Implication of Atmospheric Wetness Levels on Corrosion at a Coating Defect during Accelerated Testing

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**Title:** Implication of Atmospheric Wetness Levels on Corrosion at a Coating Defect during Accelerated Testing

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**Supplementary Notes:**

**Abstract:**

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Background

- SERDP program to develop improved accelerated corrosion test
- Many accelerated environmental tests exist
  - Developed by applying reasonable environmental conditions and ensuring resultant corrosion damage of a test system is realistic: **may or may not “excite” specific operational failure modes in other systems**
- Approach to new accelerated corrosion test
  - Thoughtful consideration of appropriate sample design
  - Make use of scientific understanding of corrosion mechanisms to develop exposure test cycle parameters
Outline

• Objectives
• Atmospheric corrosion
• Testing Approach
• Effect of RH on corrosion of steel
• Effect of inhibitor addition on coated steel
• Summary and future work
Technical Objective

• **Objective**
  – Develop an understanding of how RH affect corrosion rate and perturbations in corrosion rate with inhibited coatings

• **Why is understanding of RH effect important?**
  – SAEJ2334 shows best correlations with field. Performed under wet bottom RH conditions (NOT FOG)
  – Cyclic conditions lead to different corrosion modes
  – SCC observed at salt deliquescence
  – Realistic conditions failure modes must be replicated in appropriate accelerated test methods
Atmospheric Corrosion

- Corrosion processes in the atmosphere are controlled by a thin film electrolyte layer on a metal substrate.
- The electrolyte layer composition is controlled by:
  - Atmospheric constituents (aerosols and gasses)
  - Relative Humidity (RH) and temperature
  - The presence of inhibitors in or galvanic interactions with coatings
Experimental Approach

- Corrosion (anodic site) and reduction (cathodic site) occur at the same rate
- Electrons flow from anode to cathode
- Multiple isolated anodes or cathodes develop
- Measure current at each electrode gives corrosion rate at the corrosion potential
Experimental Procedure

• 100 electrode (250 micron) multi-electrode probe fabricated using 1018 carbon steel
• ~10mg/cm² of NaCl placed over electrode elements (factor of 10 – 100 greater than outdoors)
• Atmospheric chamber used to control RH and temp
• Exposed under different RH conditions for 2.5 hour followed by reducing RH to 40%
Multi-Electrode Measurements

- chamber assembled to control iso-humidity conditions
- Anodic and cathodic regions form on multi-electrode probe
Measurements at Iso-Humidity

- Total anodic current vs. time shows different corrosion rates over time
  - < 70% is likely flash rust (short duration, electrolyte supports rust formation near 60% RH)
  - Anodic current peaks during wetting and drying
- Integration of current vs. time gives charge passed.
  - For NaCl covered surface and RH > 70%, passed charge is similar to bulk liquid exposure
Measurements in Cyclic Humidity

• How does wetting and drying affect corrosion processes?
• Tests performed in an AutoTechnology accelerated corrosion test chamber
• RH cycled between high and low values. Temp = 30°C

Parallel plate wetness probe

MMA and RH probes
Measurements in Cyclic Humidity

- Anodic current flows when RH is well below 40% and even as low as 15% during drying (efflorescence)
- Peaks in total anodic current are observed during wetting and drying
  - 60% - 65% = Thin film electrolyte behavior where initial high corrosion rate from oxygen availability followed by protective layer formation and decreasing corrosion rate
  - Above DRH = bulk electrolyte behavior + dissolved NaCl creating non-protective rust layer
Volume of Adsorbed Water

- Work by Dante and Kelly (1993) calculated adsorbed water onto Au
- Assuming Au and steel adsorption is similar and 30nl/cm²/monolayer of water, can calculate volume of adsorbed moisture with salt
- OLI calculations used to calculate volume of water with NaCl deliquescence
- Corrosion of Steel can occur at 60% RH, would expect some protection since NaCl is not dissolved
- Above DRH, bulk water accumulation so would expect non-protective oxide
Hypothesis – Protection at a Scribe

- Ability to protect substrate at a coating defect depends on connectivity between defect and mode of inhibition.
- Moisture can promote inhibitor migration in the coating. For a given test method, wet and dry times will influence inhibitor mobility, and thus corrosion rate.
Hypothesis – Protection at a Scribe

• For coated systems, what is the controlling process in corrosion failure at a scribe?
  – Corrosion rate of the substrate as a function of RH
  – Inhibitor mobility (or galvanic connectivity) (red dots are theoretical)
Simulation of Painted Surfaces

- Electrode surface painted leaving 20 electrodes (i.e. 2 rows) uncovered
- ½” o-ring placed over electrodes and salt deposited
Effect of Inhibitor Leaching

- Inhibitors effect only below DRH
- Inhibitors suppresses the 60% RH peak for steel
Effect of Inhibitor Leaching

- Electrochemical potentiodynamic scans performed in NaCl + 0.001 M NaCl dichromate
- As NaCl decreases, cathodic current density increases
- Therefore, RH increases (NaCl decreases), total charge passed increases
Summary and Implications for Accelerated Testing

• Original hypothesis of chromate mobility decreasing with decreasing RH is not supported by the data
  – Component corrosion in cyclic environments controlled by galvanic interactions?
  – Need to determine what RH range results in decoupling of steel and aluminum

• Inhibitors protect against corrosion at 60% - 65% RH (flash rust) on steel
  – Short lived event that is likely inconsequential
Continuing Work

• Ongoing testing to define drying time as a function of
  – Time when RH > DRH
  – Drying time at differing RH values < DRH

• Testing using Aluminum electrodes