UPGRADING CORROSION CONTROL TECHNOLOGIES DURING SYSTEM RESET

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ABSTRACT

During their service life legacy ground weapon systems can suffer from corrosion deterioration either due to a lack of, damage to or depletion of corrosion control systems installed during original manufacturing. As these systems are being refurbished in RESET programs there is the opportunity to restore or upgrade the corrosion control systems of these assets. During the repair of these vehicles the systems are largely disassembled, cleaned to bare metal and repainted / reassembled to like-new condition. With such major disassembly already occurring improved coatings and corrosion resistant parts can be readily incorporated into the system during this repair. This will result in a system that has an extended service life as compared to one where repair only incorporates the use of the Chemical Agent Resistant Coating (CARC) paint systems. This paper presents the in-progress work of an OSD project to evaluate the effectiveness of utilizing zinc-rich coatings, metalizing, chip resistant polyurethane coatings and other corrosion control technologies on US Army and Marine Corps ground weapon systems.

Keywords: RESET, rebuild, corrosion, coatings, Stryker, aluminum, polyurea, chip resistant coating, zinc-rich coating, metalizing

INTRODUCTION

Both US Army and US Marine Corps (USMC) ground weapon systems suffer from corrosion that can impact maintenance costs, safety, reliability and readiness. The recently completed costs of corrosion studies estimate annually these services spend $2 billion and $0.7 billion, respectively. The largest portions of these costs are for corrective maintenance, with 56% and 76% of the totals spent by each service. This suggests that ground weapon systems are inherently corrosion prone. There exists the potential to improve the corrosion resistance of these systems by incorporating corrosion control technology upgrades during system rebuild / RESET. During this process vehicles are largely disassembled and restored to original conditions. However, with minimal additional cost or effort these systems can incorporate technologies like zinc-rich or chip and abrasion resistant coatings to reduce corrosion. This paper presents a summary of several of the technologies to be demonstrated / considered during this project.

HIGH PURITY ELECTROPLATED ALUMINUM

Cadmium (Cd) has been used for many years for coating steel components and fasteners mainly to provide corrosion protection and protection from hydrogen embrittlement. Cadmium has been shown to be highly toxic and the environmental and health problems resulting from its use are a serious concern. This resulted in a large push to eliminate Cd from all components. Many alternative coating systems have been examined in the past such as zinc and zinc alloy platings and aluminum coatings such as ion vapor deposition (IVD) and electroplated aluminum (Al).

Of these alternatives, electroplated Al may be a viable alternative as a direct replacement for Cd. The process was developed in Germany and one (1) company in the US now owns the patents and rights to the technology (and is the only company who currently manufactures and applies this coating).

Process

Electroplated aluminum can be applied only in an environment that is water and oxygen free. It is deposited in a closed cell filled with nitrogen or argon. The electrolyte is made up of a proprietary formulation of organometallic compounds and aromatic solvents.

Summary of Testing

The Joint Cadmium Alternatives Team (JCAT) and Naval Air Warfare Center (NAWC) Aircraft Division tested several Cd alternatives on 4340 steel including Zn-Ni, IVD Aluminum, and electroplated Al. The program looked at stress corrosion cracking (SCC) and fatigue. The authors concluded that the electroplated Al was the closest alternative to the performance of Cd. They also concluded that the electroplated Al is the best protector of the 4340 steel in NaCl, and that the electroplated Al provides similar corrosion fatigue performance to that of cadmium.

Ocean City Research Corporation (OCRC) evaluated the feasibility of several Cd alternatives among them electroplated Al. The electroplated Al showed competitive corrosion performance properties to Cd. The marine atmospheric exposure testing showed that the electroplated Al performance was very similar to that of Cd. The paint adhesion testing showed the adhesion properties were very similar to that of Cd. When coated with an organosilane topcoat, the data showed that the adhesion was slightly better than Cd. The data did show that the electroplated Al has a higher friction factor. This means a higher torque will need to be applied to achieve the same clamping load.[1] The OCRC testing also showed no increase in the susceptibility to environmentally assisted cracking due to the Al coating.

Amphenol Aerospace along with the vendor evaluated electroplated Al coating as a surface finish alternative to Cd plating for electrical connectors in F-35 Joint Strike Fighter (JSF) program. The primary objective was to qualify the Al coating to the connector milspec which previously called out Cd with a battery of testing so that the drawings could be changed. They focused on the connectors that were deemed to be the most difficult and challenging. The highest priority tests were the areas of corrosion, durability and conductivity. The coatings that were qualified were high purity Al over 6061 Al substrate with a class 3 chromate conversion coating (CCC) and electroplated Al over a PEEK substrate with a class 3 CCC. The connectors passed all tests including the ASTM G85 Sulfur Dioxide testing up to 336 hours retaining their functionality (i.e., able to mate and unmate) after the testing. They also passed the ASTM B117 salt fog testing to 1,000 hours with similar requirements. High purity Al coated connectors also passed the shell-to-shell conductivity requirements. The conclusion was that for both Al substrate connectors and the PEEK connectors high purity Al was qualified to replace the Cd plated connectors for these applications.

Environmental Concerns

The high purity electroplated Al process uses a patented mix of proprietary chemicals with toluene as the base solvent. The coating process occurs in a fully closed system. Air pollution emissions are low, both in total and relative to the number of pieces processed. According to the vendor, they currently operate far below the permitted levels, and can safely expand production if necessary.

CHIP AND ABRASION RESISTANT COATINGS

Chip and abrasion resistant coatings are used in place of or to compliment thin-build coatings that experience damage from sudden impacts or wear as a result of their normal use. Typical areas of use include undercarriage, wheel wells and cargo bed locations. On military vehicles and ground weapon systems painted with the Chemical Agent Resistance Coating (CARC) system these areas can rapidly show signs of wear, impact and coating loss under normal operations. These are typically thin coatings (specified minimum 0.0028-inch or 2.8 mils) used primarily for camouflage, decontamination, infra-red signature and other uses. Chip and abrasion resistant coatings are typically of a much thicker build ranging from ten to several hundred mils and as a result are more resilient and resistant to the impact from stone chipping, loading and unloading cargo and other mechanisms that easily deteriorate other coatings. These materials have been used in automotive applications, railway cargo applications and on some military ground weapon systems with much success.

Summary of Information and Testing

Chip and abrasion resistant coatings have been used on some ground weapon systems for corrosion control. To date these systems have primarily been used on interior surface of the cab floor (as a replacement for foam mats) and some use on Commercial Off The Shelf (COTS) undercarriage components (e.g., oil pans). Other testing has been done by the US Army and US Marine Corps (USMC) to evaluate their use on general undercarriage components.

[1] A friction modifier coating can be applied to electroplated Al fasteners where a desired clamp load can be achieved at the original torque for Cd or other platings, eliminating the need to update torque tables.

<u>Army Study on Chip Resistant Coatings:</u> In 1999 the US Army Tank-automotive and Armaments Command (TACOM) sponsored a study to evaluate chip and abrasion resistant coatings for corrosion performance. This study investigated several properties of commercially available chip and abrasion resistant coatings, these were:

- Resistance to damage from chipping.
- Resistance to corrosion when chipped and when scribed.
- Adhesion of the Chemical Agent Resistant Coating (CARC) system
    - Chip resistant coating applied over CARC.
    - CARC applied over the chip resistant coating.
- Resistance to DS-2 cleaning solution.

The results of this testing were most favorable for the polyurethane material tested. This showed good compatibility with the CARC system, no penetration to the steel substrate, no loss of performance when exposed to DS-2 solution (24 hour heated immersion) and minimal corrosion through 40 cycles of GM9540P testing. The results of this testing was used to develop a Commercial Item Description (CID) for polyurethane chip resistant coatings. This is CID A-A-59719, "100% Polyurethane Sprayed on Linings."

Independently a coating vendor evaluated their polyurea-based chip and abrasion resistant coatings for compatibility and performance with the CARC coating system. In 2008 they presented their results to TACOM and as a result of presentation and other information provided to TACOM a CID for polyurea chip resistant coatings was developed. This is CID A-A-59800, "Solids Aliphatic Polyurea Coating."

<u>USMC Evaluation of Chip Resistant Coatings:</u> In 2007-08 the USMC performed an evaluation of a commercially available chip and abrasion resistant coating (polyurethane) for use within their Corrosion Repair Facilities (CRFs). This was a polyurethane product with the intended application being direct to metal (no primer) trailer and truck cargo beds. As this was a top-side surface this material was to be over-coated with the CARC topcoat material for camouflage and observability. Test samples were evaluated for adhesion of the CARC topcoat to the chip resistant material at various over-coat intervals (within 5 min, 4 hours and greater than 12 hours after polyurethane application), resistance to chipping of the over-coated samples and overall corrosion resistance of scribed samples through 56 cycles of GM9540P.

The testing demonstrated that the water reducible (MIL-DTL-64159 Type II) CARC topcoat remained well adherent to the chip resistant coating based on pull-off adhesion and chip resistance test results. Visually throughout the GM9540P testing minimal corrosion was observed on the Tough Coat samples with and without a CARC topcoat. However after 24 cycles of testing evidence of cutback adjacent to the scribes was discovered by touch (pressing on the coating around the scribe a noted "give" was observed). At the end of testing there were some pertinent observations made, which were:

- All of the coating material was easily removed from the substrate (peeled off by hand once the coating was cut through).
- All of the scribed samples, once the coating was removed, were nearly 100% covered by corrosion.
- Some evidence of corrosion was observed on the chipped samples (no intentional through film damage) which appeared to start from voids along the edges.

The extensive corrosion on the scribed samples, presence of corrosion on the chipped samples and ease with which the polyurea material was removed from the substrate suggested that a primer was needed to improve the performance of this material. Subsequent testing was done evaluating the water reducible CARC primer (MIL-DTL-53030), a zinc-rich primer and a proprietary primer supplied by the vendor. Testing was repeated through 24 cycles of GM9540P (first tactile observation of cutback) and samples were destructively evaluated. Figure 1 shows the results of this evaluation. These results showed that the use of a primer improved the underfilm corrosion (cutback) of the samples (higher values indicate better performance). Based on these results a primer was recommended for use prior to application of any chip resistant material.

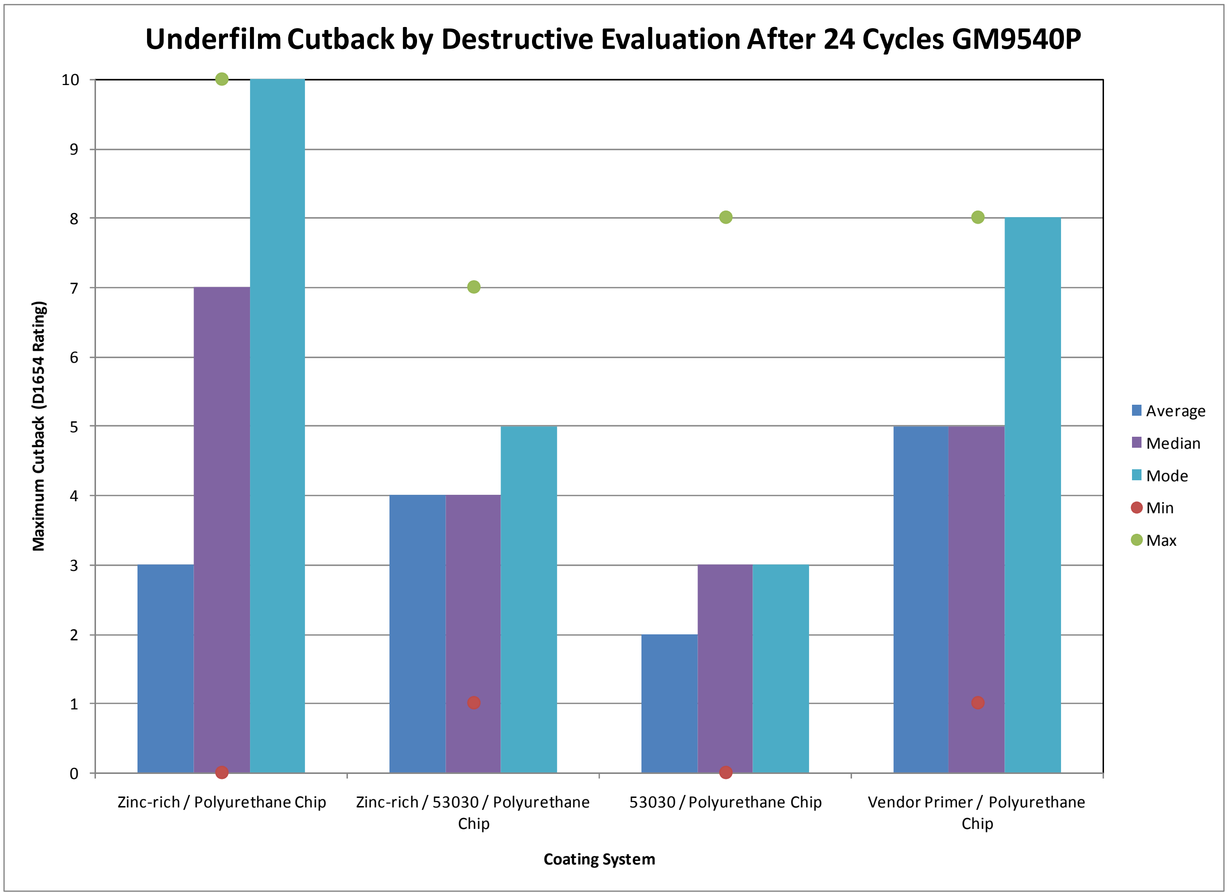


Figure 1 – Destructive Cutback Results for Tough Coating Applied over a Primer.

Considerations and Limitations

The use of chip and abrasion resistant coatings does provide additional protection to the substrate with respect to mechanical damage from rocks and other road debris. Furthermore, it would appear that when topcoated with the CARC polyurethane topcoat that coating is less prone to chipping damage (provided adequate adhesion to the chip resistant material is achieved). However, these materials do not appear to perform well when applied directly to metal if a holiday or void exists (either from the application process or by damage) and corrosion damage can progress with little to no visible evidence. Therefore these materials should only be used when applied over a suitably corrosion resistant primer.

Application Considerations

The majority of the products available as chip and abrasion resistant materials that would be used per the two CIDs (A-A-59719 or A-A-59800) are plural component materials with a rapid (<20 min) cure time. As such plural component spray equipment would be needed to apply these materials, which can be an additional capital investment.

One vendor's materials is available as a cartridge spray system (Figure 2), which can be applied via compressed air. This can eliminate the need for an investment in plural component spray equipment and only require a minimal cost (<$1,000) for the cartridge system (excluding the cost of coating materials). However, the limitation for this is that currently cartridges are only available in 700 mL (total) quantities and would require several cartridges to coat an entire cargo bed. Therefore, other than repair or in areas where a plural component system cannot be installed the cartridge method would likely not be suitable for any high volume production.

Figure 2 – Example of Polyurea Coating Cartridge Spray Application.

Current Use of Chip Resistant Coatings on DoD Ground Vehicles

Currently there are known to be at least three weapon systems using chip and abrasion resistant materials in two areas, these are:

- Undercarriage components (bottom of radiators and oil pan) – US Army, Family of Medium Tactical Vehicles (FMTV).
- Cab floors (replacement for foam mats) – USMC Medium Tactical Vehicle Replacement (MTVR) and Logistics System Vehicle Replacement (LVSR).

In addition to these applications done at the Original Equipment Manufacturer (OEM) some test applications have also been performed on USMC cargo trailers for the reserve units.

ZINC-RICH COATINGS

Zinc-rich coatings are used by many industries for the corrosion protection of steel substrates. Its uses include highway and infrastructure, industrial and automotive applications. These coating materials have demonstrated improved performance when compared to carbon steels protected only by spray applied organic coatings (such as an epoxy urethane system). Although processes such as galvanizing (through hot-dip processing or the use of galvanized sheet steel) have superior performance (and are more widely used in automotive applications), the use of a zinc-rich coating is more amenable for upgrade / repair activities (such as RESET) and will improve the corrosion resistance of underlying steel and extend the service life with respect to general corrosion.

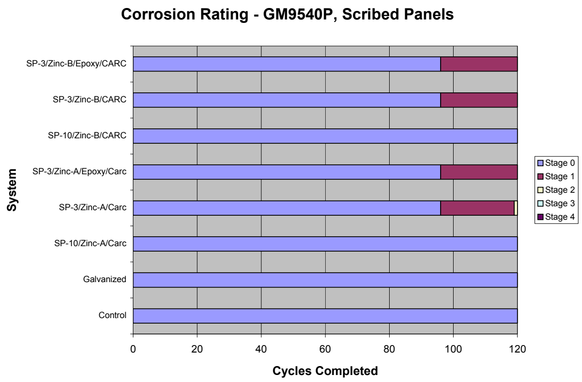
Summary of Information and Testing

The use of zinc for sacrificial corrosion protection has been performed in automotive applications since the 1970's, primarily in the form of hot-dip galvanizing and galvanized sheet steel. Zinc-rich paints provide lesser protection than galvanizing, although their protection is typically improved as compared to organically coated carbon steel. In an OEM type environment the use of galvanized components or hot-dip processes are typically preferred. However, for repair and touch-up operations (including operations during manufacturing) zinc-rich paints help restore or provide at least part of this improved protection.

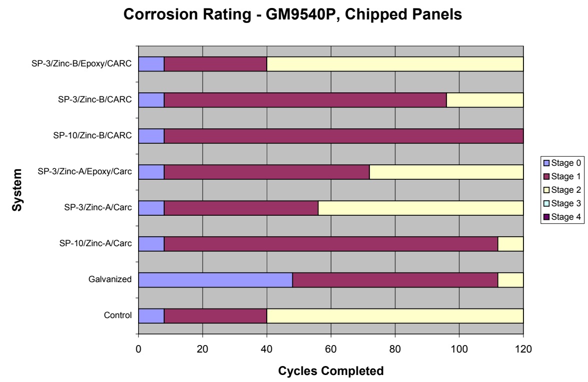
In the 2002 Tri-Service Corrosion Conference paper, "Evaluation of Zinc-rich Primers for use on Army Vehicle Systems", two (2) zinc-rich paints overcoated with the complete CARC system were evaluated for use on military vehicles. Test samples were evaluated through 120 cycles of GM9540P and in natural marine atmospheric exposure along the Atlantic Seaboard (Sea Isle City, NJ and Cape Canaveral Air Force Station, FL). Zinc-rich coatings were applied to pre-rusted steel panels cleaned to a SP-3 condition and virgin steel panels cleaned to a SP-10 condition. All samples were rated using the TACOM stages of corrosion (0 = no corrosion, 4 = complete perforation).

At the completion of the GM9540P testing all of the zinc-rich samples over a SP-10 surface with scribes had corrosion ratings of 0 (no deterioration). The zinc-rich samples over a SP-3 surface with scribes had ratings of 1, with one system having a rating of 2. On samples with chipping damage, stage 2 corrosion was observed on all zinc-rich samples, except one system applied over a SP-10 surface. However, the performance of these samples was comparable or better than the control samples with only a CARC coating (where the control samples achieve a stage 2 rating sooner than most zinc-rich samples).

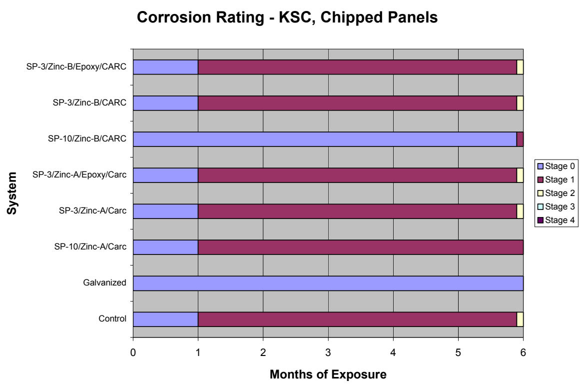
In marine atmospheric exposure similar results were observed on chipped samples through six (6) months of testing (no deterioration was observed on scribed samples). Samples where the zinc-rich coating was applied over a SP-10 surface had better performance than those applied over a SP-3 surface. In both environments all zinc-rich and control samples had some corrosion after six (6) months, although corrosion occurred sooner on the control samples and the samples where the zinc-rich paint was applied over a SP-3 condition. At the Cape Canaveral Air Force Station (CCAFS) site the zinc-rich paint applied over a SP-3 condition was rated as having stage 2 corrosion at the completion of testing. Figure 3 shows these results.



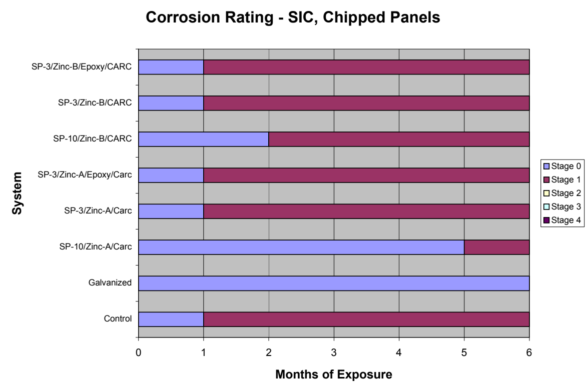
GM9540P Corrosion Results – Scribed Samples



GM9540P Corrosion Results – Chipped Samples



CCAFS Corrosion Results - Chipped



SIC Corrosion Results - Chipped

Figure 3 – Corrosion Data from 2002 Tri-Service Corrosion Paper, "Evaluation of Zinc-rich Primers for use on Army Vehicle Systems."

In the 2003 Army Corrosion Summit briefing, "Extension of Vehicle/Component Lifetime Through the Use of Sacrificial Metallic Coatings for Army Vehicles", a zinc-rich paint was evaluated through accelerated corrosion testing (ASTM B117 for 2,000 hours and GM9540P for 120 cycles). The results of this testing were that materials painted with a zinc-rich coating followed by application of a CARC system performed better than other samples (as rated by ASTM D1654). Performance was typically better in the GM9540P cyclic corrosion test, with rating ranging approximately from 8 to 8.75. In the ASTM B117 static salt fog test ratings ranged from approximately 6.25 to 8.75. The addition of a topcoat improved performance and all systems were either the top performers or amongst the top performers.

Considerations and Limitations

The use of zinc-rich paints can provide added corrosion protection to steel as compared to the use of organic coatings. However, there exist some considerations and limitations on its use.

<u>Environmentally Assisted Cracking:</u> There may be a potential issue with respect to Environmentally Assisted Cracking (EAC) if these products are used with high-strength steels (such as those used in armor applications). The concern is that due to the sacrificial protection provided by the zinc particles in the paint sufficient hydrogen may be produced that it could migrate into the steel. There it can accumulate to the point where it initiates sufficient stress to result in cracking. This can result in a weakening of the metal and decrease in its overall strength.

Currently there is little data available in industry to support or refute these concerns. The best reference currently available is a briefing given by the Joint Cadmium Alternatives Team (JCAT)[2] where a single zinc-rich paint was evaluated in deionized (DI) water, seawater and de-icing fluid. In this test the only failures observed were in seawater and it was concluded by the authors that zinc-rich coatings should only be considered for ground vehicles. Figure 4 provides a copy of their tabular data.

150 Hour Test at 45%	
Navair applied ZRC Cold Galvanized	
Enviroment	result
DI Water	passed at 150 hours
DI Water	passed at 150 hours
DI Water	passed at 150 hours
DI Water	passed at 150 hours
Sea Water	passed at 150 hours
Sea Water	failed at 128 hours
Sea Water	passed at 150 hours
Sea Water	passed at 150 hours
De-icing fluid	passed at 150 hours
De-icing fluid	passed at 150 hours
De-icing fluid	passed at 150 hours
De-icing fluid	passed at 150 hours

150 Hour Test at 45%		
Navair applied ZRC Cold Galvanized		
Enviroment	Damaged	result
Di water	Yes	passed at 150 hours
Di water	Yes	passed at 150 hours
Di water	Yes	passed at 150 hours
Di water	Yes	passed at 150 hours
Sea Water	Yes	passed at 150 hours
Sea Water	Yes	passed at 150 hours
Sea Water	Yes	failed at 14 hours *
Sea Water	Yes	failed at 98 hours *
De-icing fluid	Yes	passed at 150 hours *
De-icing fluid	Yes	passed at 150 hours *
De-icing fluid	Yes	passed at 150 hours *
De-icing fluid	Yes	passed at 150 hours *

Figure 4 – Tabular Data from JCAT Presentation.

Currently, in parallel to this effort, work is being performed to evaluate the EAC propensity of high-strength steels painted with zinc-rich coatings under atmospheric conditions. Until these results are provided the use of zinc-rich coatings on high-strength steels is not recommended.

Application Considerations

Zinc-rich coatings can be applied via brush, roller, spray and as a powder coating material. Most of the above programs have investigated these coatings through brush and spray application. In these programs spray application provided the most uniform coat and although brush application was typically more variable, it did provide sufficient protection.

When the zinc-rich material is applied as part of a system (as was done in most of these investigations and is planned with RESET) compatibility with the overcoat material must be verified. In one of the above projects when the zinc-rich material was overcoated with an epoxy primer the solvents were incompatible and resulted in cratering of the epoxy material. A tie-coat of a compatible product (to both systems) was used and alleviated this issue.

In addition to compatibility zinc-rich coatings require the use of good Quality Assurance / Quality Control (QA / QC) processes as is the case with any high-tech coating system. This is particularly important to ensure that the zinc-particles are uniformly distributed, allowing contact between each other and the steel substrate (this allows for the coating to provide sacrificial corrosion protection).

[2] Steven A. Brown, Andy Schwartz, Cadmium Repair Alternatives on High-Strength Steel, http://www.jgpp.com/projects/jcat/documents/Jan%202006/Schwarz%20sermetel%20project%20cad%20altermatives%20brief_V1.PDF

Current Use of Zinc-rich Coatings on DoD Ground Vehicles

Zinc-rich coatings have been used for ground vehicle systems within the DoD. An example of the use of zinc-rich coatings includes the Medium Tactical Vehicle Replacement (MTVR). This system uses zinc-rich paints on steel frame members for corrosion protection. This is performed during manufacturing on cargo bodies by the Original Equipment Manufacturer (OEM). Another example is the recent Naval Message by the USMC Corrosion Prevention and Control (CPAC) Program Office, which now allows for the use of zinc-rich coatings on ground weapon systems for upgrade and / or the repair of damaged galvanized sheet steels. Both of these applications of zinc-rich coating are based on products that meet the salient characteristics of the TACOM CID A-A-59745 for zinc-rich paints. Products that meet these CID characteristics will be considered for any RESET demonstration.

CONCLUSIONS

The above corrosion control technologies have been demonstrated to provide improved corrosion resistance in a military ground vehicle operating environment. All of these materials have been implemented, in limited quantities, on military weapon systems. Incorporating these technologies into rebuild / RESET is available with most requiring no additional capital investment or significant changes in current processes. Currently efforts are underway to demonstrate these technologies on RESET activities in Ft. Lewis, WA and Red River Army Depot (RRAD) in Texarkana, TX. These demonstrations will be used to develop the supporting documentation and Return on Investment (ROI) analysis to facilitate their specification by Program Managers (PMs) in the rebuild of weapon systems to reduce Operations and Sustainment (O&S) costs.

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