Degradation and Failure Mechanisms of Protective Coating Systems

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Outline

• Protective coating systems

• Coating evaluation
  • Test method development
  • Results

• Conclusions
Coating systems are comprised of multiple layers

- Individual coatings have different properties and respond differently to environmental stressors
  - Flexibility
  - Moisture uptake
  - Thermal expansion
- Interfaces and interactions between layers
- Degradation of underlying layers may go unnoticed
Multiple degradation mechanisms lead to coating failure

- Chemical
  - Hydrolysis
  - Photo-oxidation
  - Corrosion

- Physical
  - Swelling
  - Softening
  - Cracking
  - Delamination
Current test methods do not accurately predict failure

- Unable to replicate failure modes observed in service
  - Multiple environmental stressors occur during atmospheric exposure and flight operations
    - Cyclic temperature and relative humidity
    - Mechanical stress/strain
  - Testing often performed on individual coating layers rather than full coating stack-ups – not representative of:
    - Thick layers due to replacements/repairs
    - Multilayer advanced systems
- Evaluations are made post test and are often qualitative
  - Difficult to discern performance of underlying coating layers
Primary defense: coatings act as barrier

- Intact coatings act as a barrier to reduce transport of moisture and contaminants to substrate
- In service, corrosion is observed primarily in cracks, at edges, and around defects

Filiform corrosion at panel edges

Pitting beneath blistered paint

Corrosion on and around rivets
Developing a coating barrier test method

- **Objective:** Develop accelerated laboratory test protocols for multilayer coating systems that reproduce relevant failure modes
  - Focus on loss of coating barrier properties, e.g., cracking

- *In situ* quantification of coating properties
  - Embedded impedance sensors
  - Barrier properties
  - Conductive properties

- Relevant atmospheric conditions
  - Cyclic humidity
  - Temperature

- Mechanical stress
  - Coupon design
  - Stress application
Mechanical strain

• Aircraft coating failures often occur at structural discontinuities
  • Lap joints, seams, and fasteners
  • Areas of high, localized stresses and strains

• Static and dynamic strain
  • Static:
    • Four point bend fixture
  • Dynamic:
    • Vibration applied to four point bend fixture
    • Single and multi-panel dynamic, displacement controlled flexer
Coupon design: simulated lap joint

- Machined, round bottom notch enables strain development in coating across gap
  - Gap filled with aircraft sealant
  - Minimizes strain in AA7075 substrate to prevent plastic deformation and fatigue
- Panel “wings” accommodate strain during displacement of flexer
  - Provides more accurate control of applied strain using multipanel dynamic flexer
    - With wings: 10 mm displacement creates ~2% strain across top of gap
    - Without wings: 10 mm displacement plastically deforms substrate
Embedded sensors

• Embedded sensors: Thin foil strips rolled from copper, nickel, or gold wire
  • Placed between coating layers during coating application

• Multilayer coating system:
  • Gloss white urethane topcoat (top)
  • Water-based epoxy primer
  • Conductive coating
  • Water-based epoxy primer (bottom)

• Wires soldered onto embedded sensor leads, takeoff point protected using marine grade sealant

• Impedance measurements made using commercial potentiostat
Monitoring barrier properties with embedded sensors

- Temperature/Moisture
- Cracking
**In situ imaging**

- Camera within chamber captures video during testing
- Individual frames are post-processed and analyzed
Crack growth during dynamic strain

- Total crack length and number of cracks are both important
- Average and maximum crack length increases as cracks combine; small isolated cracks remain throughout test
Crack growth during vibratory strain

- Progressively higher impedance and visible topcoat cracking as frequency increases
- Effects continue to increase with vibration time
Combining the elements to understand coating failure

- Temperature, humidity, and mechanical strain
- Reversible increases in conductive coating impedance observed prior to visible cracking in topcoat
- Irreversible increase in baseline impedance after multiple cycles
Secondary defense: corrosion inhibiting coatings

- New non-chromated coating systems continue to be evaluated
- Improved Corrosion Test Suite

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
<th>Type of corrosion</th>
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<tbody>
<tr>
<td>Disbonded paint protection test</td>
<td>Ability of primer to protect substrate when paint is not directly bonded to the metal</td>
<td>Pitting under blistered paint</td>
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<tr>
<td>Cyclic corrosion test</td>
<td>Combination of filiform and salt-spray cycles to better mimic the real life conditions</td>
<td>Filiform corrosion, blistered filaments, pitted surface, pits in the clad</td>
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<tr>
<td>Outdoor exposure</td>
<td>Best way to get an idea about real in service performance in certain climates</td>
<td>Filiform and salt-spray, rivet corrosion</td>
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</tbody>
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Conclusions

• Protective coatings are the first line of defense against corrosion
  • Loss of coating barrier allows more rapid transport of moisture and contaminants to substrate

• New combined effects test methods will allow better evaluation of the combined barrier properties of multilayer coating systems
  • Embedded sensors applied to a conductive layer are sensitive to cracking
  • Image analysis can also be used to quantify topcoat cracking
  • Combining both measurement techniques can help identify coating layer in which failures initiate

• New coating systems will be qualified using a suite of test methods
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