Predictive Coating Condition Model for Advanced Asset Management WP19-1168

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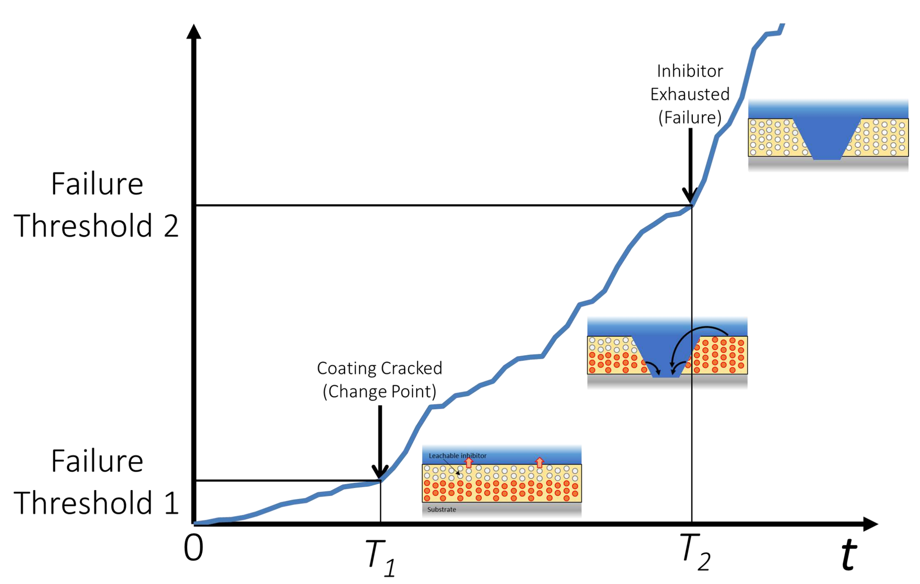
INTRODUCTION

Organic coating systems for aerospace applications are the primary means of corrosion protection. Legacy finishing processes expose workers to hazardous materials and generate HAPs, VOCs, and toxic waste streams. The introduction of new coating systems for chromate substitution requires improved knowledge of performance to mitigate risk and tailor maintenance practices. The overall goal of this project is a predictive coating condition model (PCCM) based on statistical survival analysis. **Objectives:**

- Verify assumptions and model predictions for coating damage and inhibitor exhaustion in laboratory tests, outdoor exposures, and combined effects testing.
- Establish a protocol for coating testing to extend the model to other coatings and material systems.
- Complete PCCM module for integration with asset tracking and maintenance systems.

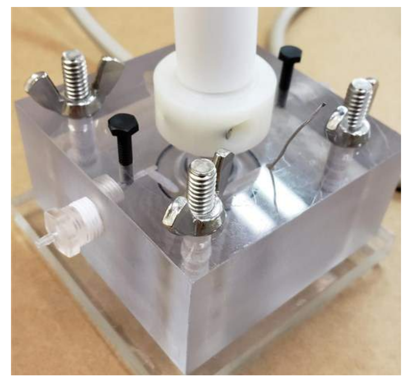


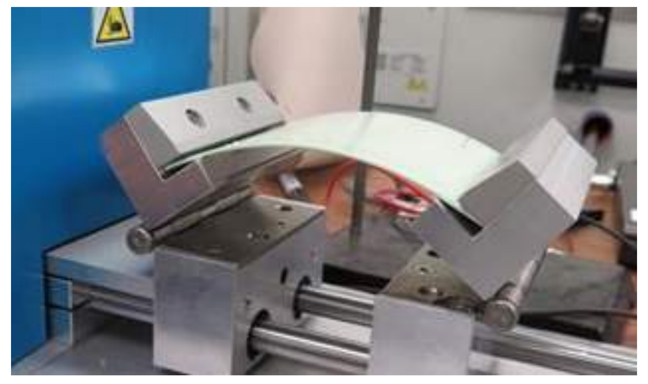
MODELING APPROACH

Failure of a properly formulated and applied outer mold line (OML) coating system consists of two distinct processes: **mechanical damage** exposing substrate and loss of protection by **inhibitor exhaustion**. The failure time is dependent on these **two stages of deterioration**.

A range of measurement techniques and tests have been used to detect the transition from a protected to an unprotected state for aluminum surfaces with organic coatings containing chromate or substitute corrosion inhibitors. Coating failure is modeled as a stochastic process of discrete degradation events.

1. Temporal point processes (TPP) are a class of stochastic models used to predict discrete events in time.
2. Self-exciting TPP (Hawkes process) assumes that past events impact the probability of future events.
3. A TPP model of degradation events is used to determine a prediction interval for coating failure.

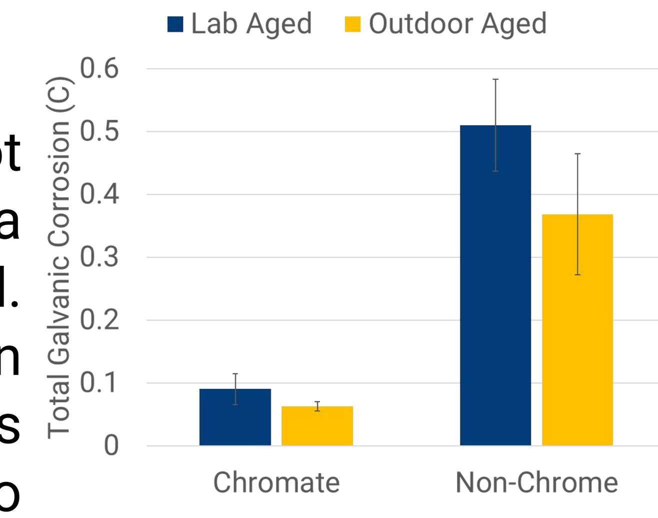




MODEL ASSUMPTION VERIFICATION

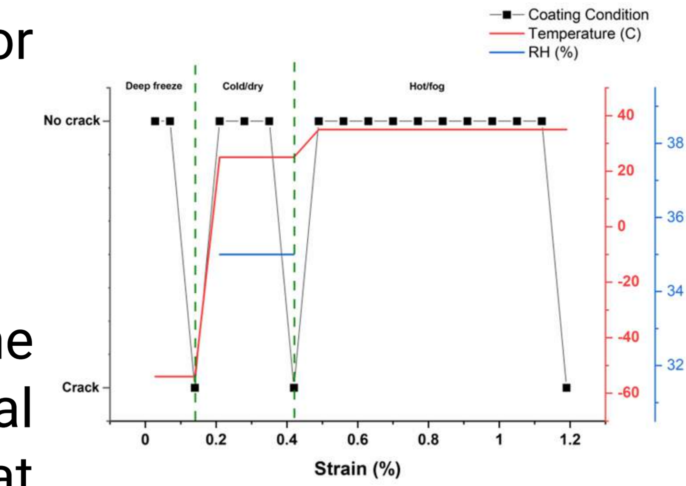
COATING AGING DOES NOT EFFECT INHIBITOR EXHAUSTION

Aging of an intact coating system does not affect the ability of the primer to protect a substrate once the coating is damaged. Coated panels exposed for three months in Florida were compared to lab aged panels in a cyclic corrosion test. There was no difference in free or galvanic corrosion for outdoor and lab aged coatings.



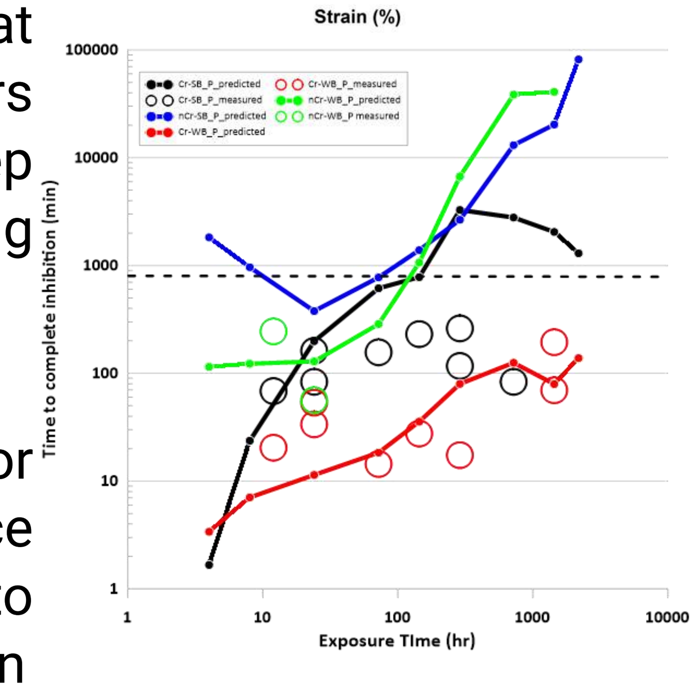
INHIBITOR PROTECTION DOMINATES COATING LIFETIME

Aerospace chromate and non-chrome coating systems crack at structural discontinuities at low strains indicating that substrate protection by corrosion inhibitors dominates coating lifetime. Under deep freeze conditions (high-altitudes), cracking occurs at very low strains 0.14%.



INHIBITOR EXHAUSTION

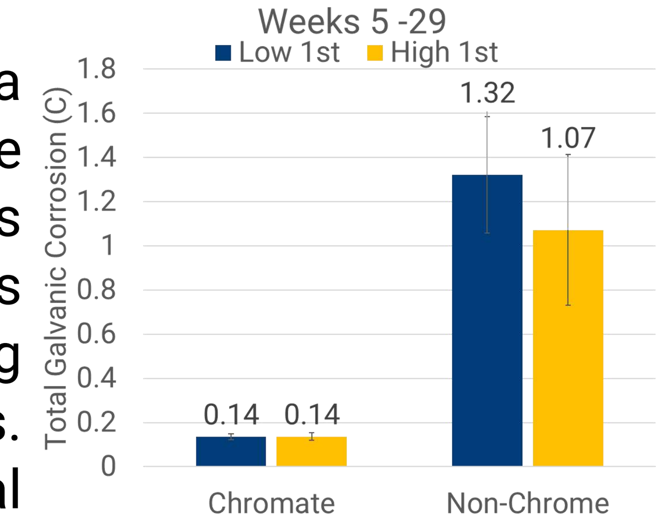
Inhibition is dependent on inhibitor chemistry, leach rate, and pH. Once inhibition occurs at a defect it is difficult to re-initiate corrosion. Continued protection is dependent on both availability of inhibitor and persistence of the passive film.



Critical Concentration
Chromate: 5×10^{-6} M
Pr_2O_3: 1×10^{-4} M

SEQUENCE OF SEVERITY DOES NOT HAVE LASTING EFFECT

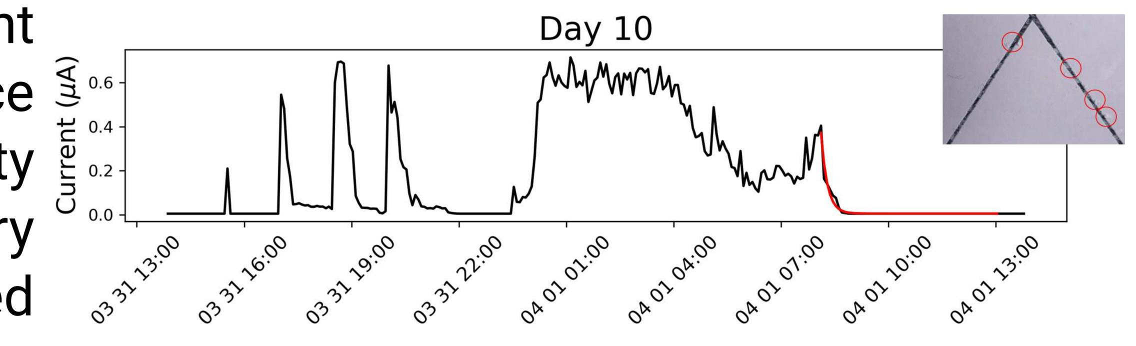
Cumulative severity could be used as a model input without considering the sequence of exposure severity. This was confirmed in cyclic relative humidity tests with the same total severity produced using different salt loading sequences. Sequence of severity did not influence total free corrosion or galvanic corrosion after the first four week period.

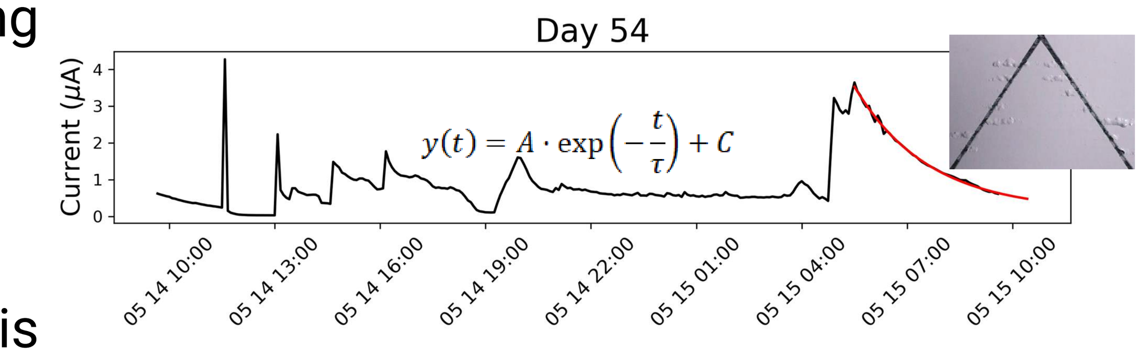


MODELING RESULTS

AEROSPACE COATING PROTECTIVE PROPERTY MEASUREMENTS

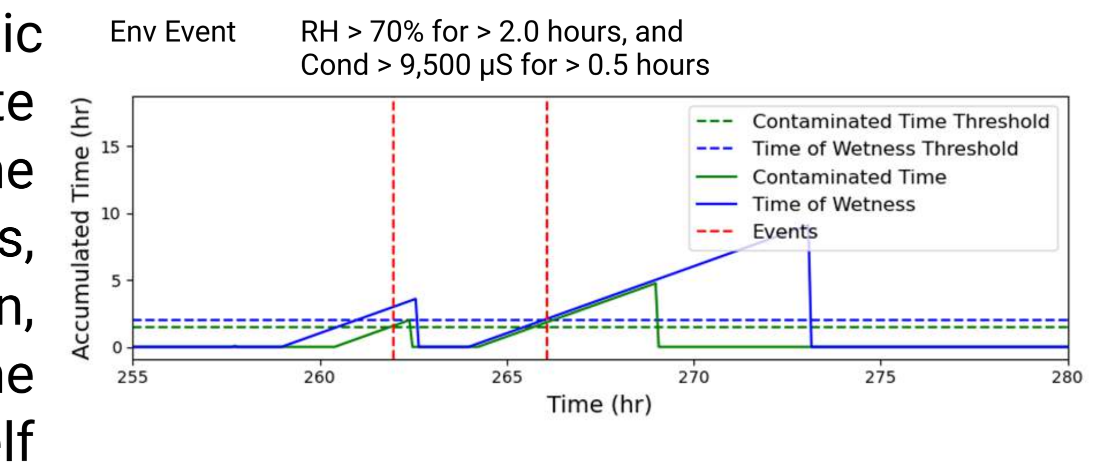
Continuous environment and coating performance measurements (Acuity CR^{TM}) in cyclic laboratory and outdoor tests were used to model the loss of coating protection at a defect.

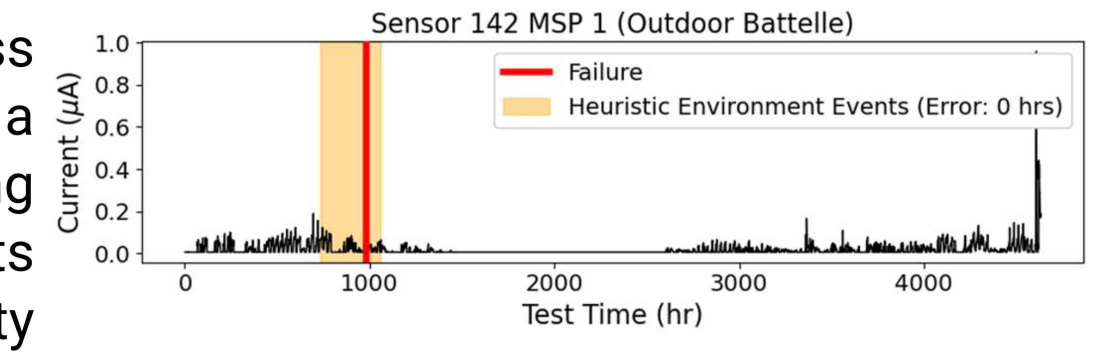




MODELING LOSS OF INHIBITOR PROTECTION

Coating degradation is modeled as a stochastic process using discrete events. Failure may be the first occurrence of blisters, start of blister propagation, or current decay time constant (τ). A self excitation point process model is used to predict a time window for coating failure. Environment events are defined by both humidity and contaminant thresholds.





PREDICTING COATING FAILURE

The number of environment events to failure are predicted using a shock model.

Non-chromate primer had shorter time to failure with less variability, as compared to the chromate primer.

Non-Chromate

	Time	Charge	# Events
Mean	1070	61.9	**11.0**
Stdev	195	12.0	**1.41**
CV		19.4%	**12.9%**

Chromate

	Time	Charge	# Events
Mean	1450	24.1	**15.5**
Stdev	541	11.5	**3.50**
CV		47.7%	**22.6%**

CONCLUSIONS

Coating failure predictions can be made using environment event shock models.

The coating performance models need to be trained on environment and corrosion data specific to the primer.

Primer testing and qualification results could be used to train models for coating life predictions for assumed or actual usage environments.

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