Real-time Measurement of Electrocoat, Powder Coat, and Organic Coatings for Atmospheric Galvanic Corrosion Protection

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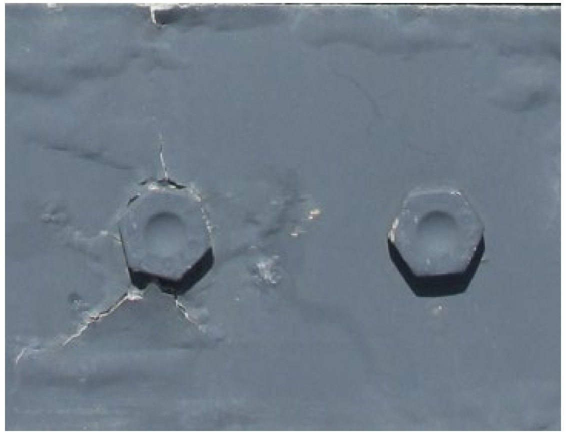
Paper No. C2024-20945
AMPP Conference 2024
Corrosion and Coatings in the Automotive Industry

March 3rd, 2024

Purpose

- Aircraft corrosion costs the U.S. Department of Defense billions due to maintenance time and costs and decreased aircraft availability
- Coatings are used to protect aircraft, but traditional aerospace coatings contain chromate primers and/or pretreatments and new coatings must undergo extensive qualification
- Electrocoat (e-coat) has emerged as an alternative to these hazardous coatings and has been approved for use on aluminum substrates by the U.S. Air Force and is undergoing approval for use on titanium
- Currently, visual inspections and ratings are used to evaluate coatings that do not account for corrosion kinetics. A system with the ability to monitor coatings in real time is needed to develop quantitative metrics
- Zero resistance ammeter (ZRA) measurements can be used to collect galvanic corrosion measurements from samples with traditional aerospace coatings, electro-coatings, and powder coatings *in situ* to enable rapid evaluation of coating responses to environmental stressors

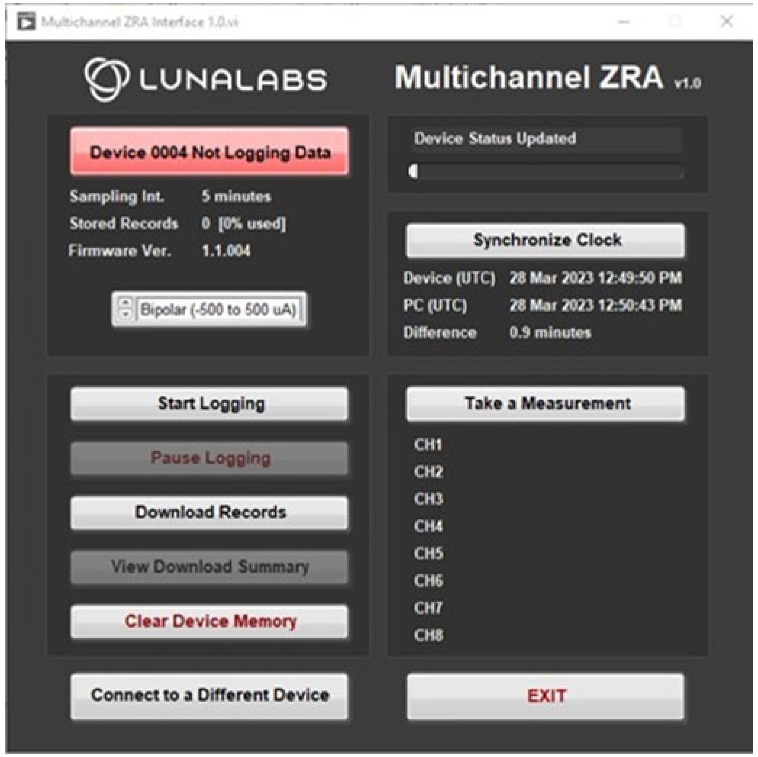


System Overview

Multi-Channel ZRA (MC ZRA) System

- A new device was developed to allow for galvanic corrosion monitoring on up to eight samples
  - Utilizes the zero-resistance ammeter functionality of the Acuity system to measure galvanic corrosion
- This design allows for e-coat and powder coat samples to be evaluated

8 sample connections

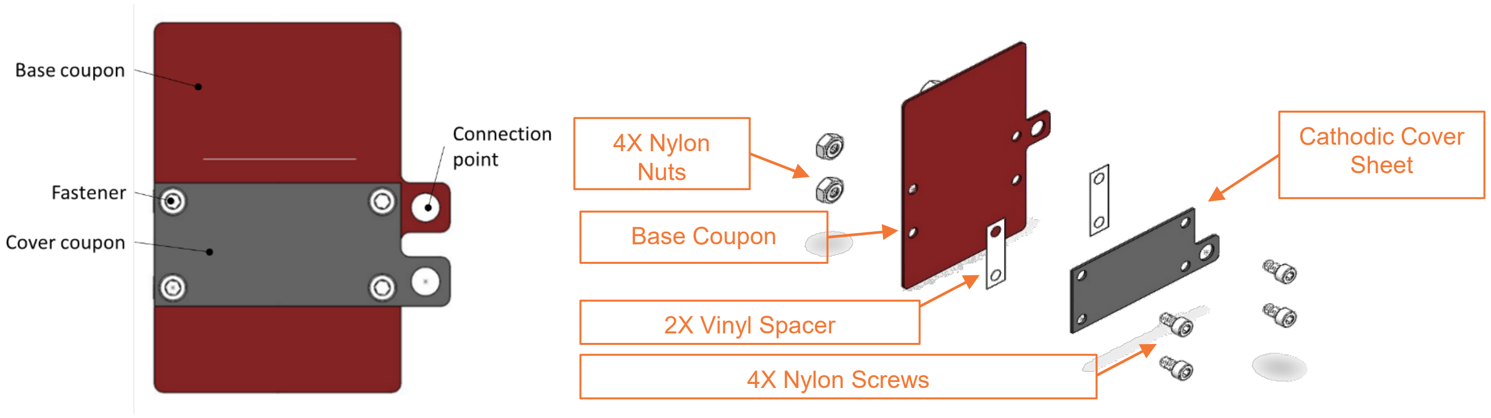


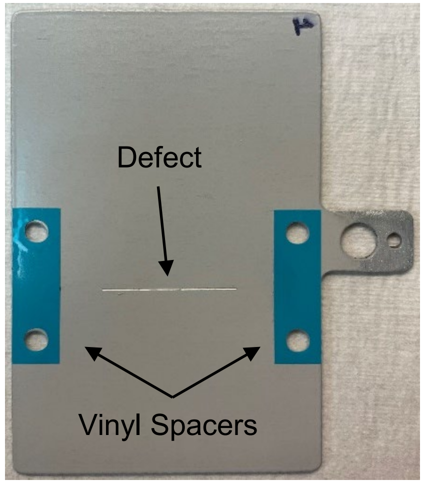
Galvanic Crevice Sample

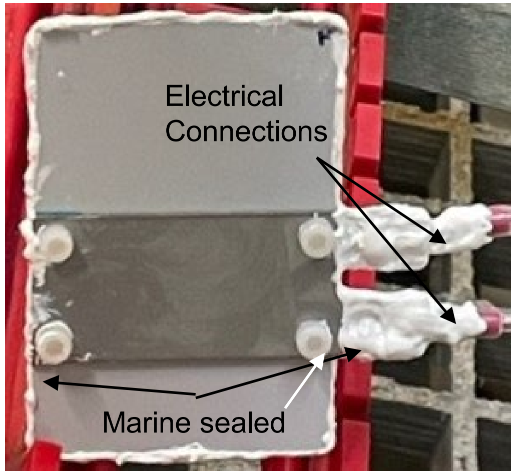
- A new sample was designed to enable e-coat and powder coat processes and is influenced by various designs currently utilized by the automotive industry
- Consists of:
  - Base Coupon (airframe, bulk material)
  - Cover Sheet (fastener, interface material)
  - Spacers (~100 μm thick)
  - Nylon Fasteners

Key Features:

- Tabs to enable coating and measurement collection
  - Can observe effects of defects in crevice conditions (under the Cover Sheet) or exposed conditions (outside of the Cover Sheet)
- Adaptable for various materials, coatings, and defect configurations







Test Set Up

Test Objectives

Preliminary evaluation to fully test system capability

- Capture changes in corrosion kinetics
- Ensure that the device collects corrosion rates that align with changes in environmental conditions
- Verify system functionality over the full data collection span
- Verify that the system can be applied to a variety of material combinations and coating systems
  - Represent aerospace, automotive, and ground support equipment
- Differentiate between various sample configurations and coating systems

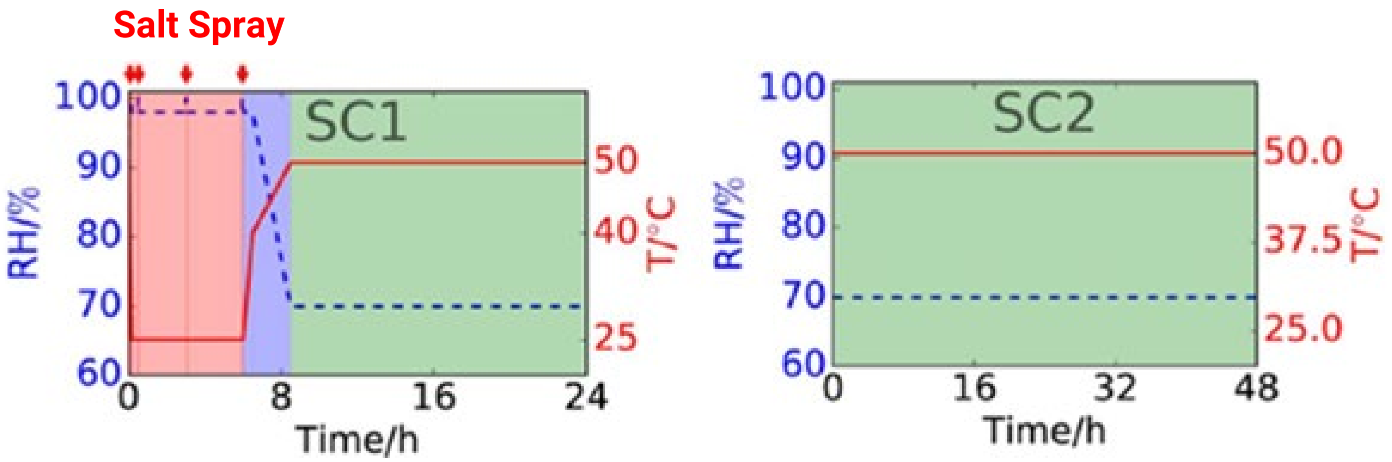
Testing was conducted at three labs:

- Data was collected on 18 sample configurations:
  - 3 Base coupons: AA7075-T6, AA6111-T4, 4130
  - 4 Cover Sheets: SS316, CRS, HDG, 2024-T3
  - 3 defect types: no defect, masked, scribed
  - 12 coating systems
- Acuity LS devices collected environmental information
  - Temperature
  - Relative humidity
  - Conductance
- 3 test cycles: Ford CETP: 00.00-L-46, GMW14872, MDACT

Test Environments

- **Ford CETP:00.00-L-467**

- Samples were tested for 1 month in each cycle



Ford CETP:00.00-L-467

Test Environments

- Ford CETP:00.00-L-467
- **GMW 14872**

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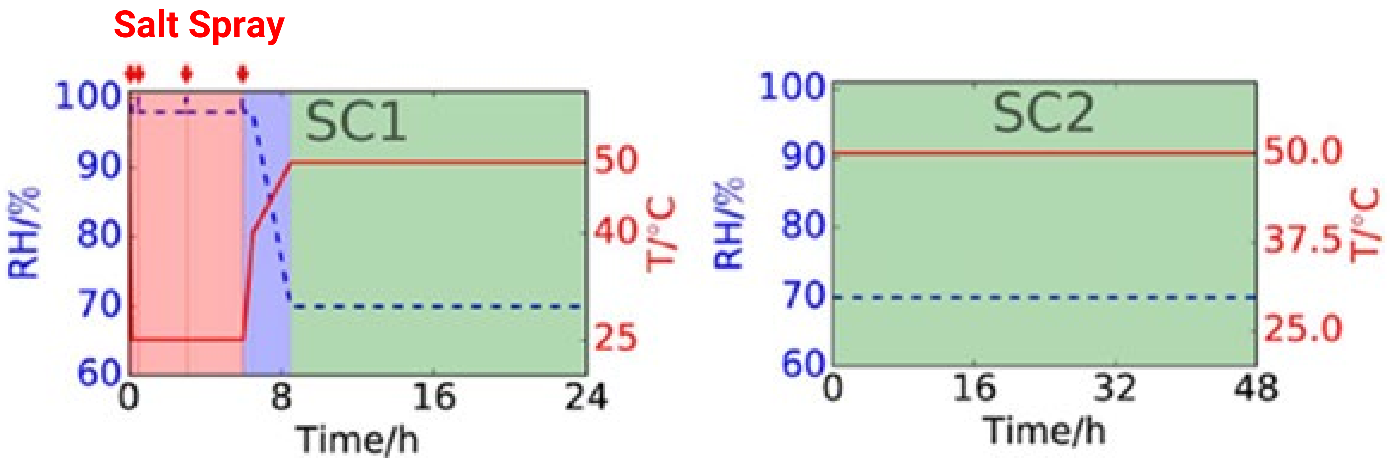

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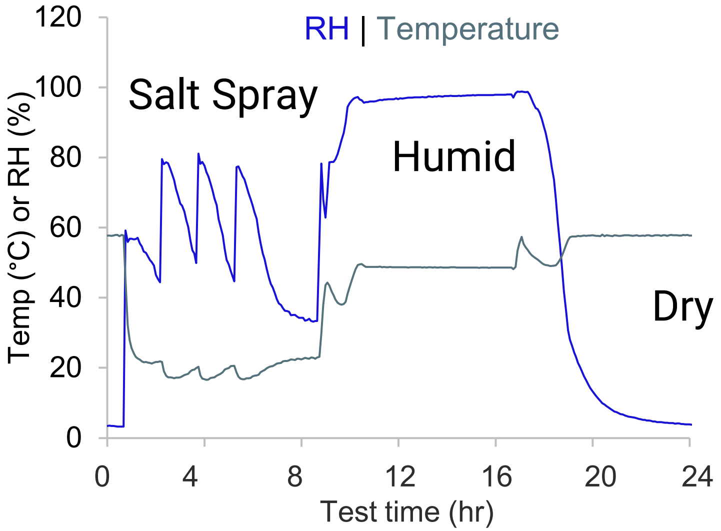

GMW 14872

Test Environments

- Ford CETP:00.00-L-467
- GMW 14872
- **MDACT**
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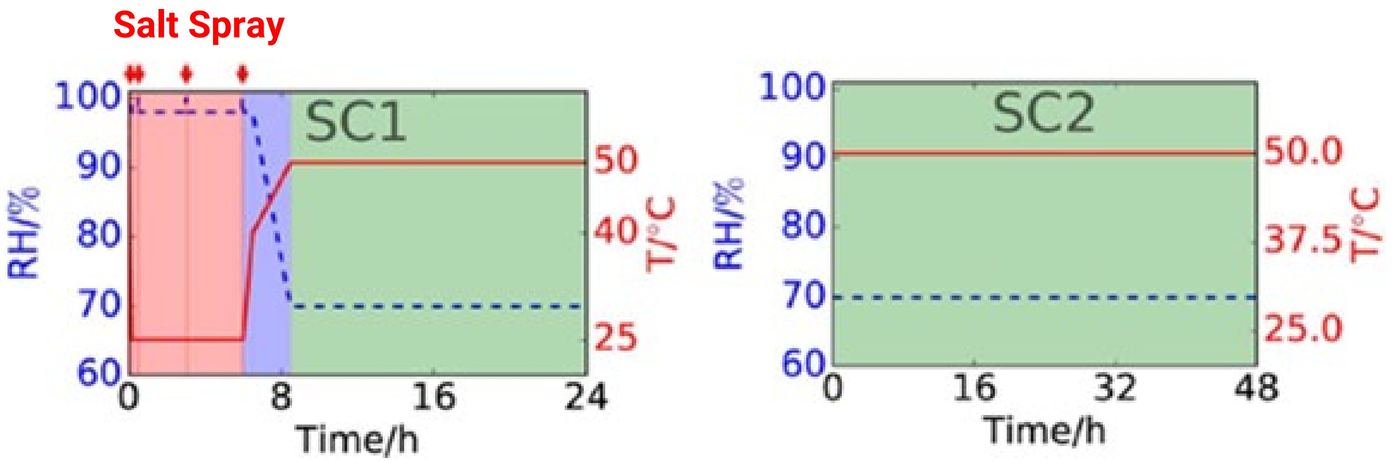

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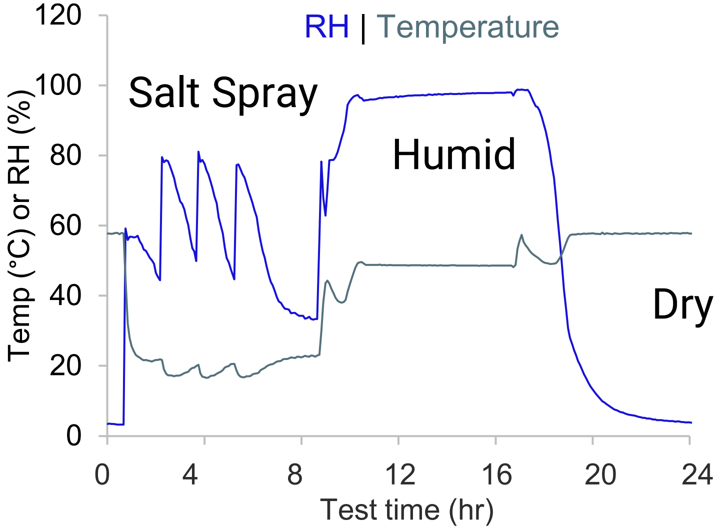
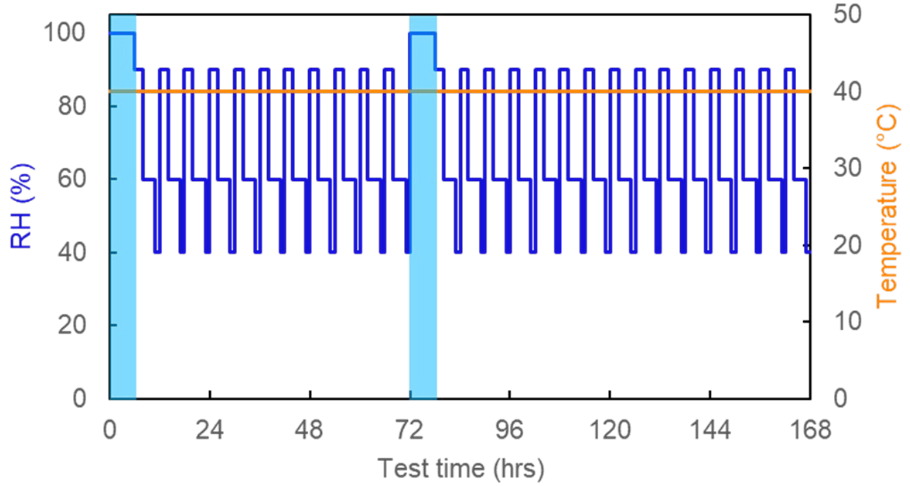


GMW 14872



Step Number	Action	Duration (h:mm)
1	Fog	6:00
2	*Subcycle 3-5*	Repeat 11x
3	90% RH Hold	2:00
4	60% RH Hold	3:00
5	40% RH Hold	1:00
9	Fog	6:00
10	*Subcycle 11-13*	Repeat 15x
11	90% RH Hold	2:00
12	60% RH Hold	3:00
13	40% RH Hold	1:00
14	Final Step	Return to Step 1

MDACT

Results

Galvanic Couple Evaluation

Component	Description
Base Coupon	AA6111 w/ Zinc Phosphate
Cover Sheet	Hot dipped galvanized (HDG) or cold rolled steel (CRS)
Base and Cover Coating	E-coat
Defect	Scribe in crevice
Environment	Ford CETP 00.00-L-467

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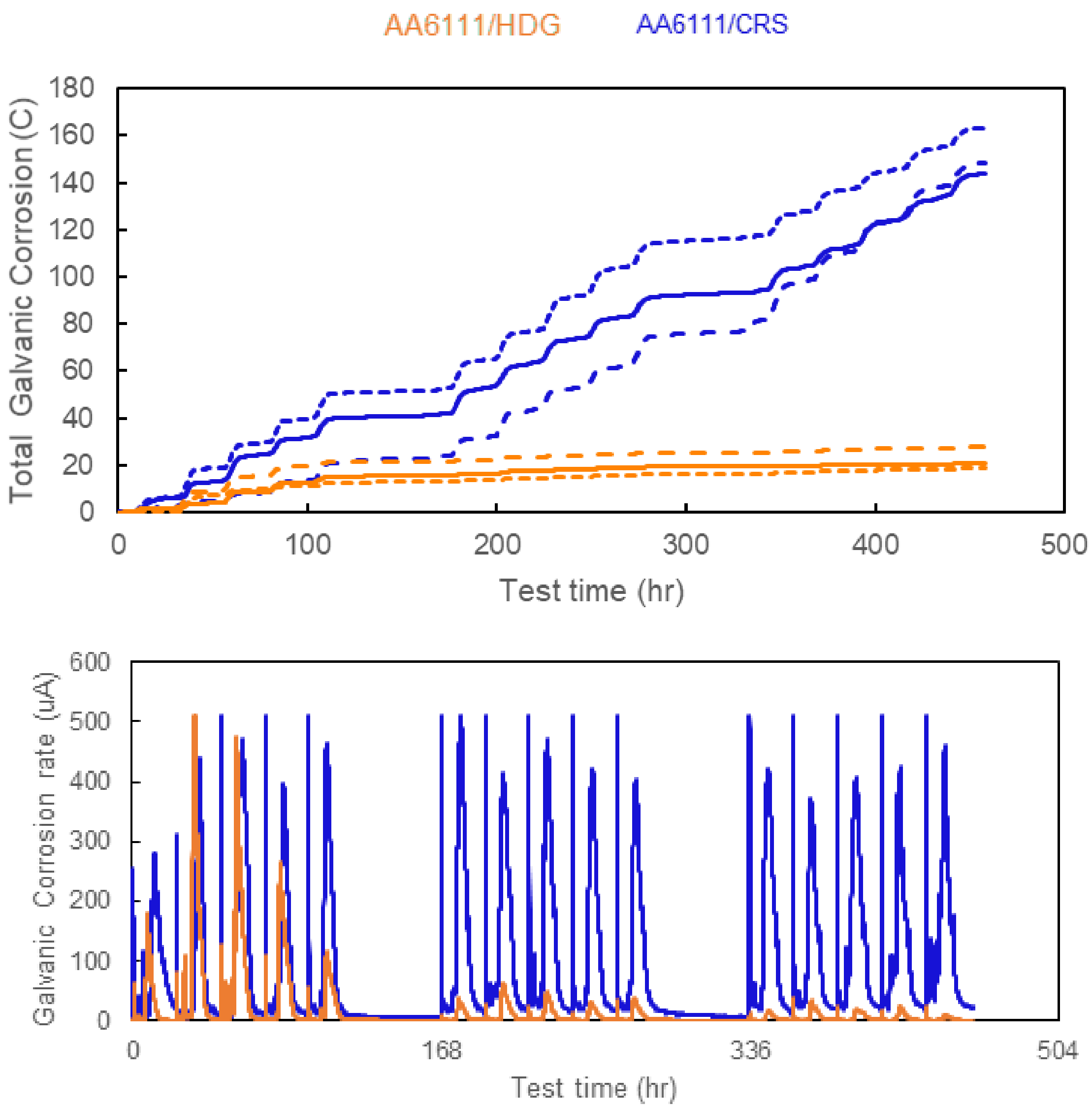
- Clear response to the environmental cycle
  - Peaks during sprays and drying
  - Little corrosion during dry weekend cycle
- The first week the two configurations behaved similarly however the configuration with the HDG Cover Sheet saw decreasing corrosion rates with time



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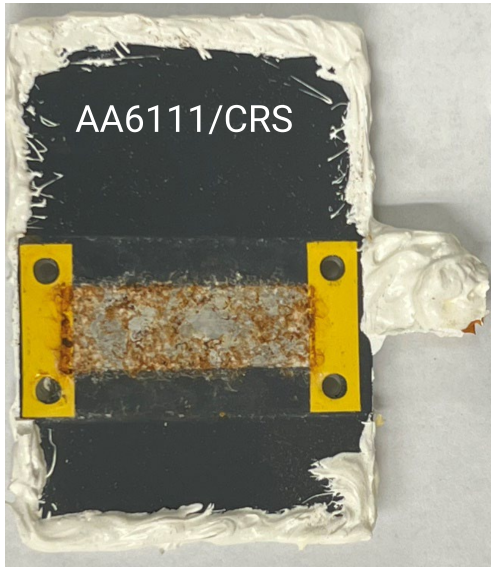
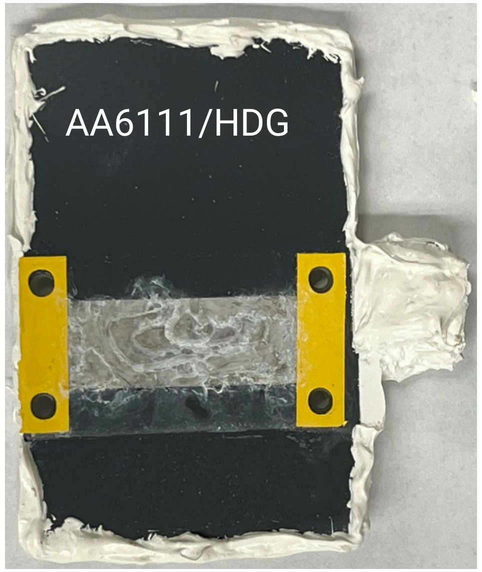
- The first week the two configurations behaved similarly however the configuration with the HDG Cover Sheet saw decreasing corrosion rates with time
  - → Passivation from corrosion products

MC ZRA system demonstrated that it can differentiate between galvanic couples and capture the evolution of corrosion kinetics





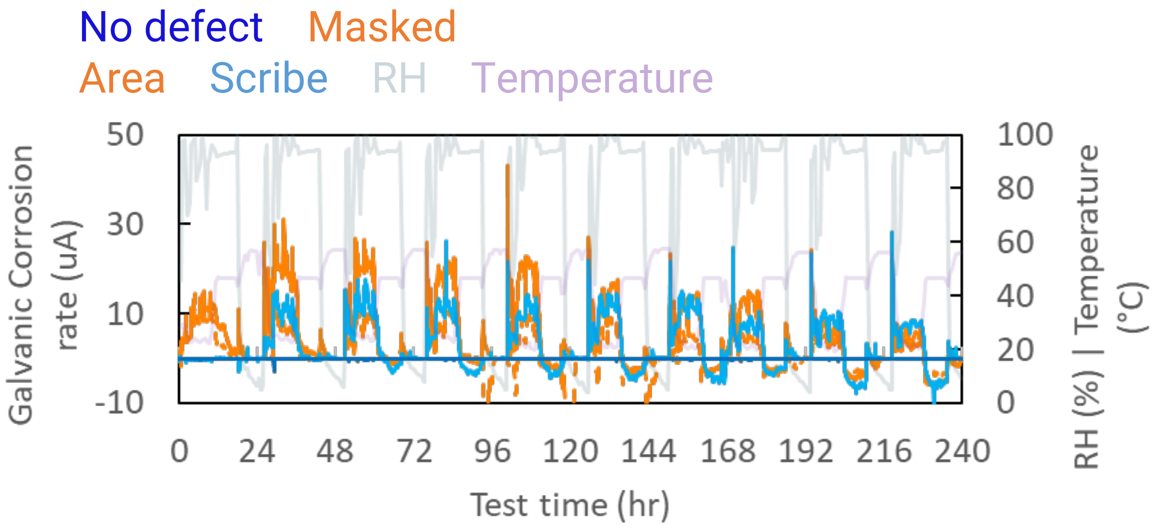
Defect Size Evaluation

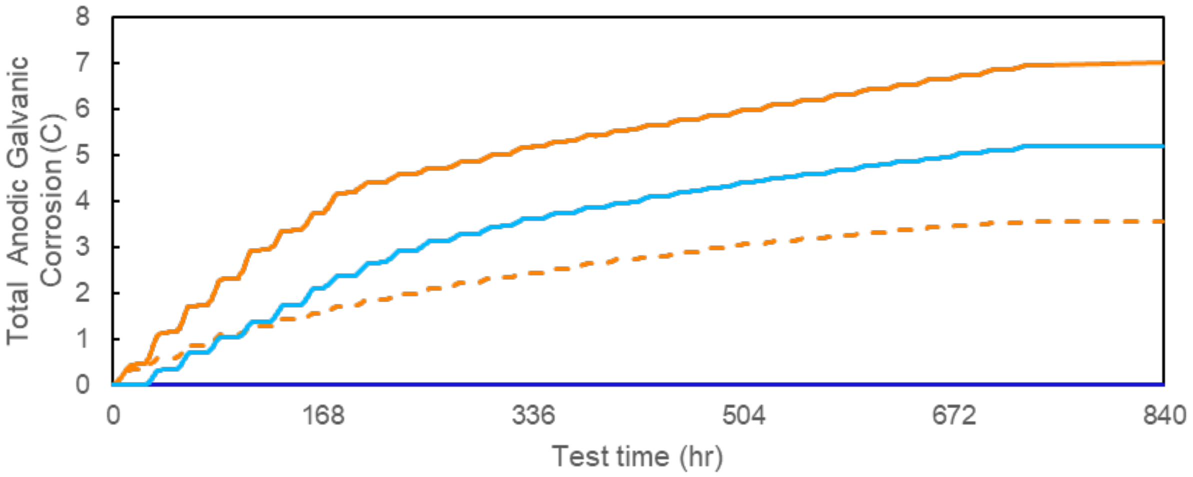
Component	Description
Base Coupon	4130 steel w/ Zn/Ni plating
Cover Sheet	AA2024
Base Coating	E-coat
Defect	No defect, masked area, or scribe
Environment	GMW14872

Defect Size Evaluation

Component	Description
Base Coupon	4130 steel w/ Zn/Ni plating
Cover Sheet	AA2024
Base Coating	E-coat
Defect	No defect, masked area, or scribe
Environment	GMW14872

- Observed an overall shift from positive currents to negative currents
  - Initially the base coupon is corroding, but over time the aluminum Cover Sheet is corroding more
  - The base corrodes during sprays and the Cover Sheet corrodes during high humidity
- Despite the masked area being a much larger defect, it did not consistently result in a greater amount of corrosion



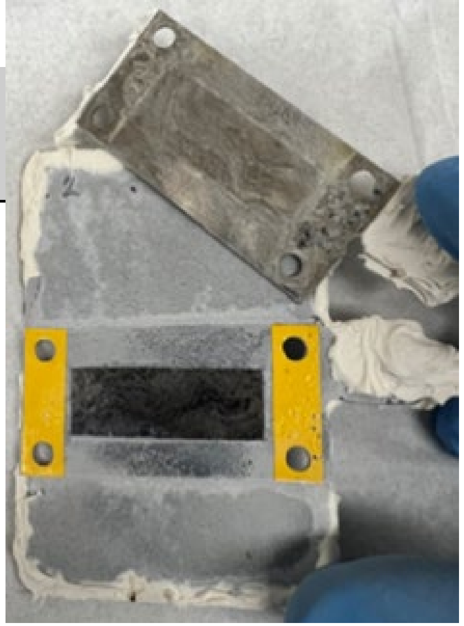


Defect Size Evaluation

Component	Description
Base Coupon	4130 steel w/ Zn/Ni plating
Cover Sheet	AA2024
Base Coating	E-coat
Defect	No defect, masked area, or
Environment	

The MC ZRA system demonstrated that it captures positive and negative currents and can flip between the two as conditions change

No defect

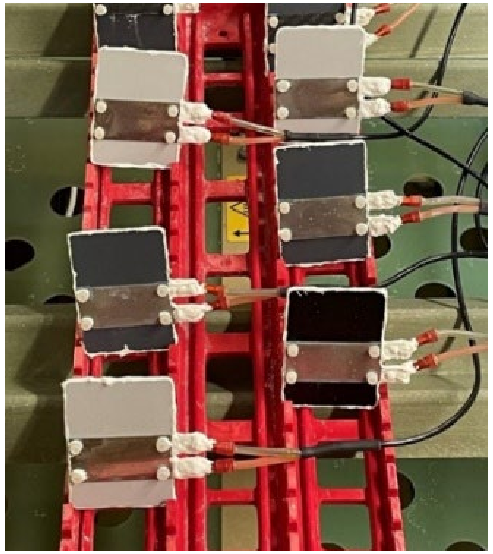


Masked Area

Scribe

Topcoat Evaluation

Component	Description
Base Coupon	AA7075
Cover Sheet	316 Stainless Steel
Base Coating	E-coat with no topcoat, powder topcoat, or standard topcoat+
Defect	Scribe in crevice
Environment	MDACT



+MIL-PRF-85285

Topcoat Evaluation

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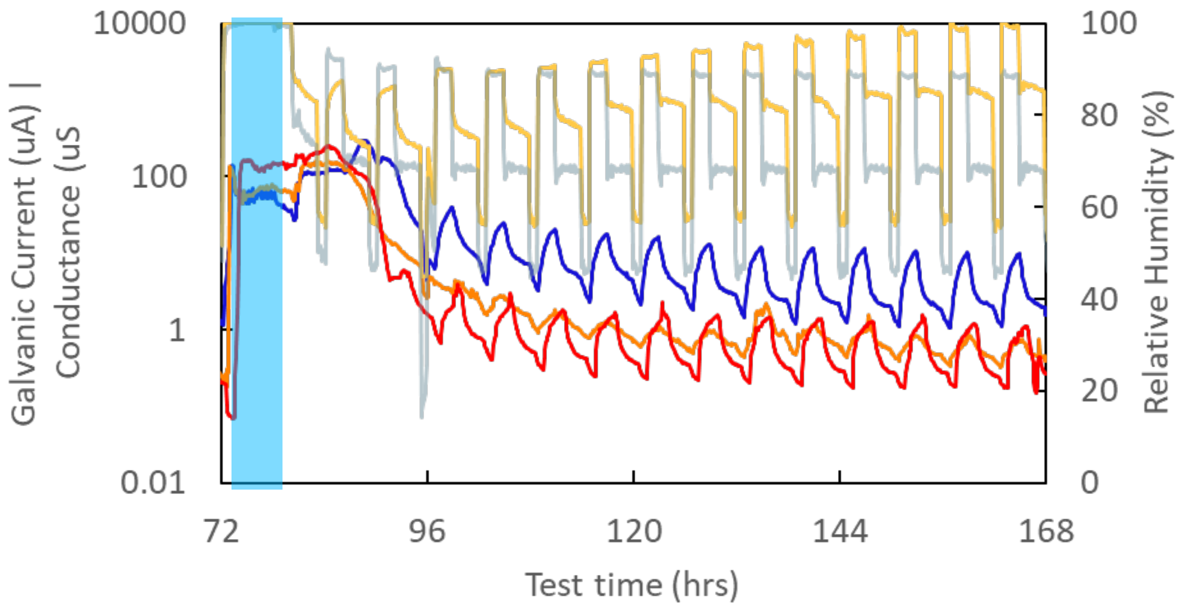
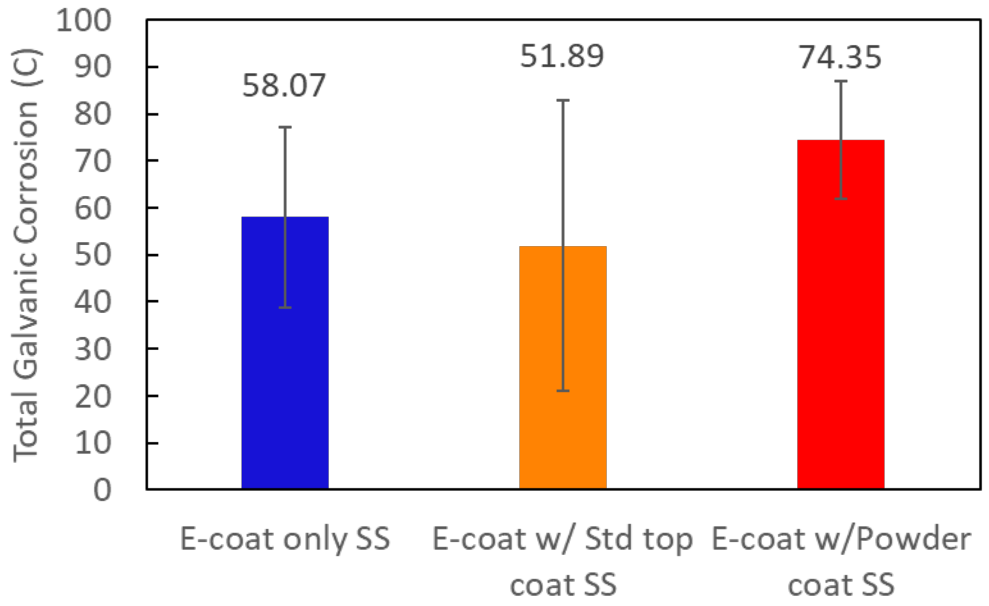
Base Coupon	AA7075
Cover Sheet	316 Stainless Steel
Base Coating	E-coat with no topcoat, powder topcoat, or standard topcoat
Defect	Scribe in crevice
Environment	MDACT

- Sustained elevated corrosion response after fog cycles for approximately 12 hours before clear peaks are observed during humidity cycling during drying
- The addition of a topcoat over the e-coat did not have a significant effect on the total corrosion
    - Topcoat does not contain inhibitors and was scribed

Fog Conductance RH E-coat only w/ SS316 E-coat w/ Standard topcoat and SS316 E-coat w/ powder topcoat and SS316





Topcoat Evaluation

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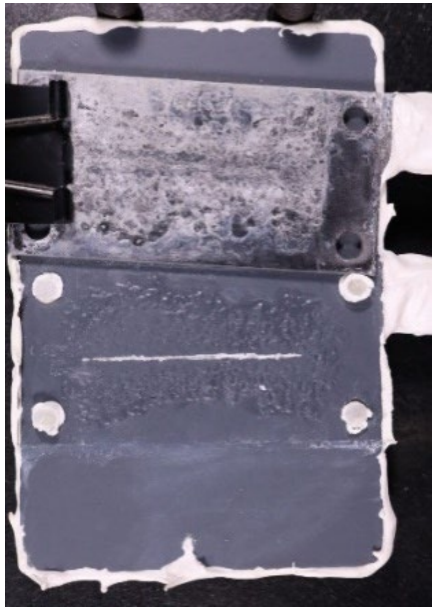
Defect	Scribe in crevice
Environment	MDACT

- Sustained elevated corrosion response to fog cycles before clear peaks are observed during humidity cycling during drying
- The addition of a topcoat over the e-coat did not affect the total corrosion
- → Similar amounts of blistering across samples

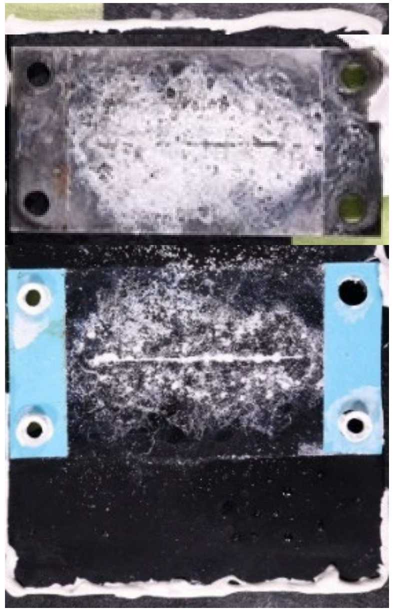
The MC ZRA system can monitor multilayer coating systems

E-coat only w/ SS316

E-coat w/ Standard topcoat and SS316



E-coat w/ powder topcoat and SS316



Corrosion Cycle Severity Comparison

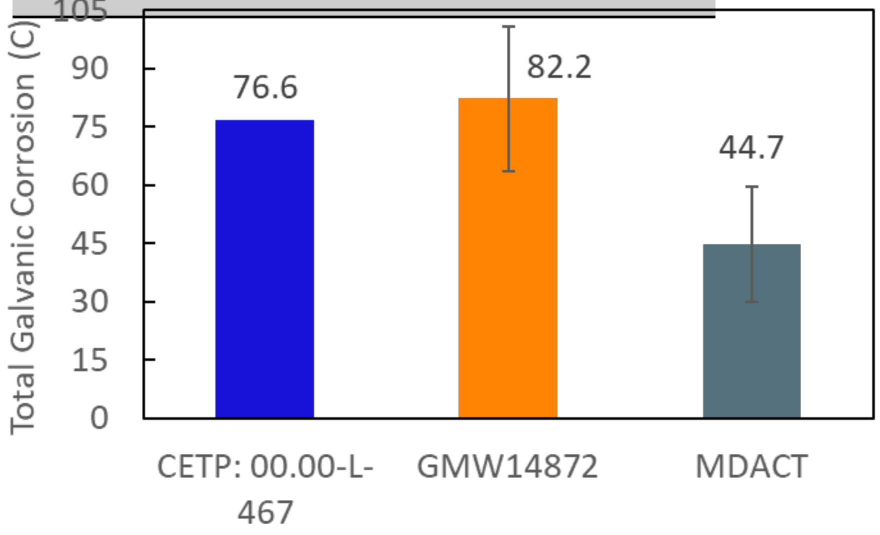
Component	Description
Base Coupon	AA7075
Cover Sheet	316 Stainless Steel
Base Coating	E-coat
Defect	Scribe in crevice
Environment	Various

Corrosion Cycle Severity Comparison

Component	Description
Base Coupon	AA7075
Cover Sheet	316 Stainless Steel
Base Coating	E-coat
Defect	Scribe in crevice
Environment	Various

- Similar amounts of corrosion and salt buildup were present on the CETP and GMW 14872 cycles after 450 hours of testing

The MC ZRA system can differentiate between various environments



CETP:00.00 – L - 467

GMW 14872

MDACT

Aerospace Coating Comparison

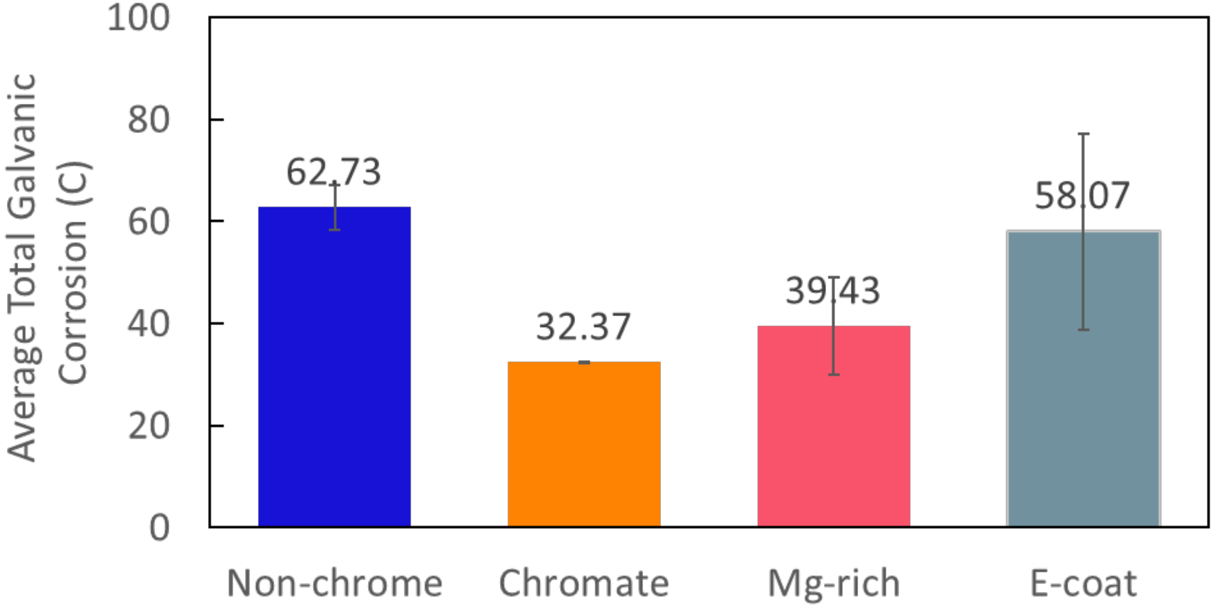
Component	Description
Base Coupon	AA7075
Cover Sheet	316 Stainless Steel
Base Coating	E- coat, Chromate, Non-chrome, Mg-rich
Defect	Scribe in crevice
Environment	MDACT

Aerospace Coating Comparison

Component	Description
Base Coupon	AA7075
Cover Sheet	316 Stainless Steel
Base Coating	E- coat, Chromate+, Non-chrome^, Mg-rich
Defect	Scribe in crevice
Environment	MDACT

- The Mg-rich was the best-performing chromate alternative followed by e-coat then the non-chrome
- E-coat had the largest amount of variation
  - Results span multiple rounds of testing

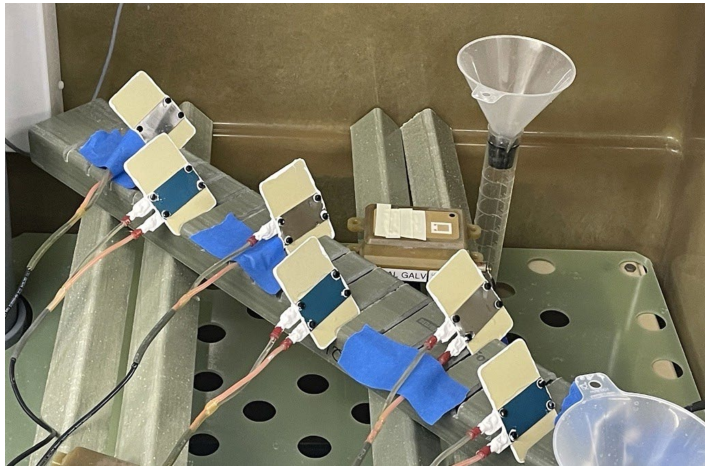
The MC ZRA system can differentiate between coatings including traditional aerospace coatings

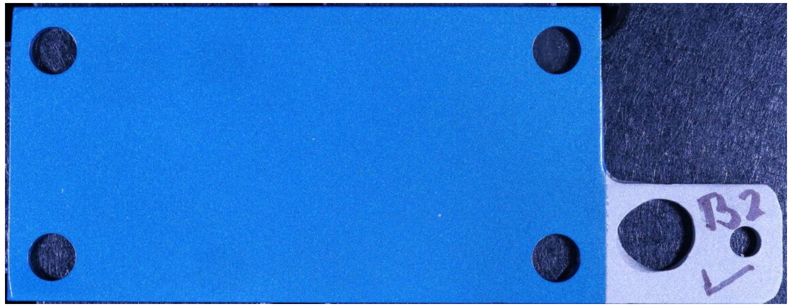


+MIL-PRF-23377 Ty I Class C2
^ MIL-PRF-23377 Ty I Class N

Cathodic Barrier Coating Evaluation

Component	Description
Base Coupon	AA7075
Cover Sheet	316 Stainless Steel
Base Coating	Chromate, Non-chrome, Mg-rich
Cover Coating	None, Sol-gel cathodic barrier coating*
Defect	Scribe in crevice
Environment	MDACT





*Blockade GC

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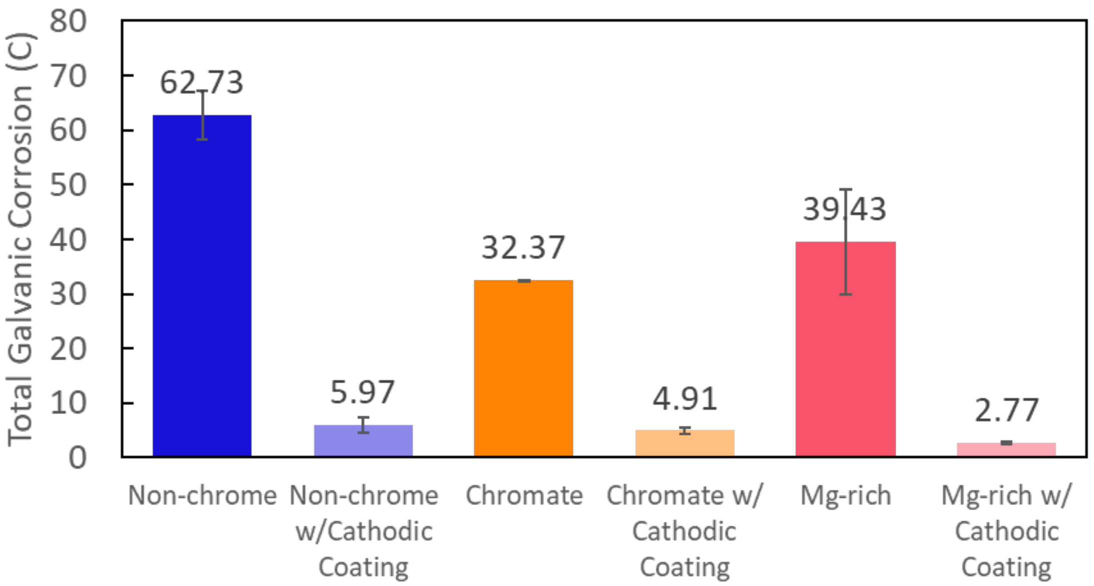

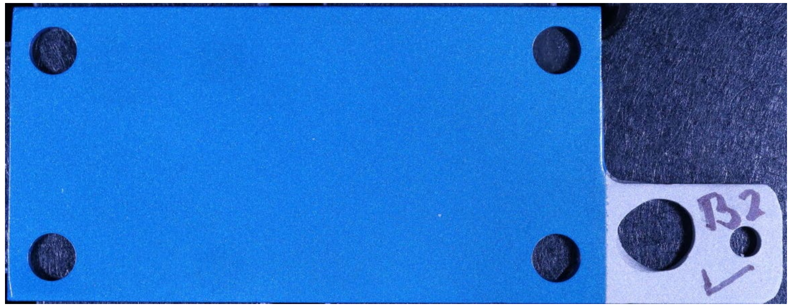

- Application of the cathodic barrier coating on the cathodic material reduced corrosion by an order of magnitude for all coatings systems.

Cathodic Barrier Coating Evaluation

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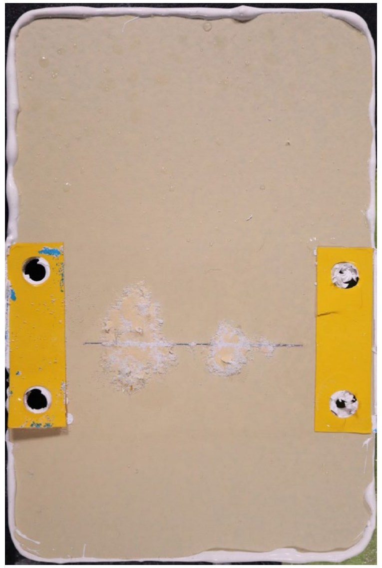
Cover Sheet	316 Stainless Steel
Base Coating	Chromate, Non-chrome, Mg-rich
Cover Coating	None, Sol-gel cathodic barrier coating*
Defect	Scribe in crevice
Environment	MDACT

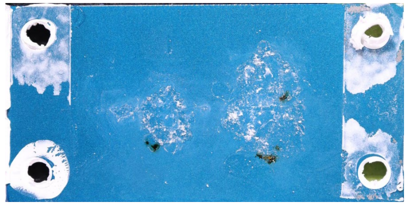
- Almost the entire area under the bare Cover Sheet was blistered compared to a few areas under the coated cover sheet
- Later tested against some other cathodic barrier coatings and Luna's formula was the best at preventing corrosion

The barrier coating helped shut down cathodic reactions

Without a barrier coating



With the barrier coating



Conclusions

Conclusions and Moving Forward

Conclusions:

1. Real-time changes in corrosion kinetics were captured with the MC ZRA system
2. The MC ZRA system was able to capture the environmental response of the galvanic crevice samples in each accelerated test cycle
3. Verified the system’s ability to collect data over its entire measurement span and flip seamlessly between positive and negative currents
4. The MC ZRA successfully collected real-time corrosion measurements on a multitude of coating systems and sample configurations
5. The collected corrosion measurements can be used to differentiate coatings and evaluate their performance

Moving forward:

- This device will continue to be used for corrosion investigations to provide real-time corrosion data
  - Monitored bare butt joint samples
  - Used in outdoor environments

Acknowledgements

This material is based upon work supported the United States Air Force AFRL/SBRK under contract FA864921P1498. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the project sponsors.

UDRI, Ford, and PPG for supporting this effort and testing this measurement system.

Questions?

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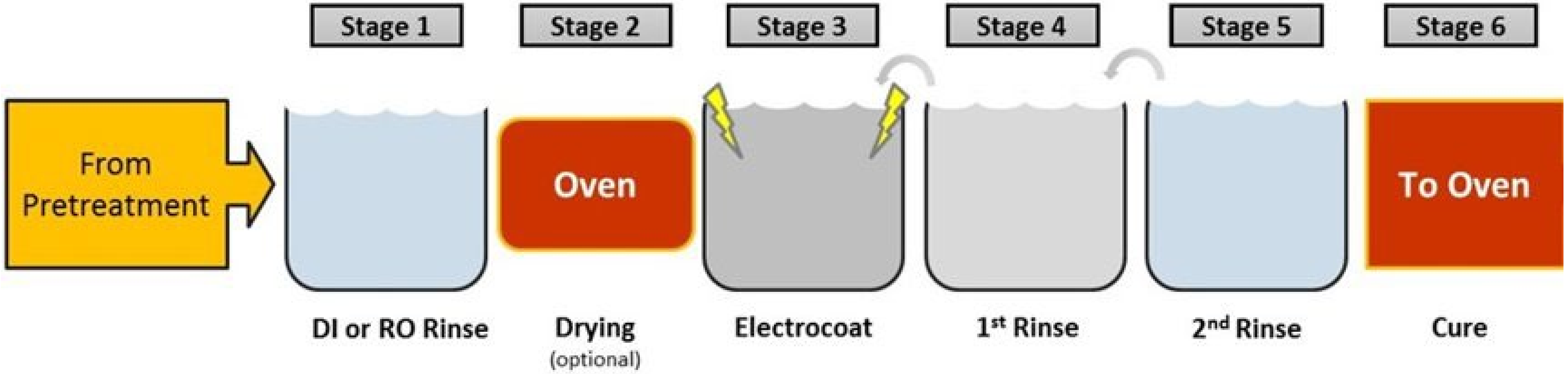
Vic Avance
Email: vic.avance@lunalabs.us

E-Coat Process

E-coat Part Processing



5 Aerocron 2100
6 PPG Matte Black 89546T25K
7 NCP Coatings Single Component Polysiloxane Topside Coating
8 PPG Deft CA9311