ARMY RESEARCH LABORATORY

# Examination of Spray-Applied Oxsilan 9810/2 Steel Pretreatment on a Mine Resistant Ambush Protected (MRAP) Vehicle

**by Jack Kelley and Tom Braswell**

**ARL-TN-578** **October 2013**

## NOTICES

### Disclaimers

# Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5069

**ARL-TN-578** **October 2013**

# Examination of Spray-Applied Oxsilan 9810/2 Steel Pretreatment on a Mine Resistant Ambush Protected (MRAP) Vehicle

**Jack Kelley and Tom Braswell**
**Weapons and Materials Research Directorate, ARL**

| REPORT DOCUMENTATION PAGE | *Form Approved OMB No. 0704-0188* |
|---|---|



**1. REPORT DATE** *(DD-MM-YYYY)*
October 2013

**2. REPORT TYPE**
Final

**3. DATES COVERED (From - To)**
June 2011

**4. TITLE AND SUBTITLE**
Examination of Spray-Applied Oxsilan 9810/2 Steel Pretreatment on a Mine Resistant Ambush Protected (MRAP) Vehicle

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
Jack Kelley and Tom Braswell

**5d. PROJECT NUMBER**
WP200906

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
U.S. Army Research Laboratory
ATTN: RDRL-WMM-C
Aberdeen Proving Ground, MD 21005-5069

**8. PERFORMING ORGANIZATION REPORT NUMBER**
ARL-TN-578

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

**10. SPONSOR/MONITOR'S ACRONYM(S)**

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**
The objective of this demonstration is to show the viability of a nonchromate conversion coating for high-hard armor (HHA) steel on Mine Resistant Ambush Protected (MRAP) vehicles, in order to improve the long term corrosion resistance of the low-volatile organic compound Chemical Agent Resistant Coating (CARC) system. The product demonstrated here is Oxsilan 9810/2, manufactured by Chemetall Inc., which satisfies the hexavalent chrome prohibition while minimizing environmental impact and worker safety. The results of a previous demonstration of Oxsilan 9810/2 on Stryker vehicles was consistent with laboratory tests conducted at the U.S. Army Research Laboratory (ARL). However, the MRAP demonstration resulted in a discoloration of the HHA. Follow up experiments were conducted to ascertain the cause of the discoloration. These results indicate that a combination of events contributed to the corrosion-like appearance of the MRAP. The flow rate of the Oxsilan 9810/2 was insufficient to convert the steel surface on a large scale of the full-size vehicle. The bare abrasive blasted surface of the vehicles was likely contaminated when left unprotected for 72 hours (h) prior to the application of the pretreatment. This likely would have affected the reaction of the Oxsilan 9810/2 with the steel surface.

**15. SUBJECT TERMS**
HHA, MRAP, steel pretreatments

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| | | | | | Jack Kelley |
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | 19b. TELEPHONE NUMBER (*Include area code*) |
| Unclassified | Unclassified | Unclassified | UU | 28 | (410) 306-0837 |

**Standard Form 298 (Rev. 8/98)**
Prescribed by ANSI Std. Z39.18

## Contents

## List of Figures

## Acknowledgments

The authors would like to acknowledge John Donofrio (Technical Applications Manager, Chemetall Americas); Tony Eng and Jay Ong (USMC Corrosion Office); Chris Wesenberg (II MEF USMC CPAC, Field Service Rep); and Charles Wolf (Camp Lejeune).

INTENTIONALLY LEFT BLANK.

# 1. Introduction

The high-hard armor (HHA) steels that are used for Mine Resistant Ambush Protected (MRAP) vehicles, and a wide range of other systems, provide good protection against armor piercing threats. However, without good corrosion protective coatings these steels corrode rapidly. Photos of newly fabricated, unfielded MRAP vehicles showing significant corrosion have circulated within the Department of Defense (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 signal from the vehicle that the topcoat camouflage usually inhibits, making the vehicle more vulnerable to detection by the enemy.

Under the Army Regulation, AR 750-1 (*1*), 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 (*2*). Typically, a CARC system consists of 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 in accordance with (IAW) MIL-DTL-53022 (*3*) or MIL-DTL-53030 (*4*) and; c) the polyurethane-based topcoat IAW MIL-DTL-53039 (*5*) or MIL-DTL-64159 (*6*). A coating exception/variation was granted to Stryker manufacturers to allow the omission of the pretreatment/conversion coating step. Permission was also extended to MRAP manufacturers to omit pretreatments on that platform, allowing the primer to be directly applied to the high-hard steel substrate prior to topcoating. As seen in figure 1, the photo on the left is a newly received vehicle with corrosion through the paint that is visible on the roof. The photo 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 the coating application (*7*).

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

Omitting this pretreatment/conversion coating step was justified because hexavalent chromium-based pretreatments, such as DOD-P-15328 (*8*) wash primer, have been prohibited from use on new ground systems and viable alternatives. Although promising in laboratory studies, they had not been demonstrated on fielded HHA-based systems, such as Stryker (*9*).

The objective of this specific demonstration is to show the viability of a nonchromate conversion coating for HHA steel on MRAP in order to improve the long term corrosion resistance of the low-volatile organic compound CARC system. The product demonstrated here is Oxsilan 9810/2, manufactured by Chemetall Inc., and satisfies the hexavalent chrome prohibition while minimizing environmental impact and worker safety.

Prior to conducting the demonstrations, laboratory tests were performed in July and August of 2010 to validate the corrosion performance of various pretreatments on steel and MIL-A-46100 HHA steel under Environmental Security Technology Certification Program (ESTCP)-funded WP 200906. Oxsilan 9810/2 was one of the selected pretreatments to be validated. In constructing the relatively large test matrix, all vendors were tasked with applying their product on U.S. Army Research Laboratory (ARL)-supplied steel test panels. When the pretreatments were completed and all of the pretreated panels were received, the primers and topcoats were applied to the panels by ARL. All panels were inspected prior to primer and topcoat application. Observations of the bare (pretreated only) panels that were received from the vendor did not indicate any objectionable discoloration of the Oxsilan 9810/2 treated panels. All Oxsilan 9810/2 panels had a light-grayish metal finish.

Furthermore, upon completion of all laboratory tests, ARL initiated a demonstration of the pretreatments on Stryker combat vehicles. The demonstration took place at Anniston Army Depot (ANAD) during an ongoing reset of Stryker DRCF-3 vehicles. The Stryker Brigade Combat Team (SBCT) agreed to allow ARL to demonstrate the pretreatments on the hatches of three Stryker vehicles (power entry panel [PEP] hatch, front access hatch, and side egress hatch). Consistent with test panels obtained from the vendor earlier in the project, the hatches treated with Oxsilan 9819/2 showed no signs of discoloration. All hatches treated with the Oxsilan 9810/2 (a front-access hatch depicted in figure 2) were light-gray in color, similar to freshly cleaned steel.


Figure 2. Container of Oxsilan 9810/2 and sprayer used to apply the pretreatments at ANAD (left), Stryker hatch treated with Oxsilan 9810/2 after 19 hours (h) (right).

Following the ANAD demonstration, HHA test panels were treated using the same batch of the Oxsilan 9810/2 used on the Strykers during the ANAD demonstration. These test panels were treated with the remaining Oxsilan 9810/2 in order to conduct additional accelerated corrosion tests and humidity testing. Below in figure 3 are pictures of a sample treated with the ANAD batch of Oxsilan 9810/2. Once again, no discoloration was observed on the panels.

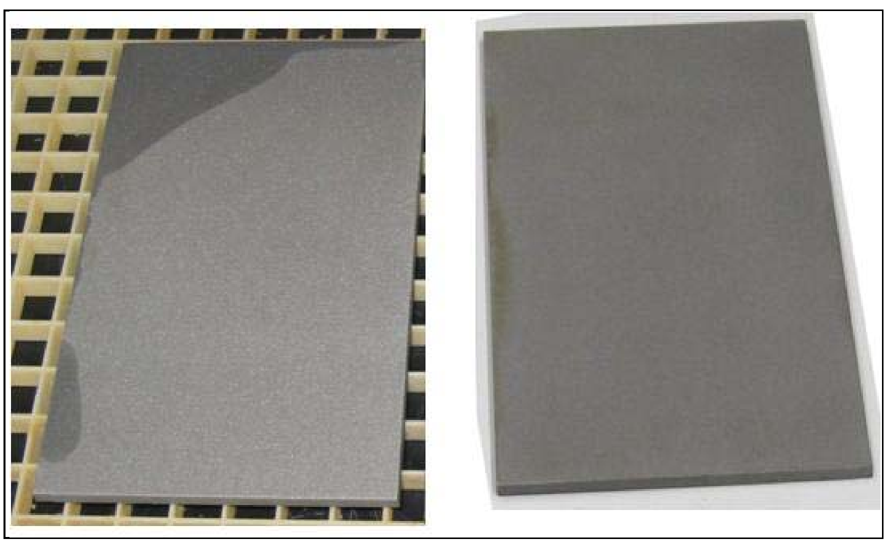

Figure 3. A panel treated with the same batch of Oxsilan 9810/2 from the ANAD demonstration of Stryker (left), shown during drying (right), fully dried 24 h.

Observations to this point showed that the Oxsilan 9810/2 product would have no adverse effect or objectionable discoloration of the surface of steel substrates. No significant discoloration or corrosion products were observed on low-carbon steel, or armor steel, even during humidity tests of bare (pretreatment only) HHA panels. Thus far, ARL's experience working with the product suggested that Oxsilan 9810/2 was a very robust product open to broad application parameters. The successful laboratory results and experience during the Stryker demonstration, along with the fact that it does not contain chrome (hex or trivalent), were the criteria for selecting Oxsilan 9310/2 for demonstrating on the MRAPs at Camp Lejeune, NC.

## 2. MRAP Demonstration at Camp Lejeune

The demonstration team arrived at Camp Lejeune on the morning of June 20, 2011. Two vehicles were presented for the demonstration. Upon arrival, MRAP No.1 (USMC VIN 634590) was fully-abrasive-blasted using 60-grit garnet blast media on the previous Friday, June 17, 2011. MRAP No.2 (USMC VIN 633359) was approximately 80% abrasive-blasted and was not finished until the following day. Application commenced on MRAP No.1 at approximately 1300 in a covered outdoor environment outside the blast booth. Environmental conditions were sunny and clear with a temperature of 85 °F and 55% relative humidity (RH) at the beginning of the application. A full account of the weather conditions from June 17–20, 2011 are shown in the appendix. The application was carried out IAW the procedure recommended by Gary Nelson, Product Manager, Chemetall, NJ. As outlined in the demonstration plan (*10*),

1. The vehicle was blown-down with shop air to remove dust from abrasive blasting;
2. Oxsilan 9810/2 was applied and allowed to dwell for 60–90 seconds (s);
3. Followed by a deionized (DI) water rinse;
4. Compressed air was blown-down to remove material accumulation in cavities and depressions.

Two pumps (depicted in the demonstration plan and in figure 4) were used to apply the Oxsilan 9810/2 and the DI rinse water. The flow rate of each of the pumps was measured at 1.1 gallons per minute (min). The process called for wetting the MRAP with Oxsilan 9810/2, allowing it to dwell for 60–90 s and rinsing it with clean DI water. The process was carried out as close as practical with two applicators and one person blow-drying with compressed air. However, during the application of the pretreatment, the color of MRAP No.1 began to change to a reddish hue within 1 min. 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 color. 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 4. Camp Lejeune demonstration. Drums of Oxsilan 9810/2 RTU (left), and pump sprayer used for applying the pretreatment (right).

Figure 5 shows MRAP No.1 during and 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 or the Stryker hatches treated at ANAD.

Figure 5. MRAP No.1 during application of Oxsilan 9810/2 pretreatment (left), and after application with the Oxsilan 9810/2 RTU from drums June 10, 2011 (right).

During a conference call meeting with Chemetall America's Product Manager on the evening of June 20, several possibilities for the unexpected results were discussed: (1) improper solution chemistry (2) application rate (not enough flow) (3) surface contamination because MRAP No.1 was abrasive-blasted 72 h 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 (expected) results from earlier tests using the batch of Oxsilan 9810/2 from the drums at Camp Lejeune, NC, as well as replicate the (unexpected) results.

# 3. Follow Up Laboratory Tests (ARL)

The objective of these laboratory tests was to determine if certain variables identified in the demonstration contributed to the reddish-brown color on MRAP No.1. Specifically, was the application (flow) rate and dwell time adequate, and/or did surface contamination play a role in the unexpected reddish-brown MRAP.

Sample Preparation:

HHA test panels (4 in × 6 in × 3/16 in) were abrasive-blasted with 60-grit aluminum oxide to the Society for Protective Coatings, Surface Preparation Standard 5 (SSPC-SP5), White Metal Blast Cleaning 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 manufacturer. In the first case, a panel is sprayed (essentially bathed) in Oxsilan 9810/2 for 90 s 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** panels were sprayed with minimum flow allowable to keep the panel wet for 30 s and subsequently rinsed with DI water.
3. **The role of contaminants on the surface** of the HHA prior to treatment with Oxsilan 9810/2 was examined. Two different sets of panels were deliberately contaminated using two methods:
    - Sodium chloride (NaCl) Spray: Test panels were deliberately contaminated by spraying down with 3.5% NaCl solution and allowed to dry prior to applying Oxsilan 9810/2 at various application rates.
    - Pre-exposed: Freshly abrasive-blasted HHA panels were pre-exposed to a covered outdoor environment for 72 h prior to applying the Oxsilan 9810/2, mimicking events at Camp Lejeune, NC.

## 3.1 Best-Case Scenario

Panels sprayed with maximum flow and maximum dwell time showed a color change. In this case, the colors of the panels were uneven and blotchy with streaks of orange, pink, gold, blue, and dark gray. Figure 6 shows two contrasting panels. On the left is a freshly abrasive-blasted

HHA panel with no pretreatment. A noticeable color change was evident and did not resemble the color seen in either the MRAP demonstration, the samples discussed earlier in the previous laboratory validation, or that of the Stryker demonstration.

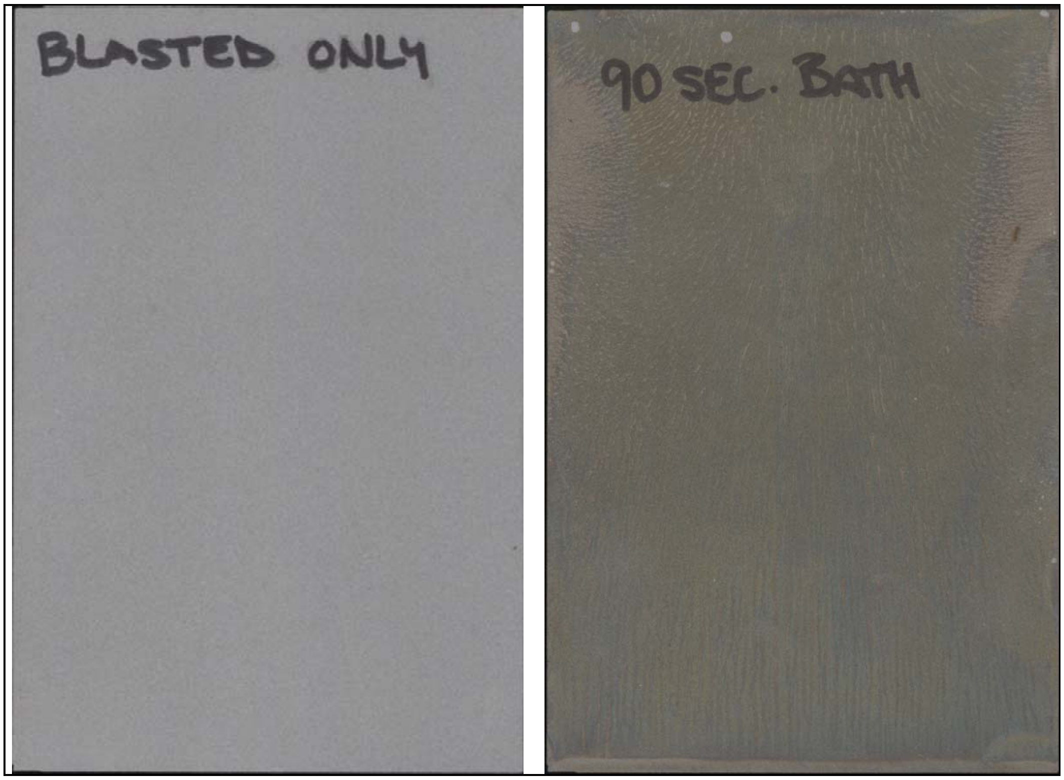


Figure 6. A freshly abrasive-blasted, untreated HHA panel (left). A panel "bathed" in Oxsilan 9810/2 for 90 s dwell (right).

## 3.2 Worst-Case Scenario

The worst-case for flow and dwell time is represented by the panel on the right in figure 7. The panel was sprayed with the minimum flow allowable to keep the panel wet for 30 s and subsequently rinsed with DI water. As seen, there is an obvious color change compared to the clean abrasive-blasted panel on the left. The panels represented by figure 7 were a bright gold. The color was relatively even, but the color change was dramatic and again did not resemble the color seen in either the MRAP demonstration, previous laboratory validation, or the Stryker demonstration.

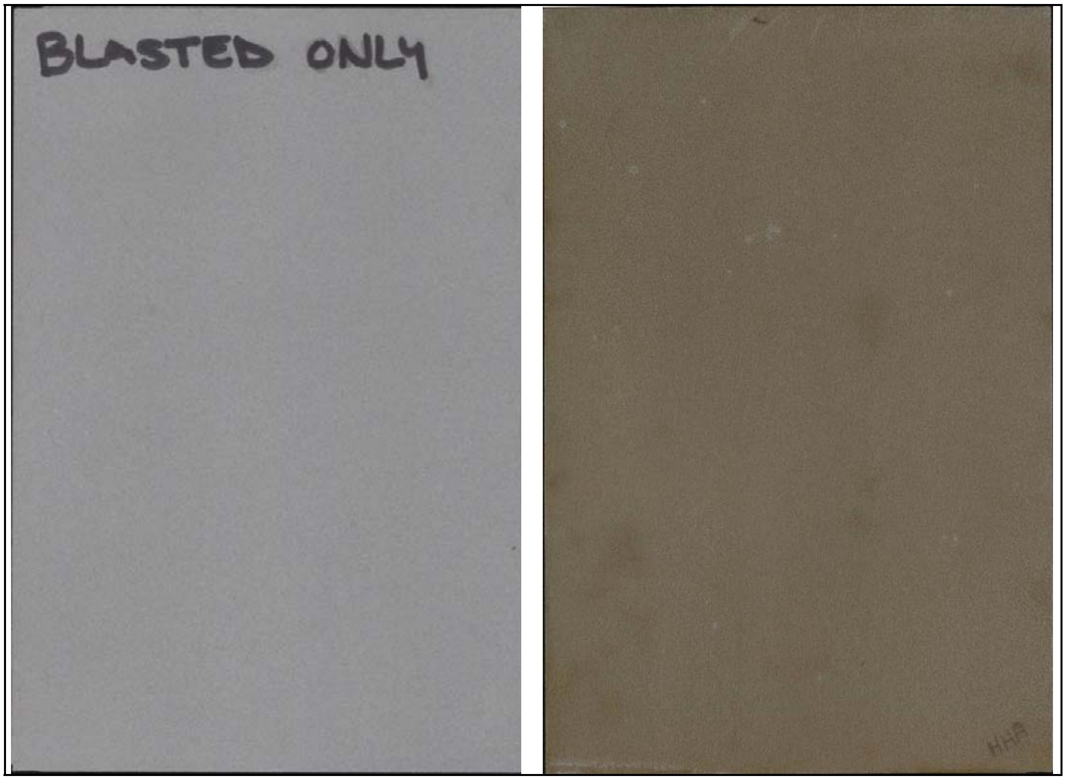


Figure 7. A freshly abrasive-blasted, untreated HHA panel (left). A panel sprayed with Oxsilan 9810/2 for 30 s dwell (right).

## 4. The Role of Contaminants on the Surface

Finally, the role of contaminants on the HHA surface prior to treatment with Oxsilan 9810/2 was tested in two ways: (1) NaCl solution spray (2) Pre-exposed to a covered outdoor environment for 72 h.

### 4.1 NaCl Solution Spray

After the HHA test panels were sprayed with 3.5% NaCl solution they were allowed to dry completely. No red rust was evident at this time. These panels were subsequently spray-treated with Oxsilan 9810/2. The pretreatment was sprayed on and allowed to dwell for 90 s as recommended by the manufacturer. After the 90 s dwell, the panels were rinsed thoroughly with DI water and allowed to dry. Figure 8 shows the NaCl spray contaminated panel after the Oxsilan 9810/2 treatment in the photo on the right. The panel appeared to have an orange hue similar to the appearance of "red" rust. This color was slightly more orange in color than panels that were not contaminated with NaCl.

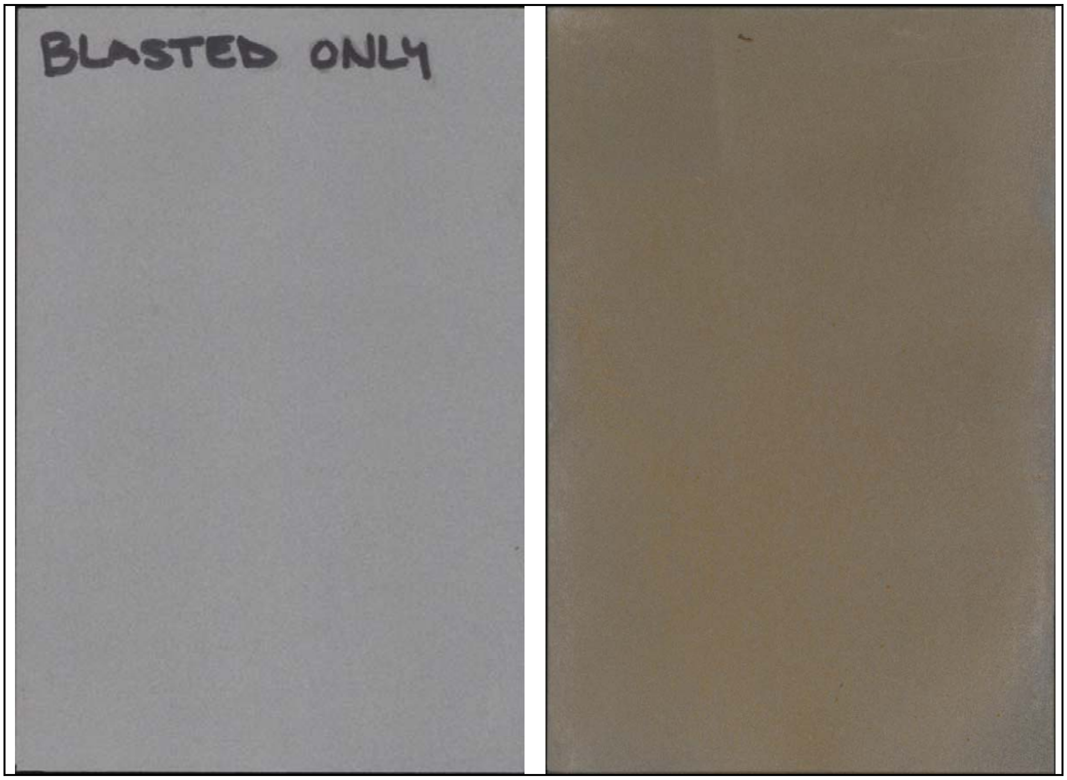


Figure 8. A freshly abrasive-blasted, untreated HHA panel (left). A panel first sprayed with NaCl solution, then treated with Oxsilan 9810/2 (right).

### 4.2 Pre-Exposed to a Covered Outdoor Environment for 72 h

The second method of contamination was achieved by leaving freshly abrasive-blasted HHA panels in a covered outdoor environment for 72 h at the Aberdeen Proving Ground. The panels were placed leaning at an approximately 15° angle on the inside of a small uncovered polyethylene bucket in a covered area, allowing for exposure to the environmental conditions, but preventing direct exposure to the elements. The humidity ranged from 65%–100% RH for the duration of the 72 h exposure, while temperatures ranged from 75 °F at night to above 90 °F during the day. This was considered similar to the exposure conditions on a piece of military equipment at Camp Lejeune during processing. The panels were then spray-treated with Oxsilan 9810/2 for a 30 and 90 s dwell. After the prescribed dwell time they were then thoroughly rinsed with DI water and allowed to dry.

A significant change in the color was evident in these panels as seen in figure 9. The color is very similar to what was seen on the MRAP during the demonstration at Camp Lejeune. Unique to these test panels versus all of the others, was the spotting and streaking of the panel that was only allowed 30 s of dwell for the Oxsilan 9810/2; again, similar to the MRAP. The surface was clearly contaminated, and the contamination appeared to have an effect on the consistency of the ability of the Oxsilan 9810/2 to react with the steel substrate. There was also a color change with the panel treated for 90 s, but it did not resemble the MRAP results.

The color change in the 90 s dwell panel was far less dramatic. In some respects, it resembled the earlier “best-case scenario.” The results of this experiment indicated that more than one factor may have affected the MRAP results. As demonstrated, the pre-exposed panel with the lower dwell time created a similar color as the MRAP at Camp Lejeune.

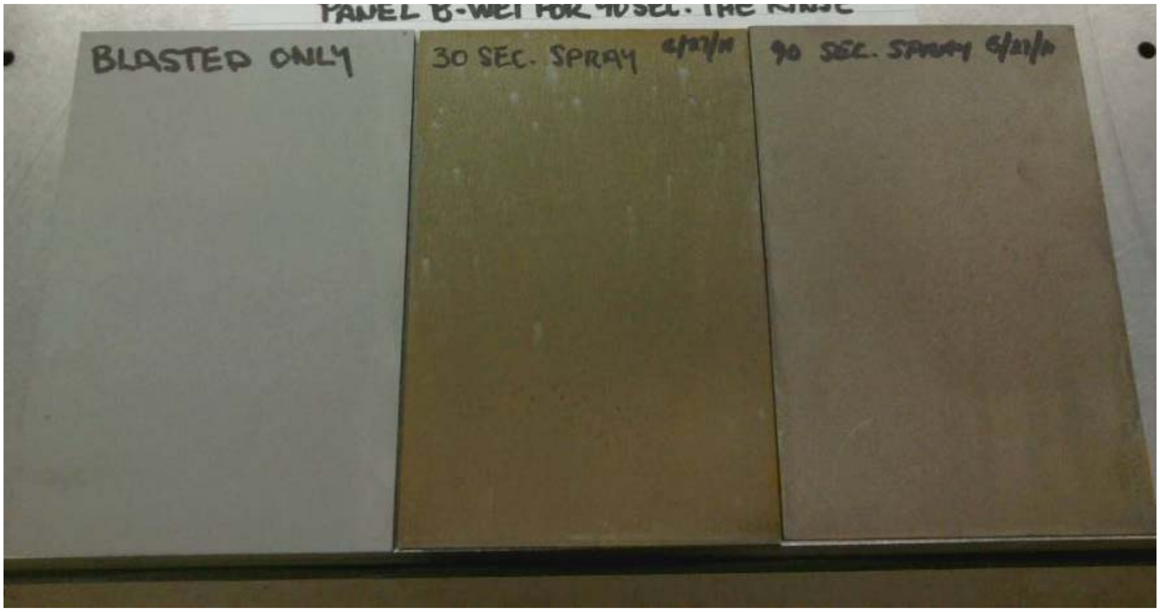


Figure 9. Example of a freshly blasted HHA panel (left). The panel in the center and right were treated with Oxsilan 9810/2 following 72 h in an outside environment. The center panel was treated using minimal flow for 30 s, and the right panel was bathed for 90 s.

## 5. Discussion of Results

Until the MRAP demonstration at Camp Lejeune, the Oxsilan 9810/2 product gave no indication that it would produce anything but a light-gray color similar to freshly cleaned steel. On the contrary, ARL’s experience working with and testing of the product, and feedback received from preliminary testing at Cherry Point on an earlier version of the Oxsilan 9809, indicated that Oxsilan 9810/2 was a very robust product open to broad application parameters. When ARL received the bare (pretreated only) panels from Chemetall, there was no discoloration of the Oxsilan 9810/2 treated panels. All of the panels had a clean light-grayish metal finish. During initiation of the Stryker, the hatches that were treated with Oxsilan 9810/2 by ARL at ANAD in September 2010 showed no discoloration, even after being left bare for 19 h after treatment. All hatches with Oxsilan 9810/2 remained a light-gray color similar to freshly cleaned steel.

The consistent discoloration that occurred in the additional lab testing described in this report suggested that the formulation may have been different than the formulation that was used for the initial validation test phase and the batch supplied for the Stryker demonstration. However, the Chemetall Laboratory determined that the solution chemistry was within their acceptable range. Therefore, the discoloration was most likely process-related.

The results of the ARL HHA test panel experiments indicate that the unusual MRAP result was caused by multiple factors. The brownish-red color of the MRAP was most likely the product of both surface contamination, and insufficient flow and rinsing of the Oxsilan 9810/2. The surface may have been first contaminated by the blast media, which may have contained soluble salts, and/or by the bare freshly blasted steel being exposed to the uncontrolled environment near the Atlantic Ocean at Camp Lejeune, NC (figure 10) for 72 h. Ionogenic contamination from abrasives is transferred uniformly onto steel surfaces. This can turn the steel surface a homogeneous light-gray-to-black color, depending on the concentration (*11*). The trucks were light-gray with no noticeable corrosion before treatment. But once the pretreatment was applied (using insufficient flow rate in this case), the reaction produced a corrosion-like color on the vehicle. Laboratory tests also indicate that it is possible for optimum flow of the Oxsilan 9810/2 to perhaps compensate for the contamination by essentially washing away the contaminants quickly enough to allow the Oxsilan 9810/2 organo-silane polymers to react with the cleaned metal, leaving a clean-gray finish behind. In addition to the panel testing, evidence of the advantage of the greater flow rate can be seen in the MRAP picture in figure 11. The light-gray streaks occurred at locations where there was a higher flow rate of Oxsilan 9810/2 (i.e., continuously running down the side).

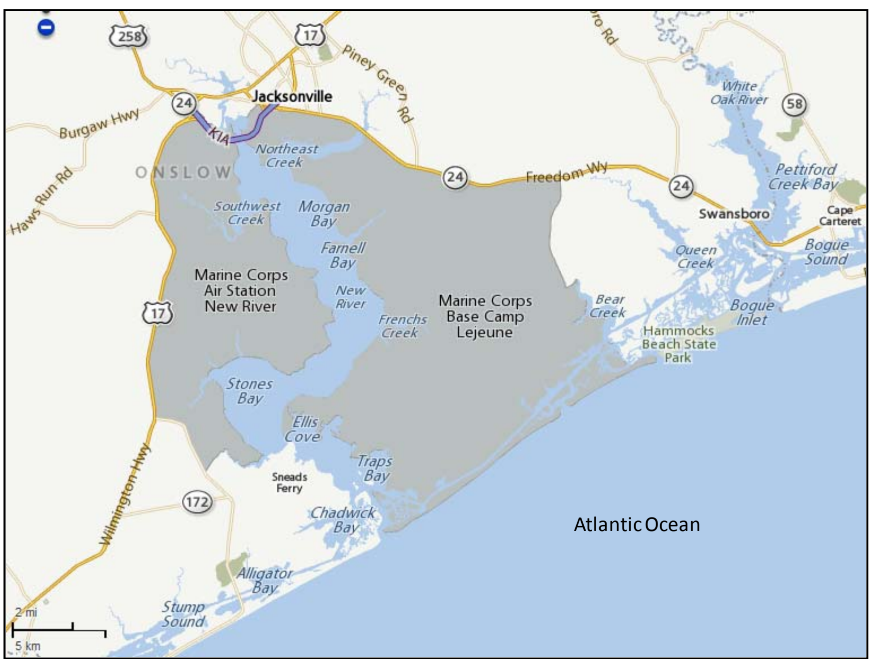


Figure 10. Marine Corps Base, Camp Lejeune, NC. Site of demonstration is within close proximity to the Atlantic Ocean (*12*).

Figure 11. Gray areas along edges of windows where there appeared to be a higher flow rate of Oxsilan 9810/2.

## 6. Conclusions

The results indicate that a combination of events contributed to the corrosion-like appearance of the MRAP. With the upscale from laboratory sized and smaller hatch-sized parts to full-sized parts, the scope of the MRAP was underestimated, resulting in inadequate flow of the applied Oxsilan 9810/2. We also believe that the 72 h 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 clean abrasive-blasted surface as soon as practical, preferably within 2–4 h of abrasive-blasting. The flow rate used for the Oxsilan 9810/2 should be sufficient enough to keep the vehicle wet throughout the treatment. Rinsing with clean water should be done, again using adequate flow rate to thoroughly remove the unreacted Oxsilan 9810/2. We are confident that the desired results can be achieved by following these recommendations.

## 7. Future Work

ARL has been working closely with the MRAP Program Management Office (PMO) to secure another demonstration of a limited scope. The MRAP PMO has agreed to provide one set of two rear doors off of an MRAP variant for pretreatment using Oxsilan 9810/2. The Aberdeen Test Center will also support this effort by preparing the doors for pretreatment and subsequently apply primer and paint. The doors will be placed in outdoor exposure, where ARL will have possession and control for the duration of the test. All parameters will be carefully monitored throughout this demonstration to ensure proper flow rate and eliminate any likelihood of contamination.

## 8. References


1. AR 750-1. *Army Materiel Maintenance Policy and Retail Maintenance Operations*, U.S. Department of the Army, Washington, DC, 2000.

2. MIL-DTL-53072. *Chemical Agent Resistant Coating (CARC) System Application Procedures and Quality Control Inspection*, U.S. Department of Defense, Washington, DC, June 2003.

3. MIL-DTL-53022. *Primer, Epoxy Coating, Corrosion Inhibiting, Lead and Chromate Free,* U.S. Department of Defense, Washington DC, January 2007.

4. MIL-DTL-53030C. *Detail Specification: Primer Coating, Epoxy, Water Based, Lead, and Chromate Free*, U.S. Department of Defense, Washington DC, 19 May 2010.

4. MIL-DTL-53039. *Coating, Aliphatic Polyurethane, Single Component, Chemical Agent Resistant*, U.S. Department of Defense, Washington DC, June 2005.

5. MIL-DTL-64159. *Coating, Water Dispersible Aliphatic Polyurethane, Chemical Agent Resistant*, U.S. Department of Defense, Washington DC, January 2002.

6. Corrosion Engineering Support to the Joint Program Office (JPO) for Mine Resistant Ambush Protected (MRAP) Vehicle Systems: Baseline Inspection of As-Produced MRAP Vehicles for Identification of Systemic and Manufacturer Specifuc Corrosion Issues, Rick Sturdevant – JPO MRAP / EG&G, Andrew Sheetz –NSWCCD, John Repp and Peter Ault – Elzly Technology Corporation.

7. DOD-P-15328D. *(Note 1): Primer (Wash), Pretreatment (Formula No. 117 for Metals)*; U.S. Department of Defense: Washington, DC, March 1992.

8. Placzankis, B.; Miller, C.; Kelley, J. *Examination of Alternative Pretreatments to Hexavalent Chromium-Based DOD-P-15328D Wash Primer for MIL-A-46100D High Hard Steel Armor*; ARL-TR-3393; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, January 2005.

9. Gary Nelson, Product Manager, Surface Treatment, Chemetall, 675 Central Avenue New Providence, NJ 07974, USA, 908-464-6900 x2180.

10. Johnson, W. C. Corrosion Failure from Water-Soluble Contaminants on Abrasives, KTA-Tator, Inc. *Journal of Protective Coatings & Linings*, September **1990**, *54*, 54–59.

11. MacNally R. Online maps, <http://maps.randmcnally.com/?s=screen&loc1 =north%20carolina#s= screen&lat=35.218047&lon=-80.2977&zoom=13&loc1= NC%20&loc2=&loc3=&loc4=&loc5=&loc6= &loc7=&loc8=&loc9=&loc10=> (accessed Oct. 2, 2013).

## Appendix. Weather History for New River MCAS, NC, 2011 <http://www.wunderground.com/history/airport/KNCA/2011/6/17/Daily History.html>

This appendix appears in its original form, without editorial change.

| | 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 |

## List of Symbols, Abbreviations, and Acronyms

| | |
|---|---|
| ANAD | Anniston Army Depot |
| ARL | U.S. Army Research Laboratory |
| CARC | Chemical Agent Resistant Coating |
| DI | deionized |
| DOD | Department of Defense |
| h | hour |
| HHA | high-hard armor |
| IAW | in accordance with |
| min | minutes |
| MRAP | Mine Resistant Ambush Protected |
| NaCl | Sodium Chloride |
| PMO | Program Management Office |
| RH | relative humidity |
| s | second |

| NO. OF COPIES | ORGANIZATION |
|---|---|
| 1 (PDF) | DEFENSE TECHNICAL INFORMATION CTR DTIC OCA |
| 1 (PDF) | DIRECTOR US ARMY RESEARCH LAB IMAL HRA |
| 1 (PDF) | DIRECTOR US ARMY RESEARCH LAB RDRL CIO LL |
| 1 (PDF) | GOVT PRINTG OFC A MALHOTRA |
| 2 (PDF) | RDRL WMM C J KELLEY T BRASWELL |