Degradation and Failure Mechanisms of Protective Coating Systems

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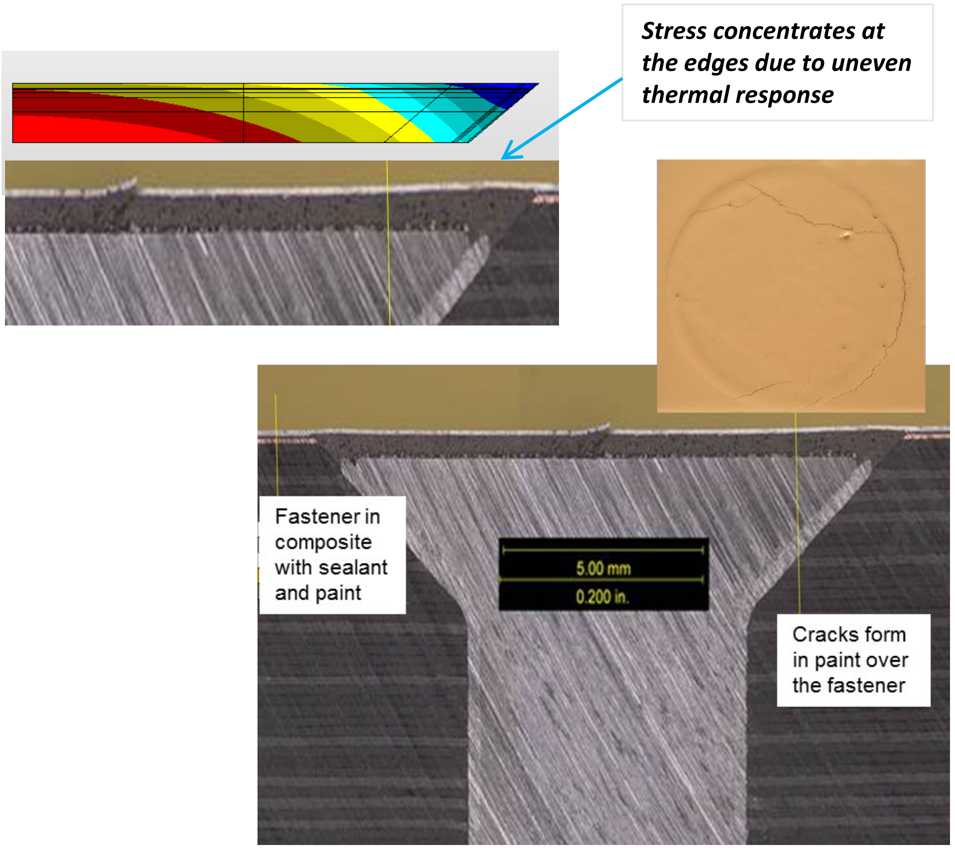
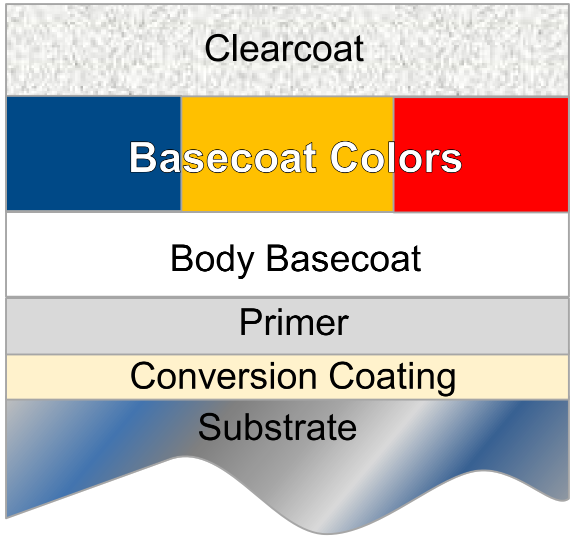
Outline

- 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





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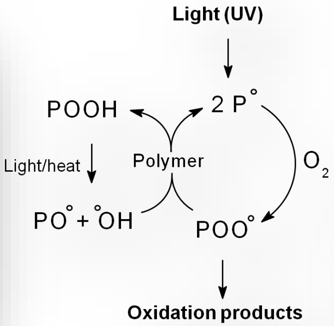
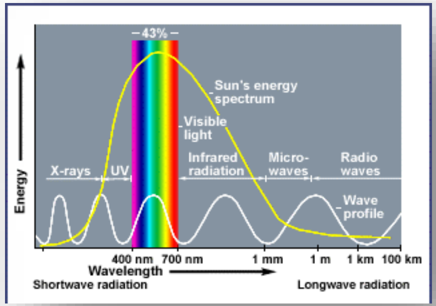
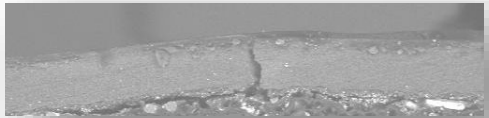
Multiple degradation mechanisms lead to coating failure

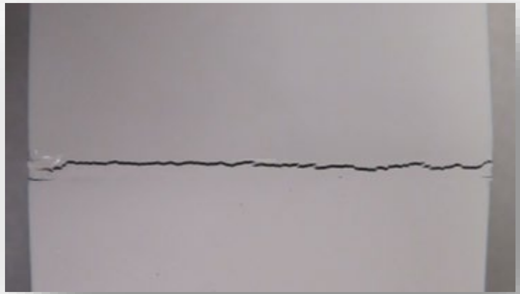
- Chemical
  - Hydrolysis
  - Photo-oxidation
  - Corrosion

- Physical
  - Swelling
  - Softening
  - Cracking
  - Delamination



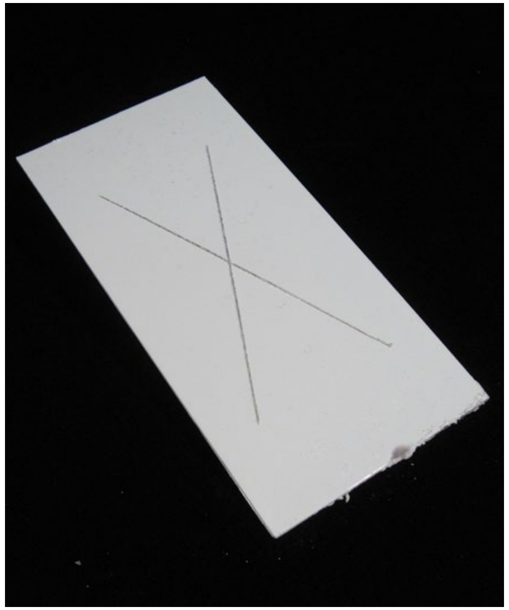






Current test methods do not accurately predict failure

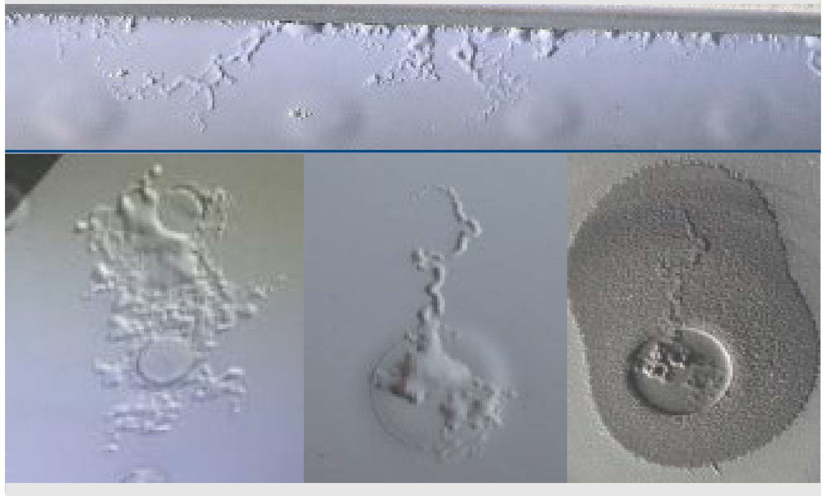
- Unable to replicate failure modes observed in service
  - Multiple environmental stressors occur during atmospheric exposure and flight operations
  - Cyclic temperature and relative humidity
  - Mechanical stress/strain
- Testing often performed on individual coating layers rather than full coating 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

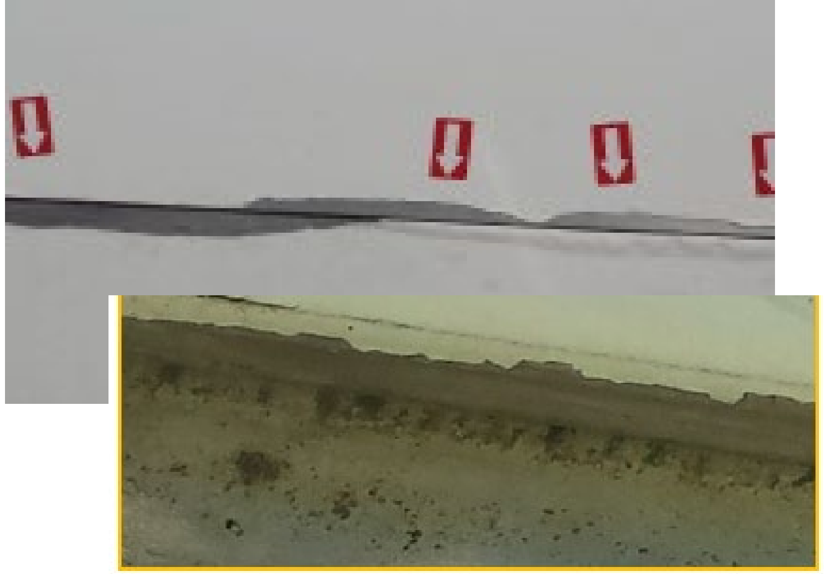
- Intact coatings act as a barrier to reduce transport of moisture and contaminants to substrate
- In service, corrosion is observed primarily in cracks, at edges, and around defects

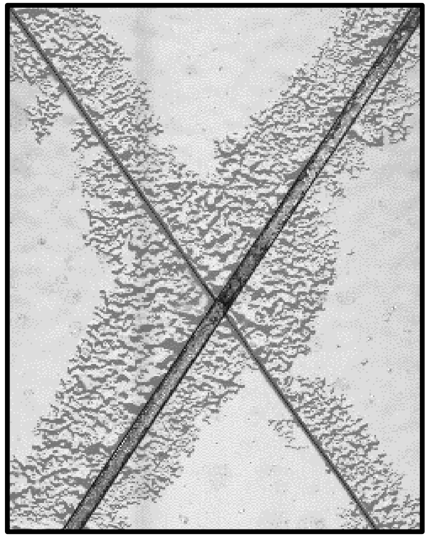
Filiform corrosion at panel edges



Corrosion on and around rivets

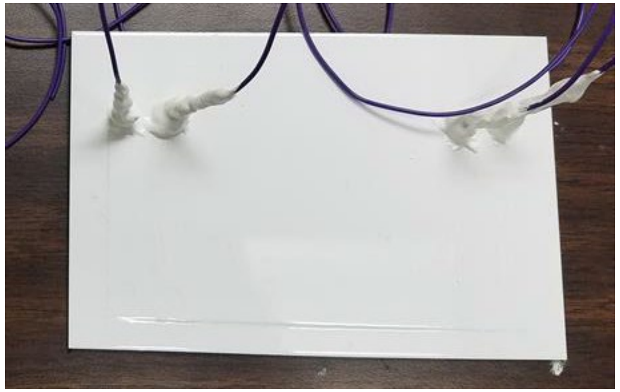
Pitting beneath blistered paint

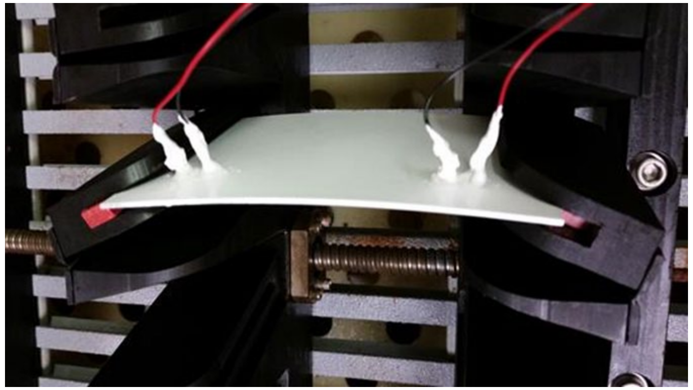




Developing a coating barrier test method

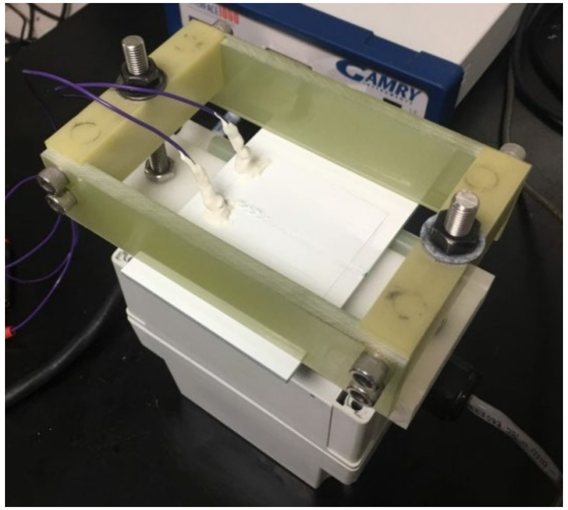
- <u>Objective:</u> Develop accelerated laboratory test protocols for multilayer coating systems that reproduce relevant failure modes
  - Focus on loss of coating barrier properties, e.g., cracking
  - *In situ* quantification of coating properties
    - Embedded impedance sensors
    - Barrier properties
    - Conductive properties
  - Relevant atmospheric conditions
    - Cyclic humidity
    - Temperature
  - Mechanical stress
    - Coupon design
    - Stress application

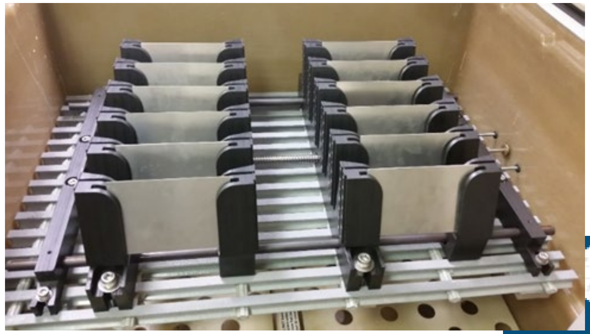




Mechanical strain

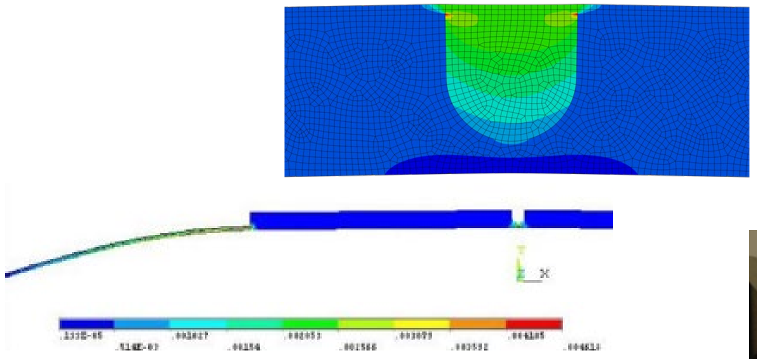
- Aircraft coating failures often occur at structural discontinuities
  - Lap joints, seams, and fasteners
  - Areas of high, localized stresses and strains
- Static and dynamic strain
  - Static:
    - Four point bend fixture
  - Dynamic:
    - Vibration applied to four point bend fixture
    - Single and multi-panel dynamic, displacement controlled flexer

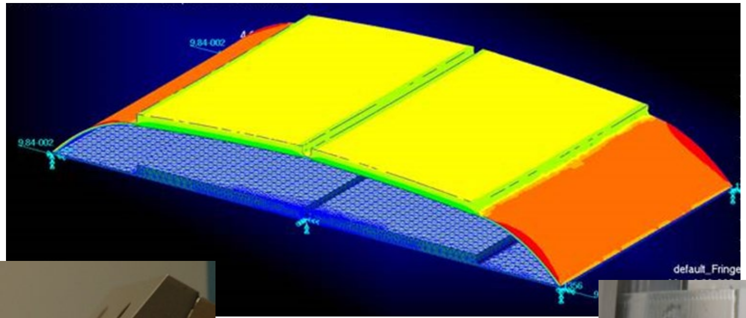




Coupon design: simulated lap joint

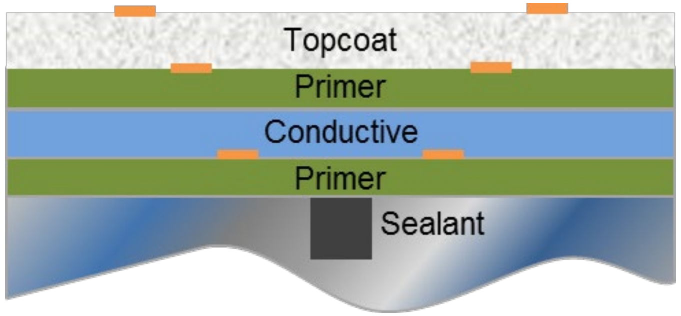
- Machined, round bottom notch enables strain development in coating across gap
  - Gap filled with aircraft sealant
  - Minimizes strain in AA7075 substrate to prevent plastic deformation and fatigue
- Panel “wings” accommodate strain during displacement of flexer
  - Provides more accurate control 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

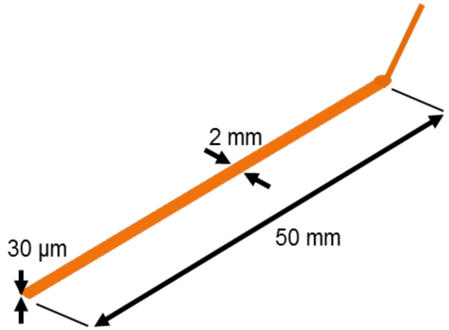




Embedded sensors

- 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)

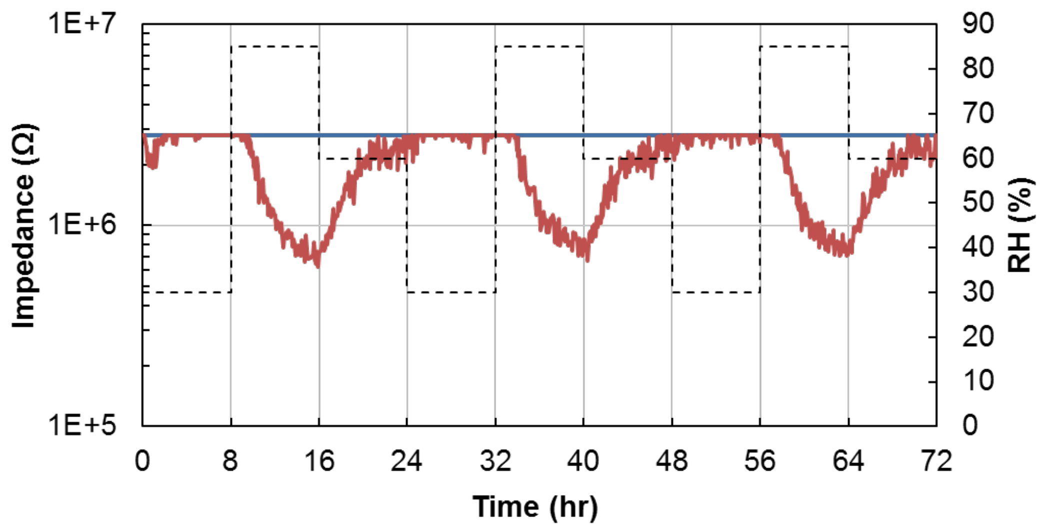


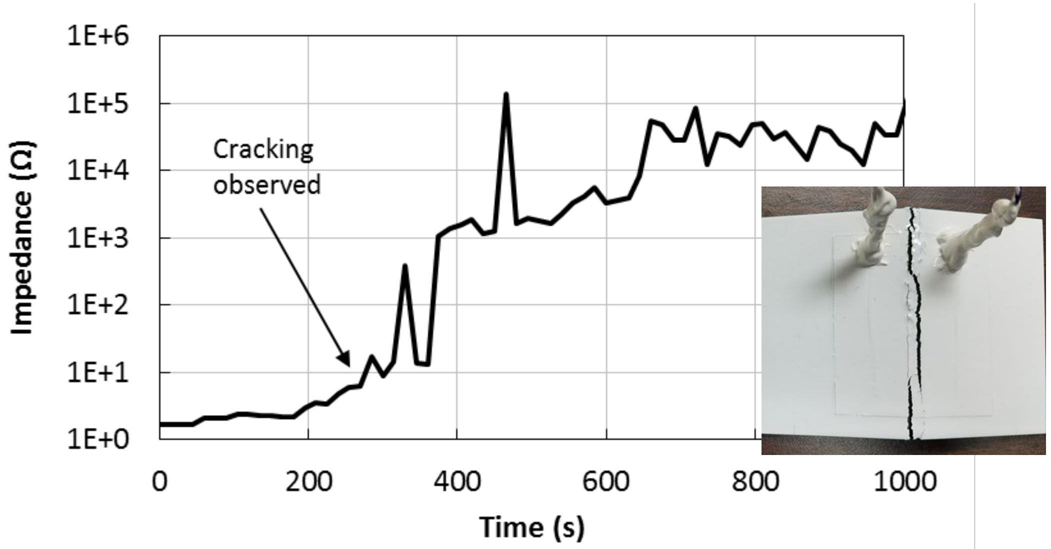


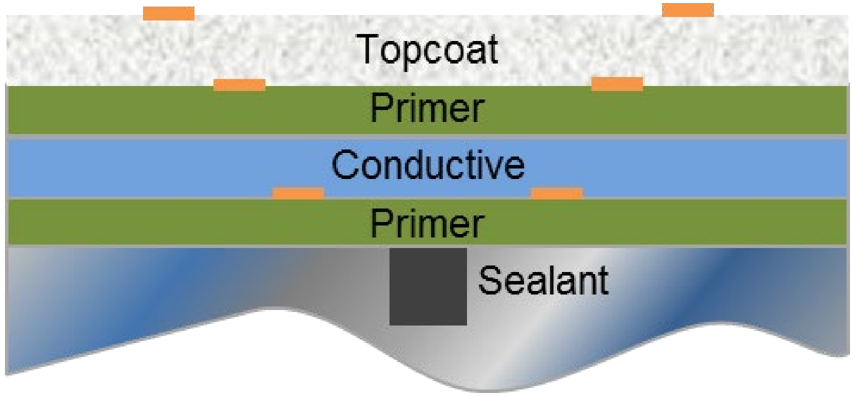
- Wires soldered onto embedded sensor leads, takeoff point protected using marine grade sealant
- Impedance measurements made using commercial potentiostat

Monitoring barrier properties with embedded sensors

- Temperature/Moisture
- Cracking

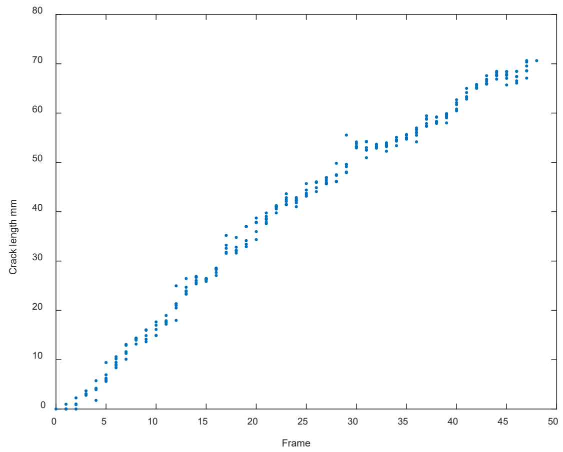


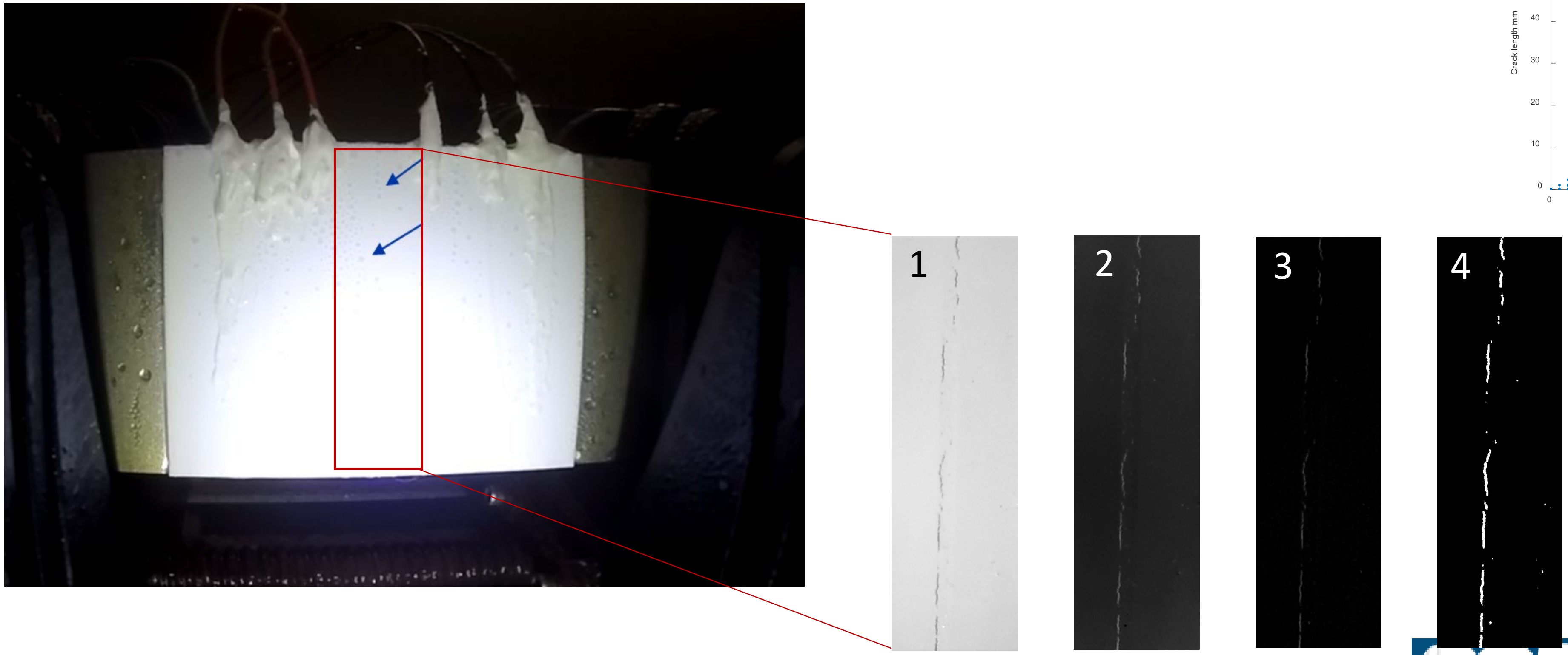




In situ imaging

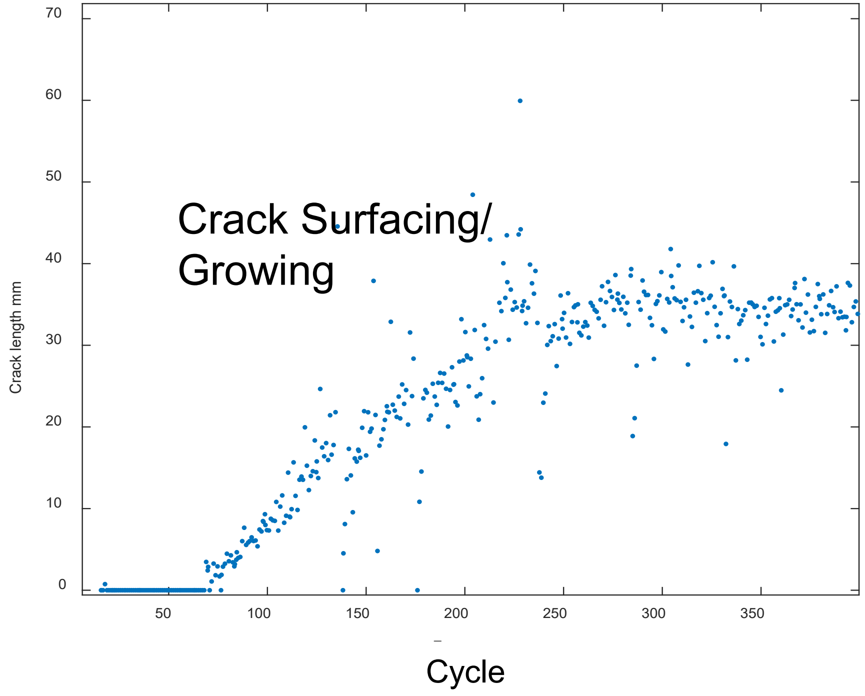
- Camera within chamber captures video during testing
- Individual frames are post-processed and analyzed

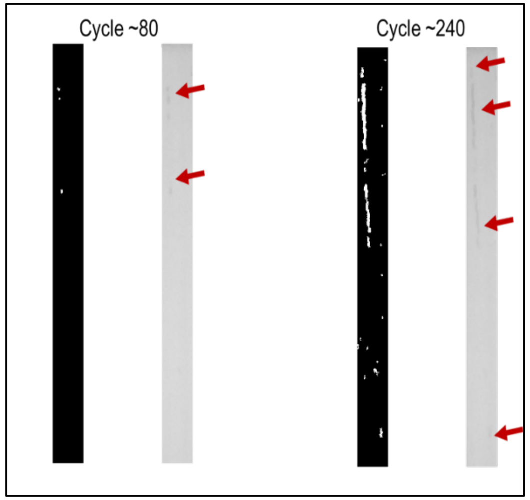


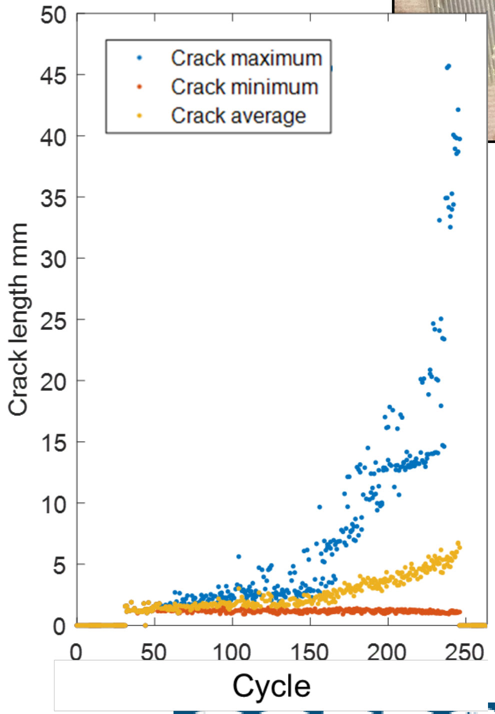


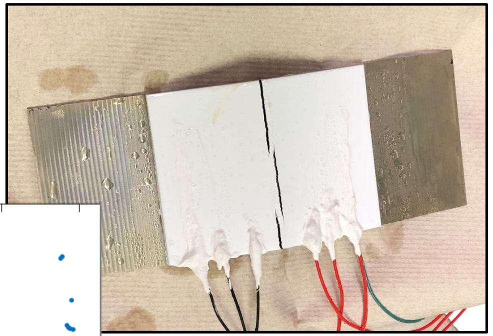
Crack growth during dynamic strain

- 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

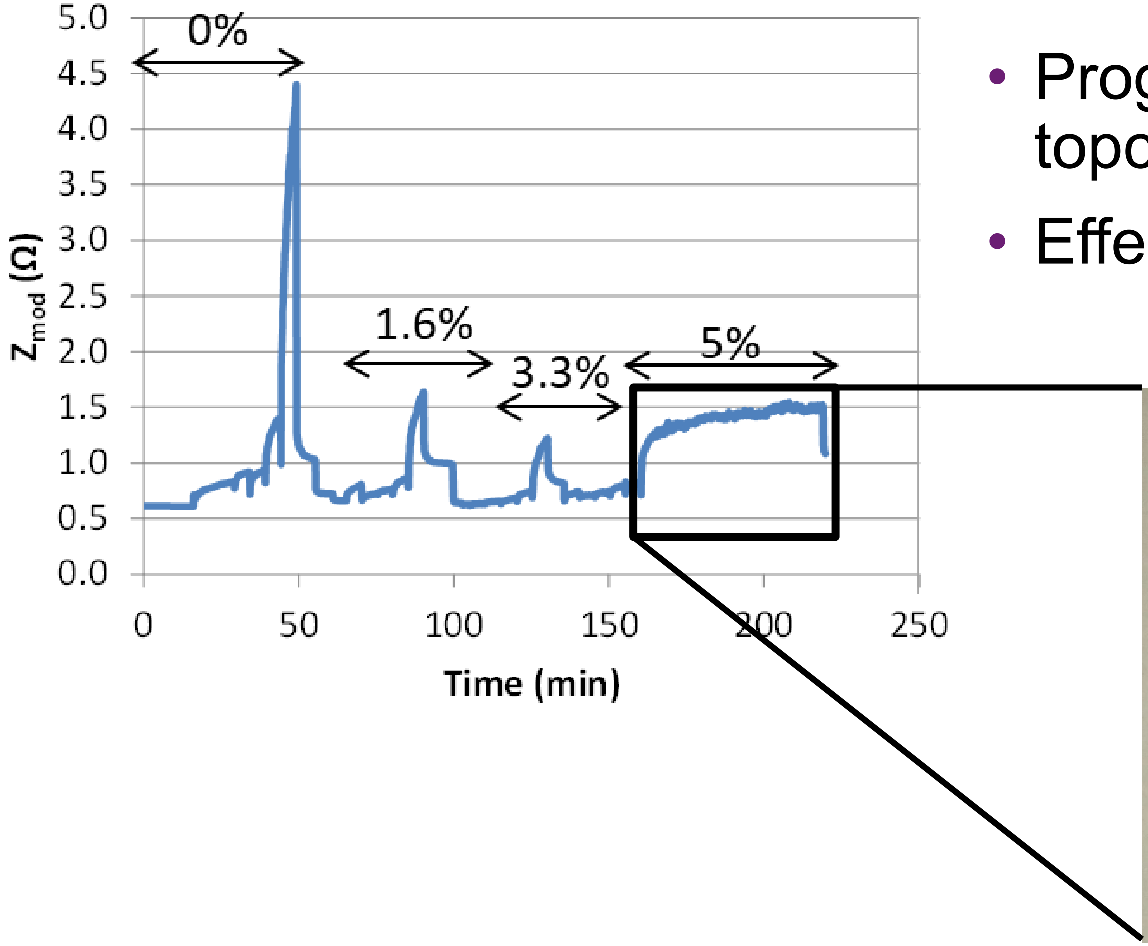




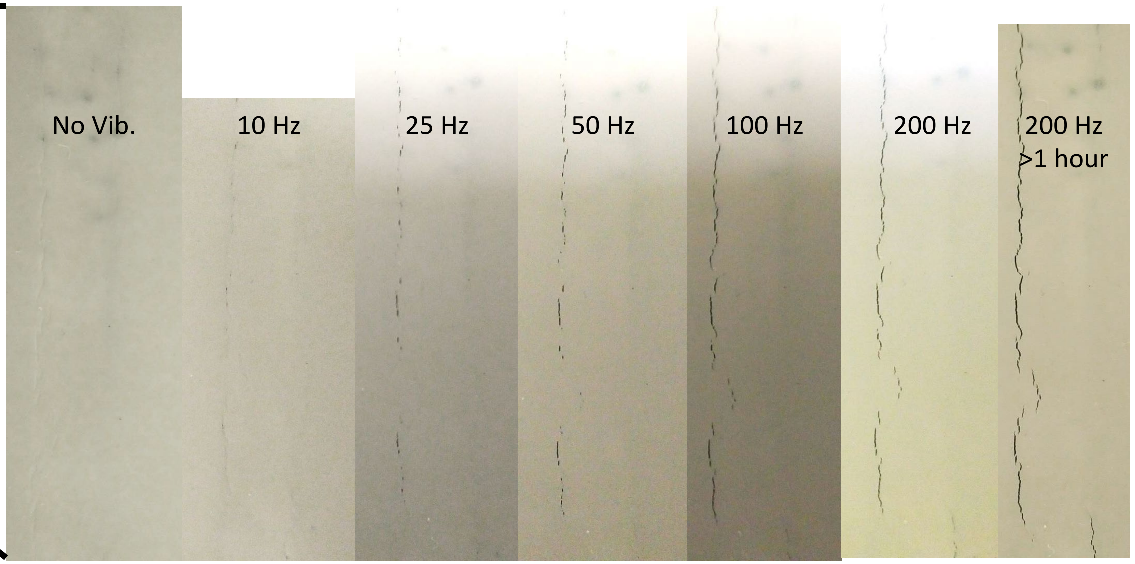




Crack growth during vibratory strain

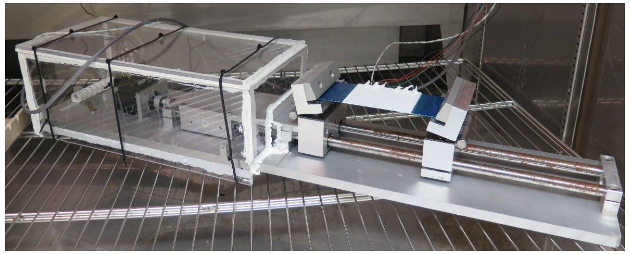


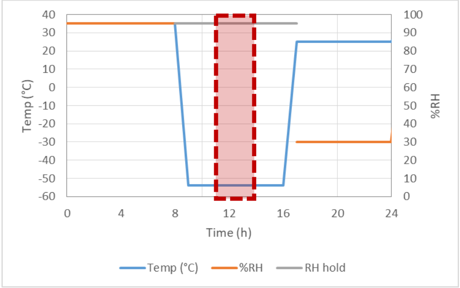
- Progressively higher impedance and visible topcoat cracking as frequency increases
- Effects continue to increase with vibration time

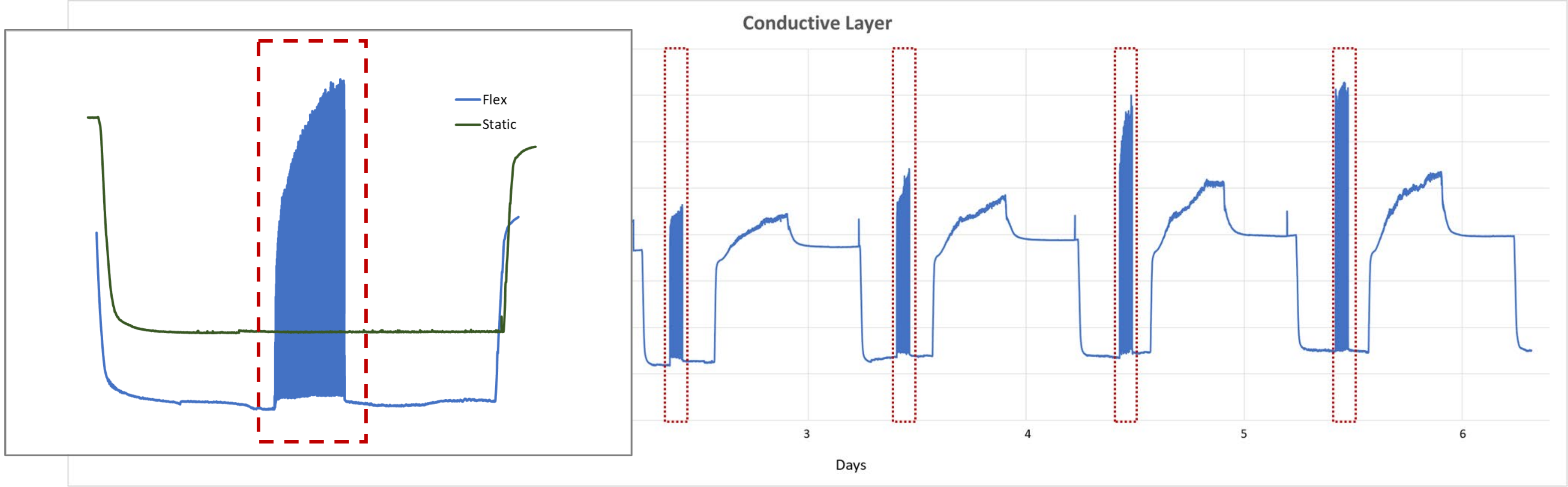


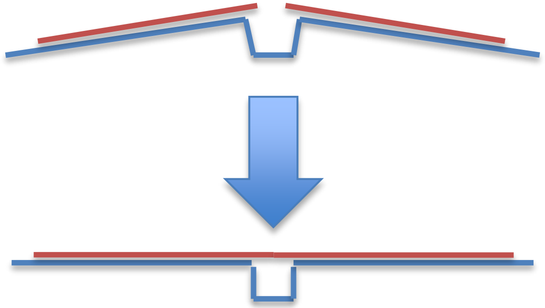
Combining the elements to understand coating failure

- 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





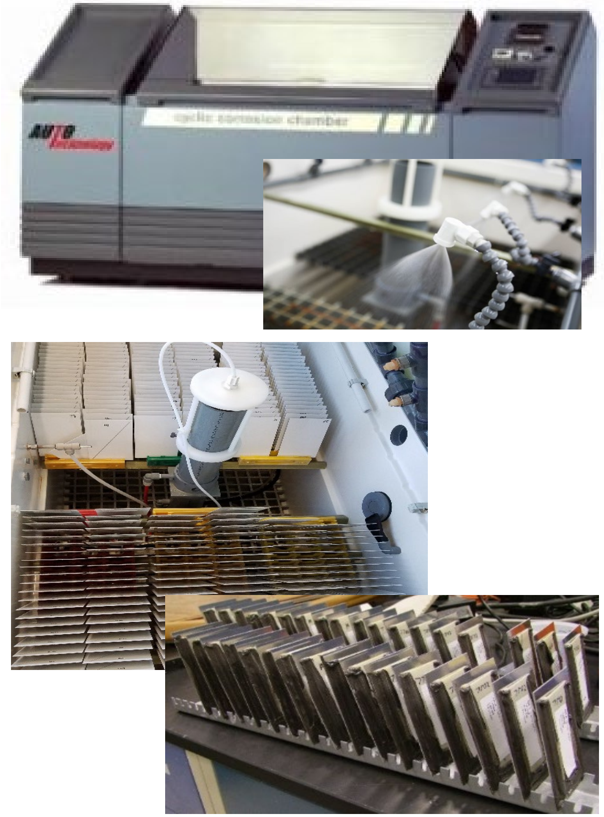




Secondary defense: corrosion inhibiting coatings

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

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



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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