Abstract

Intermediate level repairs of USMC tactical vehicles and associated equipment form a critical part of the service Corrosion Prevention and Control strategy. Over the past several years, technical guidance to these facilities has been modified to introduce new products and processes to improve corrosion control. While new technologies and materials have been introduced, less HQ emphasis has been placed on standardizing work practices and incorporating industrial specifications to control surface preparation and coating application. This may lead to inconsistent practices in intermediate repair facilities, potentially resulting in differing painting quality and corrosion control.

As part of a continual improvement process, there is interest in optimizing the coating application standards within such facilities. The introduction of such standards would also include quality assurance (QA) checks. The optimization intends to balance coating system performance with the incremental cost of achieving the standards. This paper reviews this trade-off analysis and recommends areas that might be addressed in a standardization program.

Introduction

The USMC is putting forth significant effort to improve the cost effectiveness of protective coatings used on tactical vehicles and associated ground-based assets. The application of these coatings during intermediate level repair is difficult to standardize. Unlike depot level maintenance where a vehicle may be completely disassembled to its basic components, it is not cost effective to extensively disassemble components during intermediate level maintenance. Consequently some compromises have to be made in surface preparation and coating application. Areas where these types of compromises are made include mating surfaces which cannot be disassembled and difficult to reach areas (shielded areas) which may contain residual corrosion products prior to painting. In addition, painting using hand-held equipment against surfaces of highly varying orientations (i.e., non-flat surfaces) can result in variable dry-film thickness. The following are used as examples of the problems that can occur on vehicles and other ground-based assets.

Dry Film Thickness Variations

The standard CARC coating systems are intended to be applied in accordance with the requirements of MIL-DTL-53072. This specification calls for a target dry film thickness (DFT) for the primer and topcoat in the range of 2.8 to 4.0 mils. As an example of the
variability that can result on complex vehicle surfaces, Figure 1 provides a summary of a series of DFT measurements for a new armored USMC vehicle.\(^1\)

![Paint DFT Distribution by Location](image)

**Figure 1 - Distribution of Coating DFT**

When observing the data it is immediately apparent that the vast majority of the DFT readings are above the minimum value of 2.8-4.0 mils. However for the vehicle “box” about 20-70% of the data are below the minimal required value, and in areas the primer was visible through the surrounding topcoat. In an area that will see considerable physical stresses, the lack of a complete coating system increases substantially the chances for damage.

In vehicle areas other than the “box,” about 5 to 30% of the DFT readings are also below the 2.8-4.0 mil minimum. While a small percentage of areas below the minimum specified value may seem insignificant and would probably not cause the average vehicle coating film thickness to be below the standard, a substantial area of low DFT can have a significant impact on corrosion control. These areas of low DFT will more than likely be the first to fail from through-film corrosion.\(^2\) It is interesting to note that the percentage of DFT readings below the minimum specified value is consistent with painting for other

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\(^1\) “Baseline Inspection Of As-Produced MRAP Vehicles For Identification Of Systemic And Manufacturer Specific Corrosion Issues,” Elzly Technology Corp. report for NSWC-CD / MRAP JPO, May, 2008

military equipment and industrial structures\textsuperscript{3}—these represent weak areas in the overall coating structure.

Consider that a 5\% coating damage represents a substantial part of the overall area. Figure 2 shows a surface area where 0.3\% of the total surface is colored. If the 5\% of the total surface area that is below the required DFT begins to corrode, it will rapidly create an unacceptable condition.

\textbf{Figure 2 - 0.3\% Surface Color}

One other telling factor about the impact of a low DFT is that it can create a tendency for holidays in the coatings—holidays represent non-visible defects in the coating that are the result of inadequate coating thickness. Figure 3 shows the tendency for such holidays as a function of the CARC primer thickness over the blast profile.\textsuperscript{4}

\textsuperscript{3} “Using Electronic Tools and Databases to Manage Coatings used for Corrosion Control,” J. Ellor & P. Ault, paper 081227, CORROSION 2008, NACE Houston, TX
\textsuperscript{4} Unpublished study of M113 Hull painting by Ault, et. al. (1993)
The data clearly show that as the blast profile increases a primer with a film thickness in the range of 1.5 to 2.5 mils is inadequate to cover the profile. In such cases the primer thickness has to be increased or the blast profile range has to be limited. This is problematic to assets using the CARC system in that the primer is the primary material providing corrosion control.

Similar data can also be collected to show that holiday propensity will increase over complex surfaces such as fastener heads and “sharp” angles and edges.
A low dry film thickness creating weak spots or holidays in the coatings can lead to rapid surface corrosion through the coating. Figure 4 shows the corrosion occurring on an armored vehicle mirror bracket due to poor coating application and a low dry film thickness on the coating.

Over half of the film thicknesses were below the specified minimums in these corroded areas. The problem was a systematic issue on these vehicles and resulted in 3% of the mirror brackets corroding before the vehicles were even delivered to the USMC.

Figure 4 - Through Film Rusting on Mirror Bracket

Variations in Surface Cleanliness

As suggested above it is difficult to achieve a high degree of cleanliness in all areas of a vehicle – particularly in areas where the vehicle is not completely disassembled. Figure 5 shows one example where an asset was recoated and the painting was carried out over corroded steel.

5 Elzly Technology Corp. trip report to NSWC-CD, “Inspection of Coating Delamination,” 6 OCT 2008
Because corrosion is often the result of aggressive salt species coming in contact with the steel, painting over rust usually creates a weak spot in the coating. Painting over such surfaces can greatly accelerate paint failure. Figure 6 shows the impact of different degrees of surface preparation on coating life. Coating failure in this study was defined as excessive coating cutback at a holiday or through-film corrosion.

Figure 5 - Painting Over Rust in Wheel Well

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6 “Performance of Alternate Coatings in the Environment,” SSPC 89-03, June 1989
Figure 6 - Effect of Surface Preparation on Coating Life

The data are for a range of coating systems exposed to different environments—including both marine and harsh industrial environments. While the study showed some variability in the results as a function of exposure location and coating type, the predominant effect of surface preparation was clear - Painting over residual rust creates a substantially higher likelihood of coating failure.

Tradeoff Analysis of Implementing Additional Coating Standards

The USMC currently conducts intermediate level maintenance painting at four different locations to support the local Marine Expeditionary Force (MEF): Camp Lejeune (NC), Camp Pendleton (CA), Kaneohe Bay (HI), and Okinawa. Each operates in a different environment. Within each location the condition of vehicles after painting are tracked as part of the USMC CPAC Program Office’s initiative to maintain metrics on asset condition. The “CPAC Database” is described in more detail within the USMC CPAC Program Office web site.7

The CPAC Database maintains a rating for multiple inspection areas on these items. These ratings includes such items as the condition of body panels, the cab, crevices on the vehicle, fasteners, hydraulic cylinders, undercarriage, frames, etc. Items are rated as Category 1, 2, 3, 4, or 5 as described below.

7 www.marcorsyscom.usmc.mil/cpac/usmc_cpac.asp
Category 1: Item requires no corrosion repair or preservatives, and has been assessed within the past 6 months. The goal at this level is to maintain the item as a category 1.

Category 2: Item requires surface preparation, spot paint, and preservation at the operator and/or organizational level. The goal at this level is to return the item to category 1 condition.

Category 3: Item requires maintenance performed beyond the organizational level. Spot painting has slowed the corrosion process, but the item is now in a condition that requires complete repainting and undercoating. The item must be inducted into intermediate level repair so that it will be returned to the owning unit in a category 1 condition.

Category 4: Item requires repair to sheet metal, major frame components, paint, blasting and undercoating (e.g., replacement or repair of components such as doors, fenders, and chassis frame rails, or battery boxes due to corrosion). The goal of this effort is to immediately induct the item into intermediate level repair so that it will return to the unit in a category 1 condition.

Category 5: The item is degraded to a degree that requires depot level repair and replacement or disposal based on the deterioration caused by corrosion.

The intermediate level repair facilities are designed to repair items with a rating of Category 3 or Category 4. The asset condition reports record the presence of specific defects in each inspected area along with other pertinent information concerning the asset. One of these additional pieces of data is the “paint date;” this date represents the last time the vehicle received complete repainting. The difference in the date of the assessment and the date of last repainting provides for an estimate of the paint age on the vehicle. (Short of complete repainting, certain areas of the vehicle could receive spot recoating subsequent to this date.)

As the subject paper is concerned with balancing the cost of additional standards in intermediate level repainting with the potential benefits, the CPAC Database was reviewed to identify the time it takes for one of several potential defects to be observed that would render an asset as a Category 3 or 4 item—the condition that would require the asset to be returned to an intermediate level facility for repair.

The defects of interest are those reflective of deterioration in the coating systems. From within the CPAC Database these include those listed as paint deterioration or corrosion on body panels, paint deterioration or corrosion at crevice sites, and repainting needed due to excessive (previous) spot repainting. For each MEF site, the data for the asset condition were reviewed to find the presence of one or more of these phenomena that would render the asset a Category 3 or 4. The data were sorted by the time since the last repainting (i.e., coating age). The number of occurrences of a single Category 3 or 4 condition due to one of these reasons was determined for several sequential one-year timeframes. The number of samples in each timeframe was also noted. The number of occurrences for each timeframe was calculated.

Note that the analysis does not include the deterioration of undercoatings, another primary task in intermediate level repair, as such deterioration was not considered to be as significant of a function of the initial CARC coating system applied to the external vehicle surfaces.
occurrences of a Category 3 or 4 condition per the number of samples in a timeframe provided a percentage (%) value of assets requiring work at an intermediate level due to paint deterioration. Table 1 provides a summary of the data for the four MEF locations reviewed.

**Table 1 – % of Population in each Age Group Becoming a CAT 3 or CAT 4 Due to Paint Deterioration**

<table>
<thead>
<tr>
<th>Population Age</th>
<th>Pendleton</th>
<th>Lejeune</th>
<th>Okinawa</th>
<th>Hawaii</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1 yr</td>
<td>0.2%</td>
<td>1%</td>
<td>3%</td>
<td>9%</td>
</tr>
<tr>
<td>1-2 yr</td>
<td>0.8%</td>
<td>8%</td>
<td>16%</td>
<td>4%</td>
</tr>
<tr>
<td>2-3 yr</td>
<td>1.1%</td>
<td>11%</td>
<td>36%</td>
<td>33%</td>
</tr>
<tr>
<td>3-4 yr</td>
<td>2.8%</td>
<td>20%</td>
<td>51%</td>
<td>61%</td>
</tr>
<tr>
<td>4-5 yr</td>
<td>4.4%</td>
<td>24%</td>
<td>50%</td>
<td>40%</td>
</tr>
</tbody>
</table>

As indicated the range is variable; in some areas paint deterioration is much higher than in others. The USMC generally recognizes that Camp Pendleton is the least aggressive site for maintaining assets, mostly due to the local dry conditions. The corrosivity of the conditions within Okinawa and Hawaii are much more significant. Camp Lejeune falls in between the two extremes.

Looking at the above data (Table 1), a single piece of equipment would have a 90%, 45%, 11%, and 14% chance of remaining in a Category 1 or 2 rating condition at Camp Pendleton, Camp Lejeune, Okinawa, and Hawaii, respectfully, over a 5 year period. Given a desired 5 year life time for the asset coating system, other than in Camp Pendleton, the chances of surviving this long are not high. Less than 25% of assets in Okinawa or Hawaii would remain in a Category 3 or 4 condition thru 4 years and about 50% would remain as such through 3 years.

If we assume that the conditions leading to these failures might be mitigated by increased standardization and quality assurance in the recoating of the vehicles, we should consider the question of how much more we might pay to achieve improved life (i.e., what is the warranted incremental investment.) To simplify this analysis, we can assume that the nominal cost (initial investment) in intermediate painting of an asset is $5,000. We can assume that the lost investment is proportional to the time prior to 5 years where the asset first becomes a Category 3 or 4 item. Thus an asset failing in the first year costs the USMC $5,000, in the second it is $4,000, all the way to the last year, where it is $1,000. If we assume a hypothetical base of 100 assets, we can predict the number with better than a Category 3 or 4 rating as follows:

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9 As indicated by Body Panel (4_1,3), Crevice (4_1, 3), and Repainting (3_1) ratings
Applying the cost per year figures we can calculate the “lost” investment. For example consider Camp Lejeune. In the first year, one of the 100 assets would have been a Category 3 or 4 item—thus $5,000 x 1 asset = $5,000. Table 3 summarizes this data and the total cost, as compared to the initial investment of $5,000 per asset.

Table 2 – Summary of Number of Assets with Less Than Category 3 or 4 Rating Over Five Years

<table>
<thead>
<tr>
<th>Population Age</th>
<th>Pendleton</th>
<th>Lejeune</th>
<th>Okinawa</th>
<th>Hawaii</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>0-1 yr</td>
<td>100</td>
<td>99</td>
<td>97</td>
<td>91</td>
</tr>
<tr>
<td>1-2 yr</td>
<td>99</td>
<td>91</td>
<td>81</td>
<td>87</td>
</tr>
<tr>
<td>2-3 yr</td>
<td>98</td>
<td>81</td>
<td>52</td>
<td>58</td>
</tr>
<tr>
<td>3-4 yr</td>
<td>95</td>
<td>65</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>4-5 yr</td>
<td>91</td>
<td>49</td>
<td>12</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 3 – Cost to the USMC for Paint Deterioration before Five Years Life

<table>
<thead>
<tr>
<th>Population Age</th>
<th>Pendleton</th>
<th>Lejeune</th>
<th>Okinawa</th>
<th>Hawaii</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1 yr</td>
<td>-</td>
<td>5,000</td>
<td>15,000</td>
<td>45,000</td>
</tr>
<tr>
<td>1-2 yr</td>
<td>4,000</td>
<td>32,000</td>
<td>64,000</td>
<td>16,000</td>
</tr>
<tr>
<td>2-3 yr</td>
<td>3,000</td>
<td>30,000</td>
<td>87,000</td>
<td>87,000</td>
</tr>
<tr>
<td>3-4 yr</td>
<td>6,000</td>
<td>32,000</td>
<td>54,000</td>
<td>70,000</td>
</tr>
<tr>
<td>4-5 yr</td>
<td>4,000</td>
<td>16,000</td>
<td>13,000</td>
<td>9,000</td>
</tr>
<tr>
<td>Totals</td>
<td>17,000</td>
<td>115,000</td>
<td>233,000</td>
<td>227,000</td>
</tr>
</tbody>
</table>

% of Original | 3.4% | 23.0% | 46.6% | 45.4%

The original cost figure is simply the $5,000 per asset times 100 assets. So the lost investment is quite significant in Okinawa and Hawaii—the most corrosive areas. The analysis presented is somewhat simplistic. It does not account for time value of money nor the fact that replacement / repainted assets would again be subject to a variable coating failure rate. But it does suggest that for the most corrosive areas, a significant additional investment is warranted. However any incremental cost must provide additional corrosion control benefit. The areas of surface preparation, application thickness, and holiday control are simply three areas of potential enhanced standardization; in some cases it may be necessary to continue to seek new materials and procedures to improve corrosion control.
It is also worth noting that the complete optimization of incremental investments may also be a function of the type of asset being maintained. Table 4 provides a summary of the paint deterioration rates for three specific types of assets maintained in the corrosive environment of Okinawa.

**Table 4 – III MEF Data by Vehicle Type (General Classifications)**

<table>
<thead>
<tr>
<th>Population Age</th>
<th>HMMWV</th>
<th>MTVR</th>
<th>&quot;Trailer&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1 yr</td>
<td>14%</td>
<td>20%</td>
<td>46%</td>
</tr>
<tr>
<td>1-2 yr</td>
<td>13%</td>
<td>30%</td>
<td>54%</td>
</tr>
<tr>
<td>2-3 yr</td>
<td>15%</td>
<td>N/R</td>
<td>49%</td>
</tr>
<tr>
<td>4-5 yr</td>
<td>19%</td>
<td>40%</td>
<td>57%</td>
</tr>
</tbody>
</table>

N/R - No failures noted; only a population sample of 5 MTVRs.

In this table we can see that the percentage of assets with paint deterioration is a function of asset type as well as time. For some assets such as HMMWVs with substantially more aluminum body panels and boldly visible structures there is more of a tendency for lower corrosion ratings (less total corrosion). For trailers, with multiple crevices, complex surfaces / angles to coat and abrasion damage to load-carrying surfaces, the paint deterioration rates are substantially higher. Each type of asset also is substantially different in initial cost and thus different investment practices may also be warranted for such factors. More analysis of such factors is required before optimizing the overall painting processes.

**Conclusions**

1. The lack of dry film thickness control, presence of coating holidays, and painting over corroded surfaces can reduce the lifetime of the standard CARC coating systems. To some degree such practices are unavoidable during intermediate level recoating work.

2. For assets that operate in the most corrosive environments, it is reasonable to consider substantially increased focus and efforts to improve paint quality to increase asset life in a Category 1 or 2 condition. Given that USMC assets are expected to perform in highly corrosive marine environments, such improvements are also probably warranted in less corrosive areas, such as Camp Pendleton, that currently stores equipment.

3. Asset condition as listed within the CPAC Database should continue to be analyzed to determine optimum investment strategies.