3 4.4.4 4.4.12	DoD
SAE J400	Test for Chip Resistance of Surface Coatings	All	Chip Resistance at	4.4.6 4.4.14	SAE
GM 9540	Accelerated Corrosion test	All	Corrosion Resistance (Cyclic)	4.4.4	SAE
MIL-DTL-53072	Chemical Agent Resistant Coating (CARC) System Application Procedures And Quality Control Inspection	All	All		

Appendix B: Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
Jack Kelley	US Army Research Laboratory B4600 Deer Creek Loop Aberdeen Proving Ground MD	PH: 410-306-0837 FX: 410-306-0829 BB: 240-429-8485 John.v.kelley8.civ@mail.mil	Project Lead
Tom Braswell	US Army Research Laboratory B4600 Deer Creek Loop Aberdeen Proving Ground MD	PH: 410-306-0935 FX: 410-306-0829 thomas.braswell2.civ@mail.mil	Testing, and Specifications
Amy Fowler	NAVAIR, Code 4.3.4.2 48066 Shaw Road, Bldg. 2188 Patuxent River, MD 20670	301-342-0986 (phone) 301-342-7566 (fax) amy.fowler1@navy.mil	TCP technology development
Luwam Hagos	NAVAIR, Code 4.3.4.2 48066 Shaw Road, Bldg. 2188 Patuxent River, MD 20670	(301)342-8159 (phone) (301)342-8062 (fax) luwam.hagos@navy.mil	Navy Co-Performer
Patricia Dodson	Patty Dodson Anniston Army Depot 7 Frankford Avenue Bld. 106 Anniston, AL 36201	Patricia.dodson@us.army.mil COMM: 256-235-6700	Coordinate demonstration at Anniston
James Swann	Jacobs-ASG PM SBCT LNO-ANAD Anniston Army Depot	com: 256-235-7408 DSN: 571-7408 BB: 586-219-4352 James.swann1@us.army.mil	Stryker demonstration coordinator

Appendix C: Federal Specification TT-C-490F

TT-C-490

Appendix D: PMO Letters of Support

DEPARTMENT OF THE ARMY
US ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND
ARMY RESEARCH LABORATORY
ABERDEEN PROVING GROUND MD 21005-5069

MEMORANDUM OF AGREEMENT
BETWEEN
THE U.S. ARMY RESEARCH LABORATORY,
WEAPONS AND MATERIALS RESEARCH DIRECTORATE
AND
PMO STRYKER BRIGADE COMBAT TEAM

SUBJECT: ARL and PM-SBCT MOA

1. REFERENCES:

   a. Annex A: Enhanced Coatings and Products for Environmental Compliance and Durability.

   b. Annex B: PMO Stryker Brigade Combat Team Corrosion Prevention and Control Plan

2. PURPOSE: To formalize the longstanding partnership between ARL and PMO SBCT Environmental Management Team for environmental compliance, enhanced materials, advanced coatings, improved processes at OEM and depot facilities, and technical support for the PMO Stryker Brigade Combat Team Corrosion Prevention and Control Plan.

3. PROBLEM: Environmental degradation of fielded Stryker assets and ever changing environmental regulatory policies from local, national, and international sources.

4. SCOPE: ARL and SBCT will follow the guidelines agreed upon under Annex A.

5. CHANGES/TERMINATION: Changes or termination may be made by mutual agreement and/or negotiations between both organizations with 90 days written notice. Changes will be documented by modifications to this plan.

6. EFFECTIVE DATE: Nov 1, 2007.

JOHN M. MILLER
Director
U.S. Army Research Laboratory

KEVIN M. FAHEY
Program Executive Officer
Ground Combat Systems

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DEPARTMENT OF THE ARMY

UNITED STATES ARMY TANK-AUTOMOTIVE AND ARMAMENTS COMMAND

WARREN, MICHIGAN 48397-5000

MEMORANDUM FOR: US Army Research Laboratory 15 Nov.2010

SUBJECT: Memorandum of Agreement for considering the use of non-hex chromium pretreatments for steel substrates on MRAP vehicles.

1. PURPOSE: To formalize support of the US Army Research Laboratory (ARL) efforts to mitigate corrosion of High Hard armor through improved inhibiting pretreatments and processes.

2. PROBLEM: The current MRAPs were produced without a steel pretreatment/conversion coating step as added protection against corrosion and enhance paint adhesion. Hexavalent chromium based pretreatments such as DoD-P-15328 Wash Primer are typically prohibited for new ground systems and their corresponding service facilities. Furthermore, viable alternatives have not yet been fielded on actual high-hard armor based systems in order to be considered for implementation.

3. SCOPE: The US Army Research Laboratory (ARL) is leading an effort to identify effective pretreatments for steel substrates, including High Hard Armor that are hexavalent chrome free. PM-MRAP supports ARL in their effort to identify, validate, and demonstrate these environmentally compliant pretreatments for steel for the purpose of enhancing the corrosion resistance of the chemical agent resistant coating (CARC) system used on MRAP vehicles. The PM's office is prepared to assist ARL in locating potential vehicles for demonstrations and provide a technical POC to represent the interests of MRAP as a stakeholder at scheduled Integrated Product Team (IPT) meetings. This office also will consider for implementation IPT recommendations in upcoming reset operations.

4. POC for this action is Todd P. Weimer

Todd P. Weimer

Deputy Chief Engineer MRAP