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Predicting Coating Life Cycles for Ground Vehicles

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ABSTRACT

In-service coating performance data is often collected in an effort to predict coating life expectancy and time to failure. Having a general knowledge of coating life expectancy has many benefits such as being able to project future maintenance requirements, prioritize repairs, estimate the impact of application parameters on the coating life, and quantifying the risk of deferred maintenance. The DoD maintenance communities benefit from knowing which assets are a priority for repair as well as the performance factors influencing coating life.

The following paper addresses how to integrate asset inspection data, engineering data and statistical methods to illustrate ground vehicle coating life cycle and subsequent materiel degradation.

Key words: Ground Vehicle, Life Cycle, Environment, Maintenance Intervals, Coating Failure

INTRODUCTION

Knowing when to expect a coating failure is a powerful tool for the designer, owner, operator and maintainer of a ground vehicle. This information will allow you to predict necessary maintenance schedules and when combined with corrosion rate estimates, metal loss. Utilizing this data, preventative maintenance programs can be implemented to reduce maintenance costs.

The following presents a method of ranking the effects of various environments on a ground vehicle (although it is applicable to other structures in the same climate). The corrosion information gathered from this method affords us the ability to predict preventative service and or maintenance intervals. While it can be used without additional information, it is best utilized in conjunction with in-service coating condition data from documented exposure to provide a corrosion model applicable to locations of which there is no first hand in-service knowledge.

EXPERIMENTAL PROCEDURE

Ground Vehicle Coating Failure Phenomena

For ground vehicles there are two major steps of concern in the onset of corrosion. First the coating must breakdown and no longer function to protect the substrate material. Secondly, once coating breakdown occurs corrosion of the substrate begins. This corrosion progresses until it is determined that the level of corrosion is no longer acceptable.

Coating Breakdown

Coatings breakdown over time as a result of outside stressors. Some stressors such as mechanical abrasion through use of the vehicle (i.e., loading and unloading, wear from terrain) are unpredictable. Other stressors such as environmental factors within the operating climate can reasonably be used to predict coating performance over time.

A study[1] of the effects of the environment on rusting suggested that the predominate environmental characteristics that effect coating deterioration are an increasing rate of absolute humidity and to a lesser extent increase in temperature. This testing considered a wide range of organic coatings over steel exposed in different natural environments.

Absolute humidity is a measurement of the absolute amount of water that the air contains. Absolute humidity differs from relative humidity in that relative humidity is a measurement of the amount of water vapor that is in the air relative to saturation at a given temperature. Absolute humidity directly correlates to rust-through as seen in Figure 1[1] below.

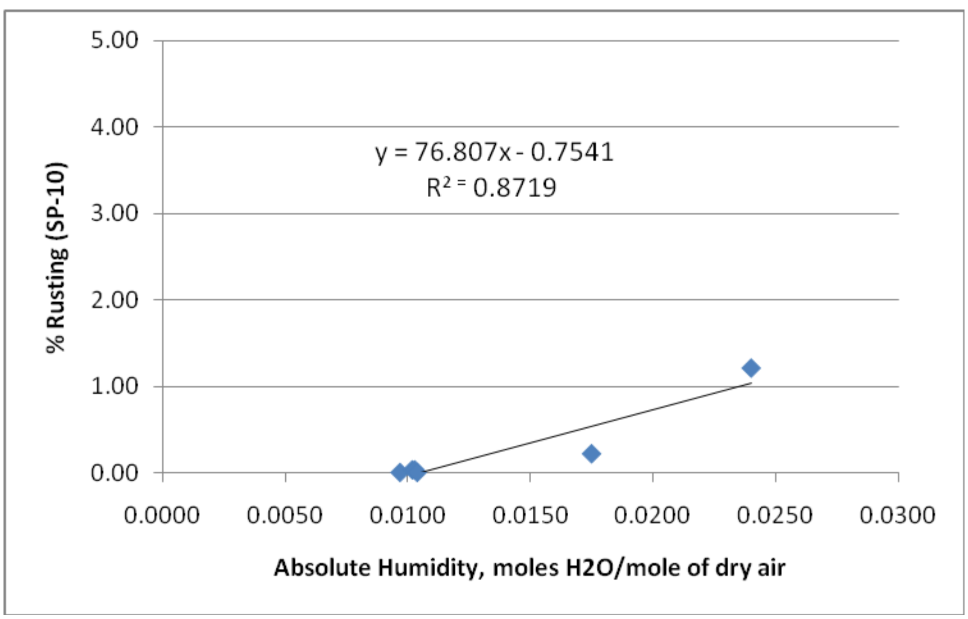

Figure 1: Percent Area Rusting vs. Absolute Humidity (SP-10) at 5 Years

The above figure shows us the correlation between percent area rusting and the absolute humidity. It can be seen that as the absolute humidity increases, the percent area rusting increases linearly. Areas with higher absolute humilities will show greater amounts of rusting. Not only is this true for a near white metal surface (SP-10) but is also shown to be true for a power tool cleaned (SP-3) surface as seen in Figure 2[1].

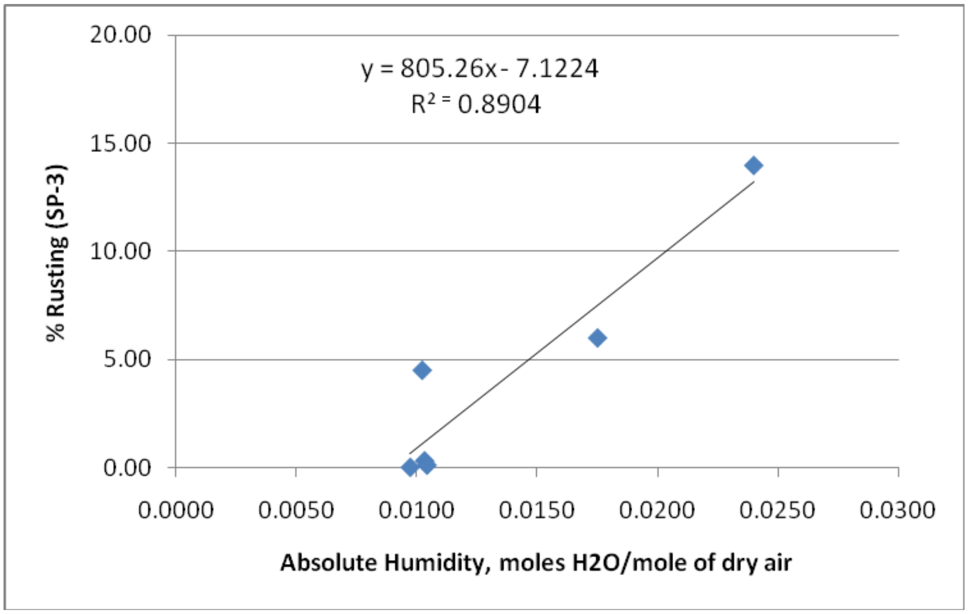

Figure 2: Percent Area Rusting vs. Absolute Humidity (SP-3) at 5 Years

The study authors also plotted their SP-10 findings vs. SP-3 findings as seen in Figure 3[1]. This figure shows that the correlations are linear and are a relatively good fit. From this we can infer that coating breakdown and subsequent rust through is influenced by cleanliness and/or surface preparation methods; the break-down rate over SP-3 is about 10 times that of the SP-10 cleaned surface.

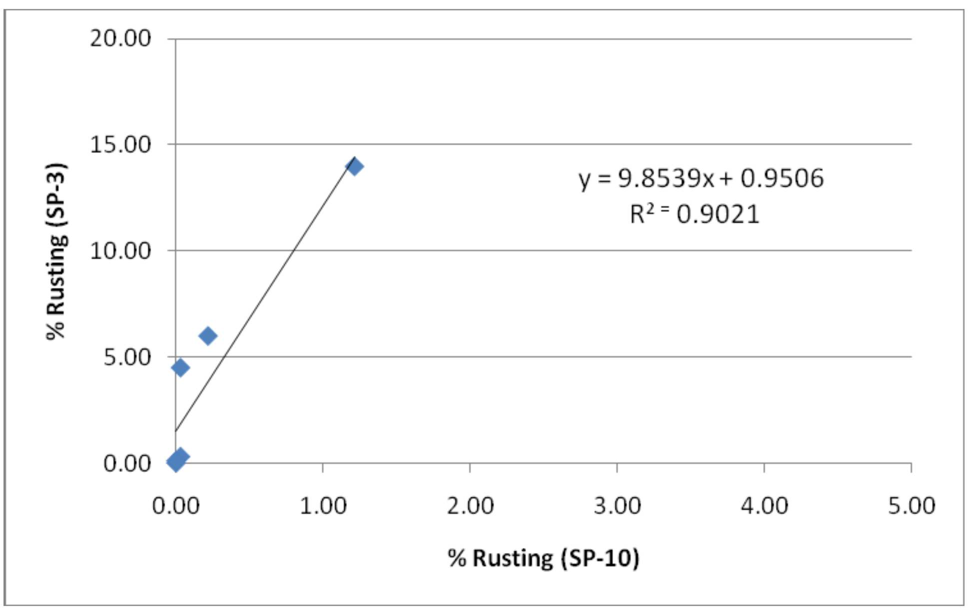

Figure 2: Percent Area Rusting, SSPC SP-3 vs. SSPC SP-10 at 5 Years

The effects of absolute humidity on ground vehicles are dependent on the operating location of the vehicle. Through the use of average temperatures and average relative humidity data published through known weather databases, we are able to assign an estimated absolute humidity to an operating location.

Corrosion Rate

Much work has been done in determining corrosion rates of metals in certain environments. Of the more extensive works is the ISOCORRAG[2] International Atmospheric Exposure Program. Exposure tests were done of several different alloys in over 53 exposure sites located within 13 countries. The purpose was to test several different locations (i.e., rural, industrial, urban, marine) experiencing various environmental conditions.

Data was collected for environmental conditions as well as mass loss and corrosion rate. The in-depth study allowed the authors to determine the kinetics of the corrosion reaction and therefore allowed them to determine a function which would allow for categorization of corrosivity of a particular site based on the effects of sulfur dioxide (SO_2), chlorides (Cl), time of wetness (TOW) and temperature (T). Functions[2] were presented for generic categories of alloys: carbon steel, zinc, copper and aluminum.

Carbon Steel

$$C_{St} = 0.085 * SO_2^{0.56} * TOW^{0.53} * \exp(f_{st}) + 0.24 * Cl^{0.47} * TOW^{0.25} * \exp(0.049T)$$

$$f_{st}(T) = 0.098(T-10) \text{ when } T \leq 10^{o}C\text{, otherwise } f_{st}(T) = -0.087(T-10)$$

We then apply this equation to the data for each site location to determine a corrosivity rating. Carbon steel was chosen as the determining function as majority of the components on the ground vehicles which present corrosion issues are steel. Additionally the carbon steel function was chosen since it had a higher correlation value (R^2) than aluminum which is the other common alloy used in vehicle production.

RESULTS

Application to Ground Vehicles

Ground vehicles have the potential to operate (includes storage) in several different climates throughout their lifespan. For the purposes of ranking local corrosivity and recommending service intervals, one hast to assume the assigned base will represent the major climate influence.

Knowing the vehicle location, one can determine the local conditions contributing to coating breakdown and surface corrosion. Table 1 provides a source for these data.

Item	Key	Data Source
Coating Breakdown	Absolute Humidity	Use average Dew Point and Temperature to estimate average Absolute Humidity IAW Ref (3). Weather data from local databases.
Corrosivity	Time of Wetness (TOW)	Estimate TOW based on temperature and relative humidity IAW Ref (4). Temperature and relative humidity based on local weather databases.

Corrosivity	Cl^-	Cl^- modeled from NADP data for salt fall IAW practice described in Ref (5). Use NADP (National Atmospheric Deposition Program) dataset for Cl^- data.
Corrosivity	SO_2	Use SO4 from NADP dataset. Models as for Cl^-.
Corrosivity	Temperature	Use local weather databases.

Based on condition assessment data, the condition of vehicles at actual locations is known. This includes sites that are highly corrosive and those that are very low in corrosion. Maintenance intervals for vehicles at each site type have been previously established based on empirical observation of their condition and tracking the merits of different maintenance intervals. The question remains on how to extend this knowledge to other sites.

The procedures described above provide a basis for estimating coating breakdown rate and the subsequent corrosion rate of exposed metal. The corrosion damage to vehicles stored at such sites will be a combination of coating breakdown followed by metal loss. The propensity for coating breakdown is shown to be reasonably directly proportional to absolute humidity. The level of absolute humidity can therefore serve as an index on the likelihood for coating breakdown. Subsequent to coating breakdown, the corrosion rate of the underlying metal is reasonably approximated by the ISOCORRAG model. The predicted corrosivity would be an index on the range of probable corrosion rates for different exposure sites.

From the actual condition data and knowledge of the local atmospheric deposition and weather conditions, one can confirm that actual deterioration rates were highest where both absolute humidity and expected (ISOCORRAG) corrosion rate were high (e.g., marine sites in the tropics). Deterioration rates were lowest in arid environments (e.g., deserts).

To be able to establish a reasonable service interval for alternative sites for which there is no empirical data, one can turn to the relative rankings of a specific sites propensity for coating breakdown and corrosivity vs. the range of these parameters for all sites. For sites that were most similar, i.e., having both a high absolute humidity and expected corrosivity, recommendations were made to treat these assets similarly to those in the most corrosive environments. Conversely if sites were expected to be low in both of these parameters they would have extended service intervals such as other assets stored in an arid environment.

Intermediate levels of service intervals could be established between these two extremes as either the absolute humidity increased and / or the local corrosivity increased. This process provides a reasonable and objective basis for predicting the life cycle of the protective coatings and the resultant corrosion on ground vehicles.

CONCLUSIONS

Through the use of environmental data for the operating climate of a ground vehicle it is possible to determine a corrosion condition model. For ground vehicles a two step process of coating breakdown and corrosion rate outlines the method of coating system failure. Since we are able to determine the major factors which cause coating breakdown (absolute humidity and temperature) and corrosion rate (salts, temperature, time of wetness) we can accurately depict corrosion levels for desired locations.

Utilizing these corrosion levels, preventative maintenance or corrective maintenance processes can be implemented to the greatest benefit to the service. Corrosion condition assessment data can then be used to determine any locations that do not fit exactly with the model and need to have maintenance intervals modified.

ACKNOWLEDGEMENTS

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