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Predicting Atmospheric Corrosion Rates for 1010 Steel using a Cumulative Damage Approach

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Introduction

There have been numerous past attempts to develop models to predict atmospheric corrosion rates. Such models, which are often called "Damage Functions" or "Dose-Response Functions" were often constructed using statistical regression techniques or by using "power-law" approaches. They were calibrated by statistically comparing corrosion test results to predictions based upon environmental characterization measurements such as long-term (e.g., annual) deposition measurements of chloride aerosols and/or SO_2. Relative humidity, if explicitly considered, was only used to define the amount of time during the year when conditions were favorable for corrosion. Most models ignored temperature effects but those that do only consider annual averages.

A new approach has been constructed to predict corrosion rates using the concept of cumulative damage. This approach is based upon the Eyring equation, which was originally developed to predict the dependence of chemical reaction rates on levels of the presumed acceleration factors. The new model makes hourly predictions, which when added together makes longer-term "cumulative" predictions. The principal advantage of using hourly predictions is that the effects of diurnal and seasonal temperature cycles and related changes to relative humidity are explicitly considered. The stochastic nature of atmospheric contaminants is considered as well.

Methodology

An inverse modeling approach using Monte Carlo simulations was used to fit various candidate models to proxy environmental characterization data representing conditions at corrosion test sites. Proxy data (measured elsewhere and for other purposes) was used to facilitate the possible usage of this approach as a future design analysis methodology should this initial work succeed.

For the final models developed under this effort, quarterly corrosion test results and related hourly environmental characterization data were used during the calibration process. The corrosion test data was previously published by Battelle. Hourly proxy SO_2 and ozone levels were obtained from the U.S. Environmental Protection Agency's Air Quality System (AQS) database while the related chloride deposition data was obtained from the National Atmospheric Deposition Program database. Hourly weather data was obtained from the U.S. Air Force. Large databases of hourly measurements (for an entire year) of each acceleration factor were constructed to calibrate the model and later make predictions.

Results

Figures 1 and 2 illustrate one of the candidate models developed under this effort. All predictions shown on these figures were made through summation of the hourly predictions made by the model. Figure 1 shows the model as it fits to the calibration data points, which correspond to three locations with diverse environmental conditions. These include Kennedy Space Center, FL (five miles from the coast); Dobbins Air Reserve Base (metro-Atlanta), GA; and Fort Drum, NY. These three locations provided a wide variety of high and low values of each acceleration factor considered by the model. The coefficient of determination value (R^2) of 0.9832 is very high, which as shown by the figure indicates an excellent fit of the model to the calibration data.

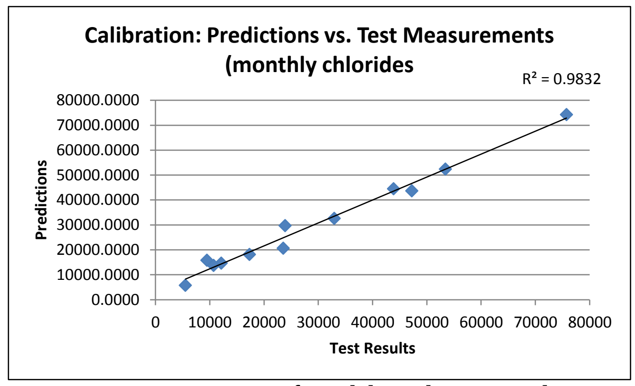

Figure 1. Comparison of Model Predictions and Test Measurements for Three Calibration Locations

Figure 2 shows the model applied to eight independent and diverse locations where corrosion tests had been conducted but not used for calibration. These include one site each in Alabama, Florida, Illinois, Kentucky, New Mexico, and Texas, and two sites in Ohio. As can be seen, the R^2 value for this independent validation is nearly 0.84, which indicates a very good fit of the model to data.

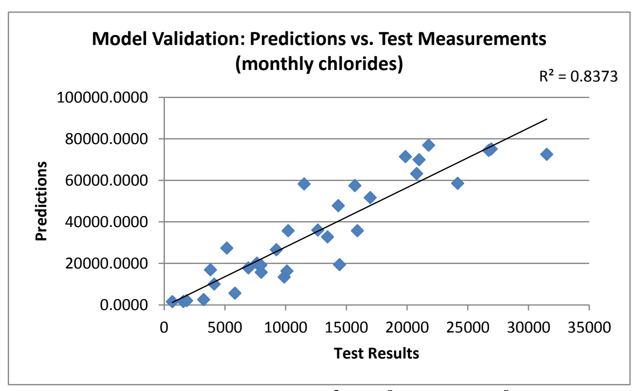

Figure 2. Comparison of Predictions and Test Measurements for Eight Validation Locations

Conclusions

A proof-of-concept approach to predicting corrosion rates based upon cumulative damage has been successfully developed. Predictions made using the optimum models are based upon readily available data, which could eventually lead to a practical design analysis tool. Subsequent analysis has identified improvements to the mathematical formulation of the model that could further increase accuracy over the calibrated model shown here.

References

Rose, D.H., A Cumulative Damage Approach to Modeling Atmospheric Corrosion of Steel (2013), Ph.D. Dissertation, University of Dayton