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

James F. Dante
Southwest Research Institute

ASETS Defense
8/28/2012
1. REPORT DATE  
28 AUG 2012

2. REPORT TYPE

3. DATES COVERED  
00-00-2012 to 00-00-2012

4. TITLE AND SUBTITLE  
Implication of Atmospheric Wetness Levels on Corrosion at a Coating Defect during Accelerated Testing

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  
Southwest Research Institute, 6220 Culebra Rd, San Antonio, TX, 78238-5166

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES  

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:

   a. REPORT  
   unclassified

   b. ABSTRACT  
   unclassified

   c. THIS PAGE  
   unclassified

17. LIMITATION OF ABSTRACT  
Same as Report (SAR)

18. NUMBER OF PAGES  
19

19a. NAME OF RESPONSIBLE PERSON

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18
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
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

- 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