



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

Victoria Avance, Fritz Friedersdorf

Automotive Symposium 2024

April 11th, 2024

Opportunity

Opportunity: Electrocoat (e-coat) and powder coatings are widely used for coating automotive components and were recently approved for use on aluminum aircraft components.

The increasing applications and use of e-coat and powder coat highlight the need for improved qualification testing.

- Currently, the visual inspections and ratings that are used to evaluate coatings do not account for corrosion kinetics. A system with the ability to monitor coatings in real-time is needed to develop quantitative metrics
- The introduction of new coatings using traditional test methods often takes ten or more years. The development of continuous real-time measurements could reduce this time



Proposed Solution

Solution: A dual-span measurement system for rapid, quantitative measurement of coating performance on samples adapted to the high-temperature processing requirements for e-coat and powder coatings

Benefits of durable e-coat and powder coat products:

- Increased readiness and reduced sustainment costs
- Improved coating process throughput
- Reduced hazardous wastes
- Enhanced worker safety

Technical merit:

- Solution leverages measurement systems that are already being used for civil and military applications to measure environmental severity, coating performance, and corrosion



System Overview

Multi-Channel ZRA (MC ZRA) System

- A new device was developed that enables precise monitoring of galvanic corrosion rates *in situ*
 - Utilizes the zero-resistance ammeter (ZRA) functionality of the Acuity system¹
 - Can measure positive and negative currents from – 500 μA to 500 μA
 - Efficiently multiplexes between up to eight samples
 - Enables monitoring of various sample geometries and coatings

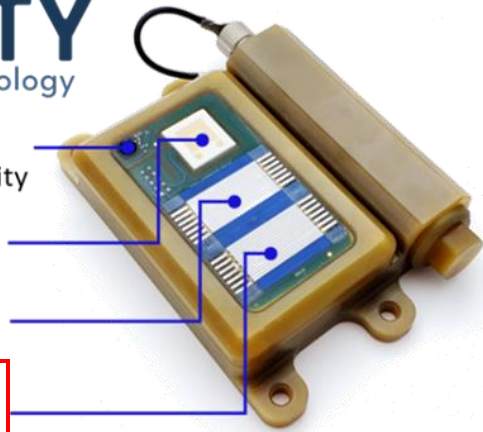


Temperature
Relative Humidity

Contaminants

Single Material
Corrosion

Mixed Material
Corrosion



8 sample
connections

¹ F. J. Friedersdorf, J. C. Demo, N. K. Brown, and P. C. Kramer, "Electrochemical Sensors for Continuous Measurement of Corrosion and Coating System Performance in Outdoor and Accelerated Atmospheric Tests," in *ASTM STP1609, Symposium on Recent Advances in Electrochemical Techniques for Corrosion Monitoring and Laboratory Corrosion Measurements*, 2017, vol. ASTM STP16.

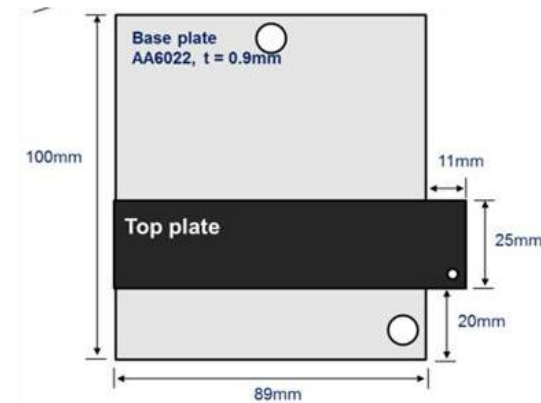
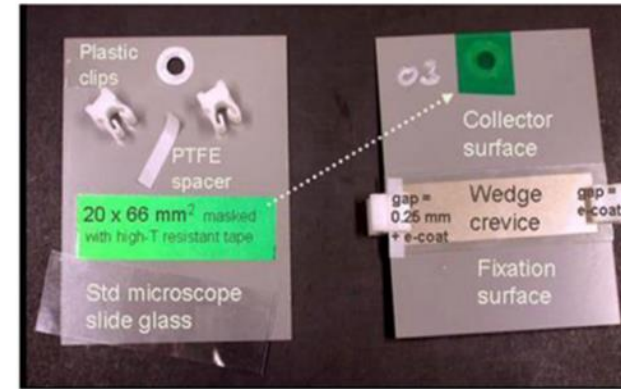
Sample Design Requirements

A new sample design was needed to enable e-coat and powder coat processes. Sample configuration was influenced by various designs currently utilized by the automotive industry.

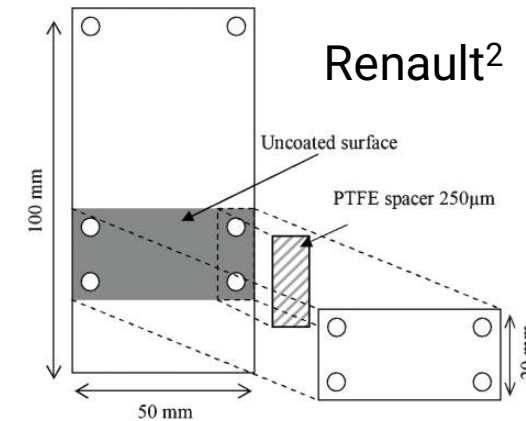
Key considerations:

- Straightforward to fabricate and coat
- Able to monitor crevice or boldly exposed conditions
- Adaptable to various component materials and coatings
- Can be instrumented for connection with a ZRA measurement device

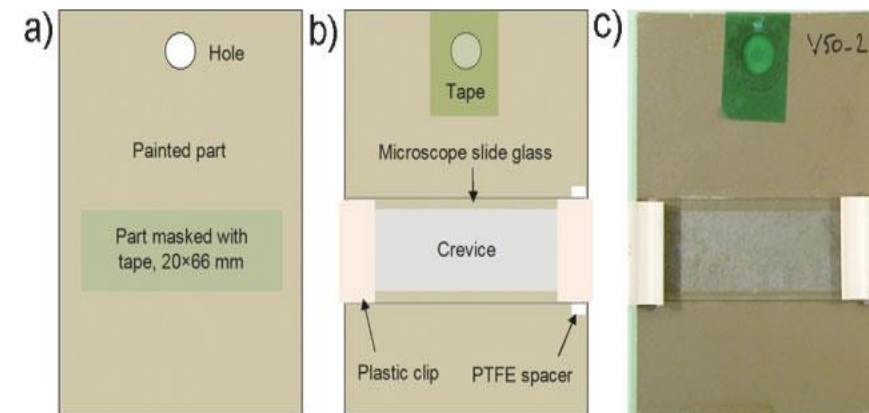
Ford*



Renault²



Volvo²



* Courtesy of Ford

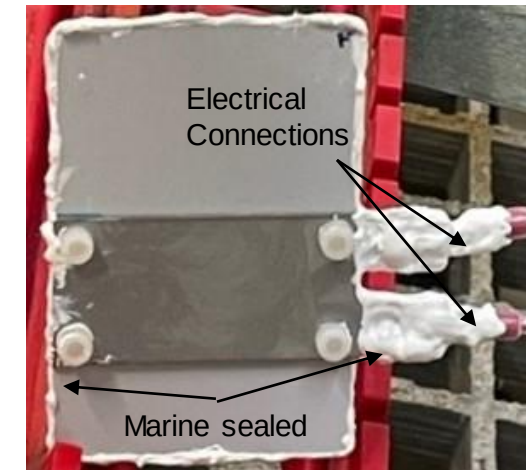
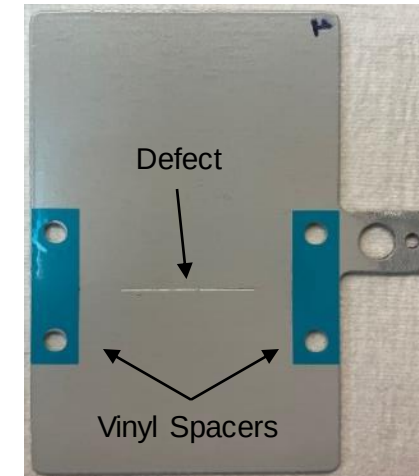
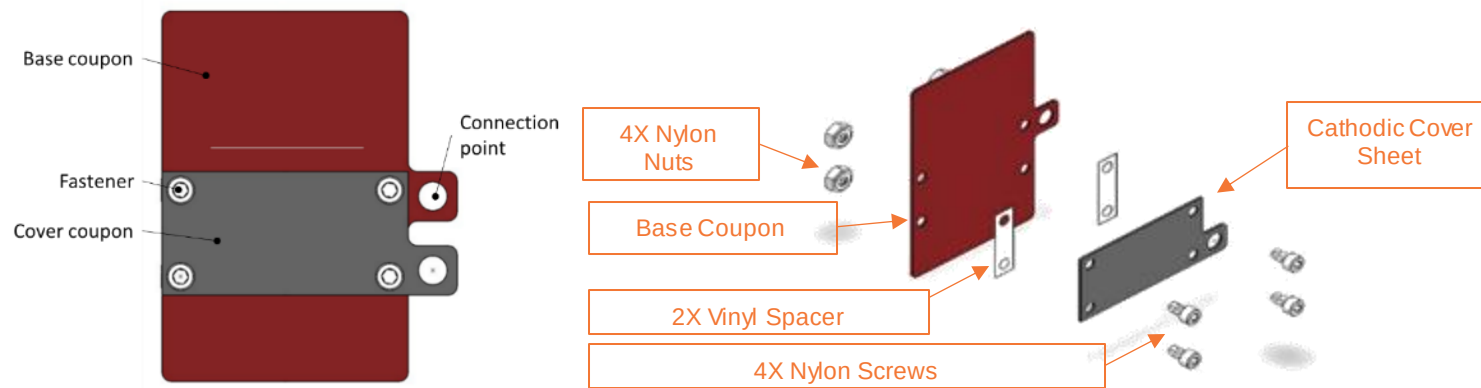
² T. Prosek, N. Larché, M. Vlot, F. Goodwin, and D. Thierry, "Corrosion performance of Zn-Al-Mg coatings in open and confined zones in conditions simulating automotive applications," *Mater. Corros.*, 2010.

Galvanic Crevice Sample

- Consists of:
 - Base Coupon (structural frame, 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

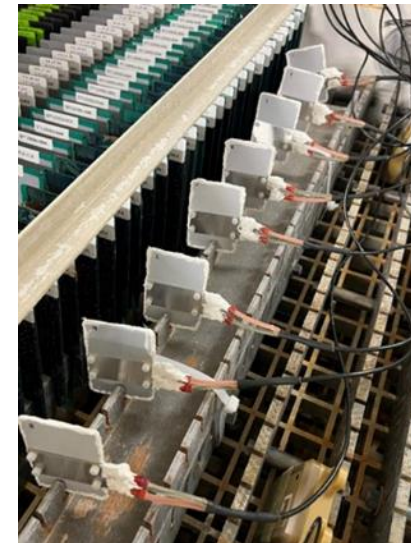
Test Objectives

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

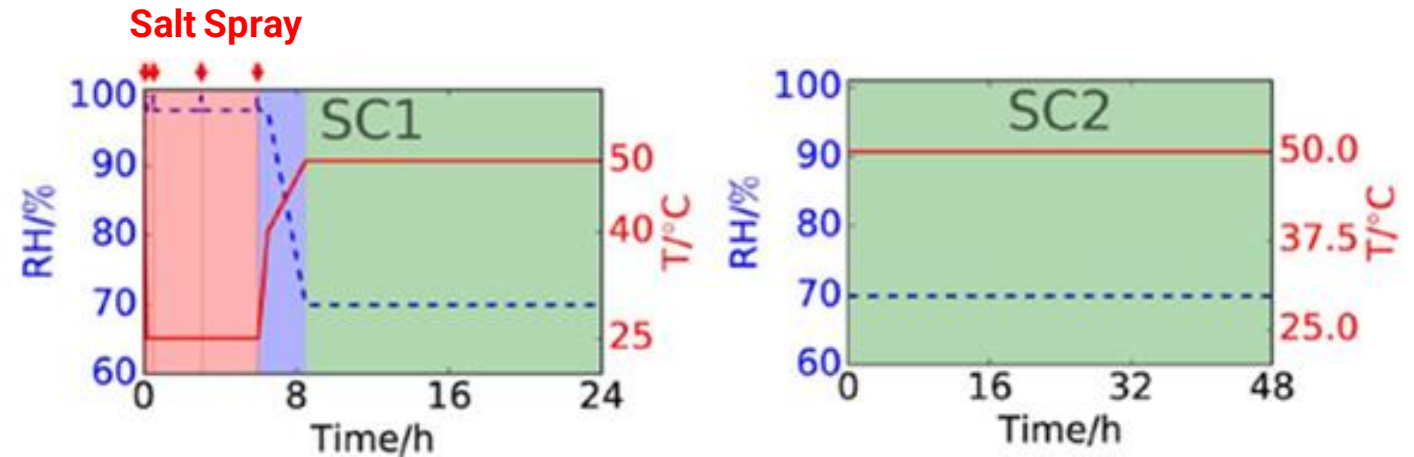
Testing was conducted at four labs:

- 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
- 3 test cycles: Ford CETP: 00.00-L-46, GMW14872, MDACT



Test Environments

- **Ford CESTP:00.00-L-467³**
- Samples were tested for 1 month in each cycle

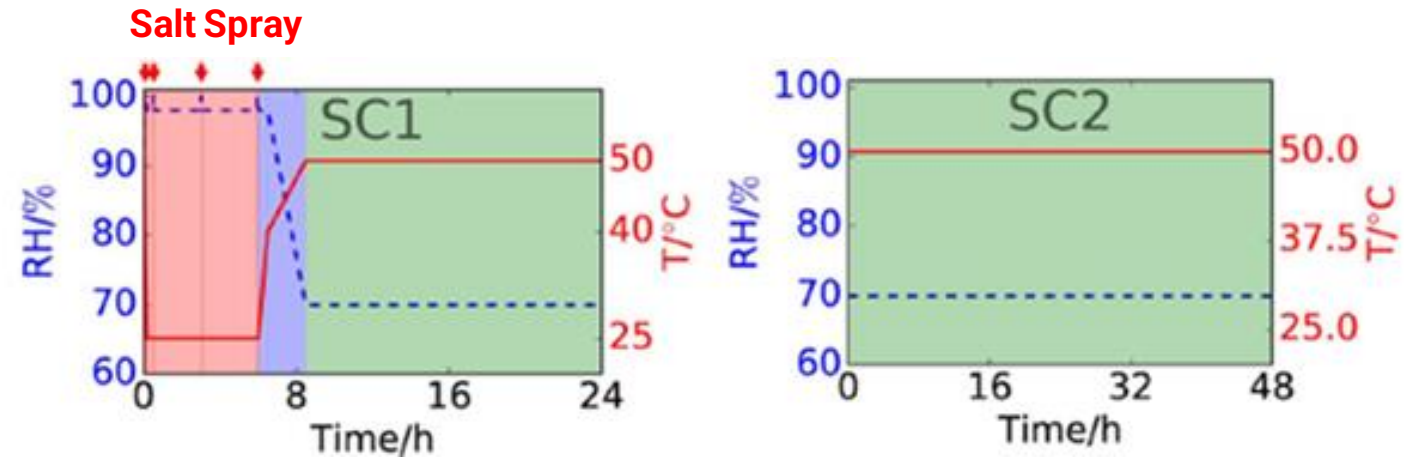


Ford CESTP:00.00-L-467

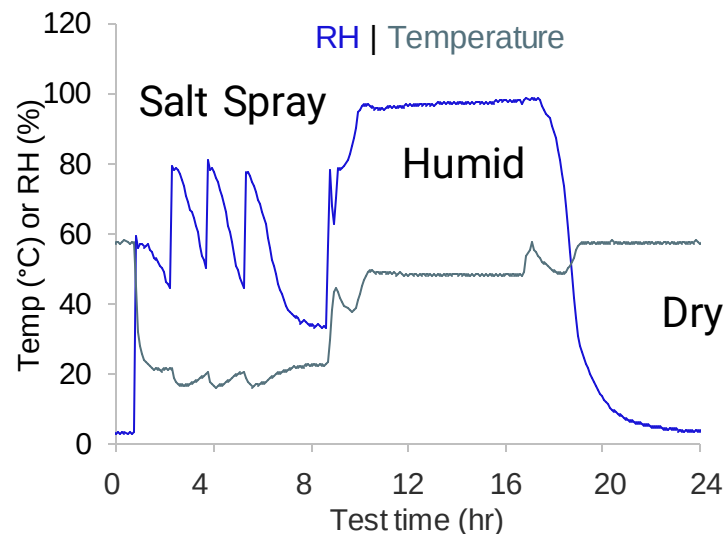
³ "Ford CESTP:00.00-L-467." Ford Motor Company.

Test Environments

- Ford CETP:00.00-L-467
- **GMW 14872⁴**
- Samples were tested for 1 month in each cycle



Ford CETP:00.00-L-467

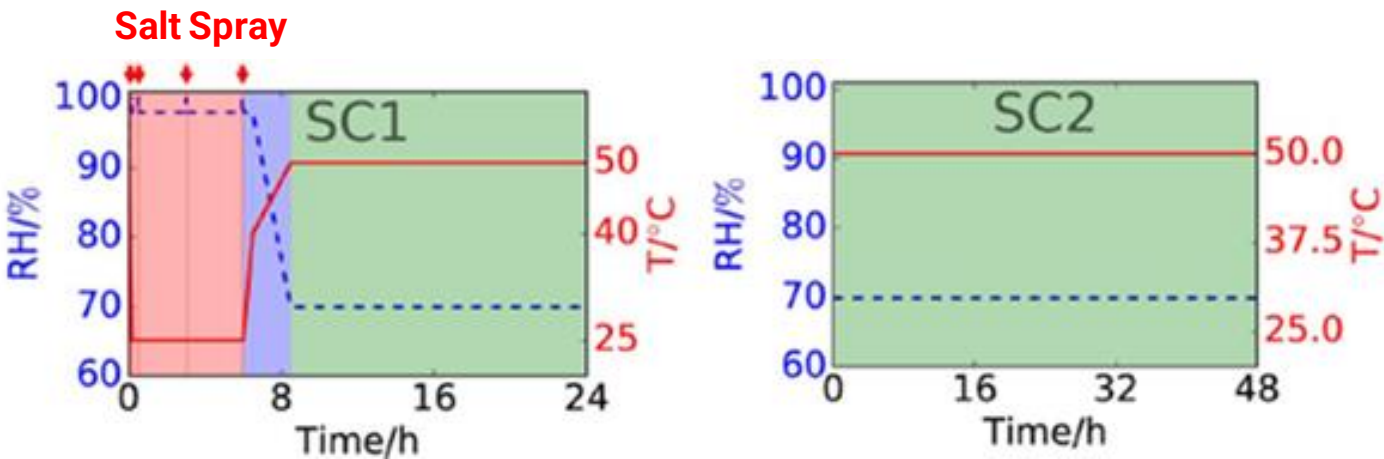


GMW 14872

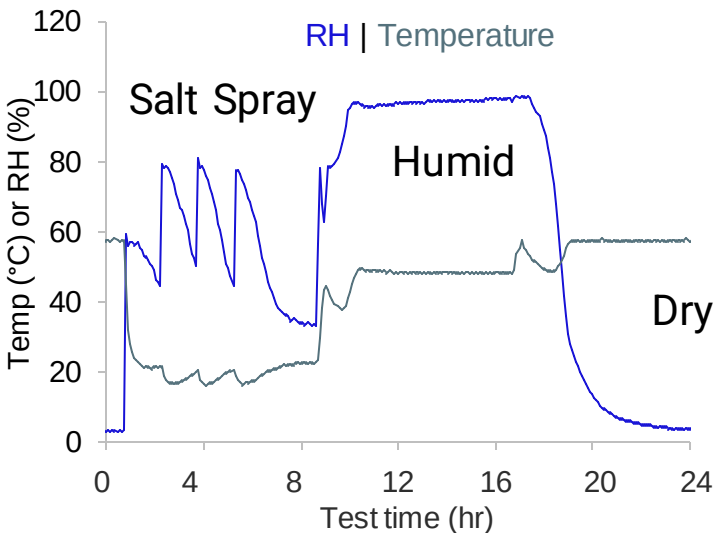
⁴ G. M. Company, "GMW14872," General Motors Company, 2021

Test Environments

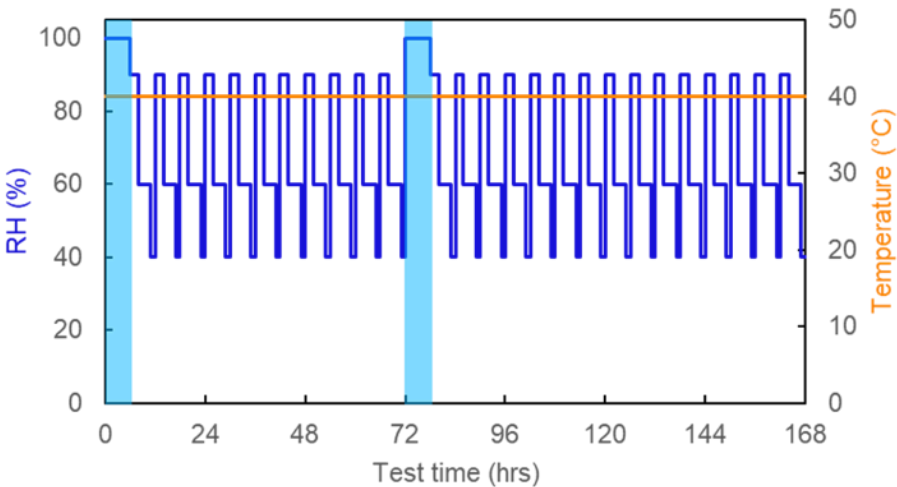
- Ford CETP:00.00-L-467
- GMW 14872
- **MDACT**⁵
- Samples were tested for 1 month in each cycle



Ford CETP:00.00-L-467



GMW 14872

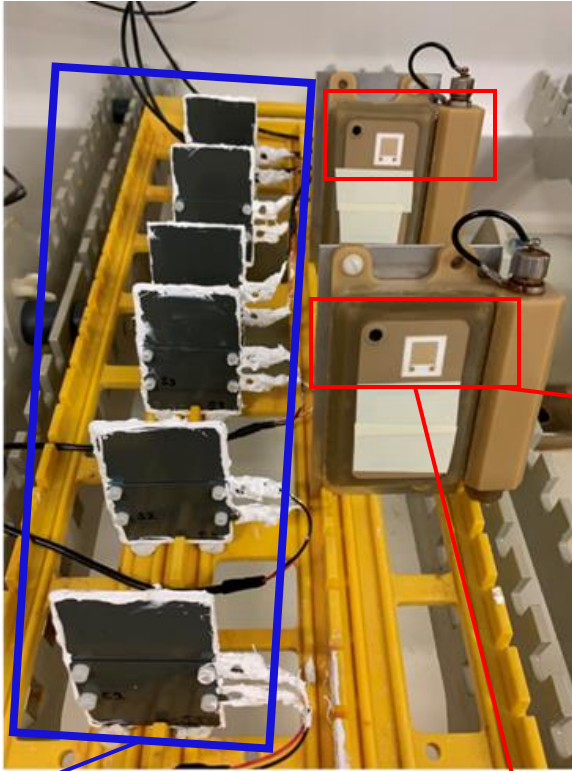


Step Number	Action	Duration (h:mm)
1	Fog	6:00
2	Subcycle 3-5	Repeat 11x
3	90% RH Hold	2:00
4	60% RH Hold	3:00
5	40% RH Hold	1:00
9	Fog	6:00
10	Subcycle 11-13	Repeat 15x
11	90% RH Hold	2:00
12	60% RH Hold	3:00
13	40% RH Hold	1:00
14	Final Step	Return to Step 1

MDACT

⁵ A. Lilly and S. Kopitzke, "Validation and Demonstration of Relative Humidity Controlled Accelerated Corrosion Test: New Specification Development ESTCP Project WP18-5087," Demonstration Plan, Jun.

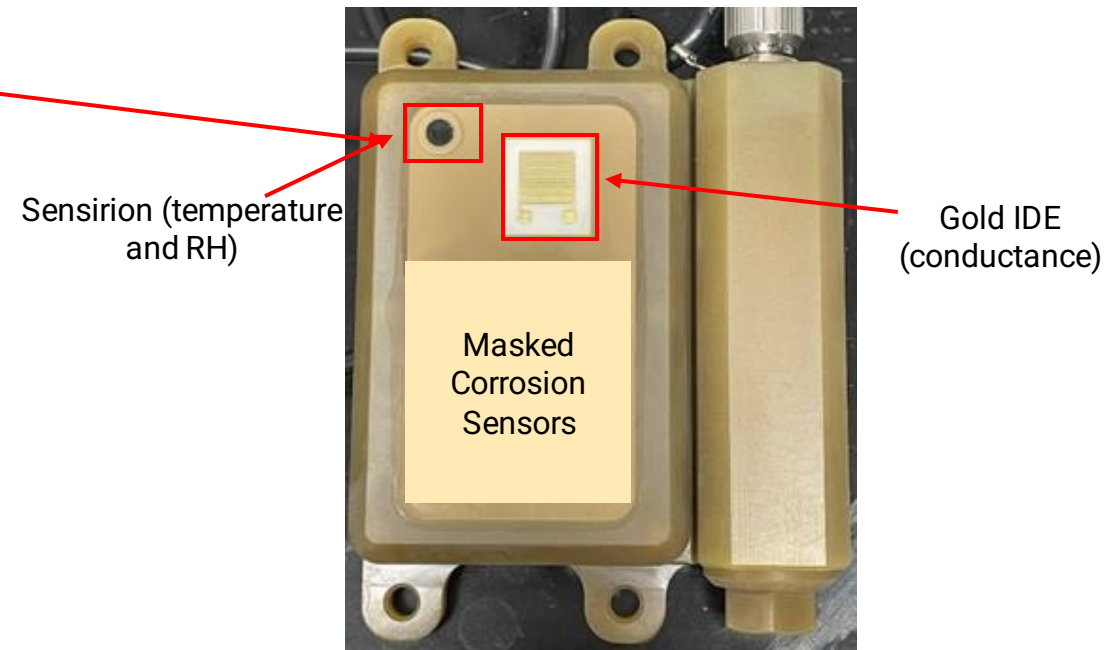
Environmental Monitoring



Galvanic Current
measured by MC
ZRA

Environment
measured by Acuity
Devices

- Acuity LS devices collected environmental information during testing
 - Temperature
 - Relative humidity
 - Solution Conductance/ Contaminants



All data will be presented such that a positive current indicates the base plate is corroding while a negative current indicates the cover sheet is corroding.

Results

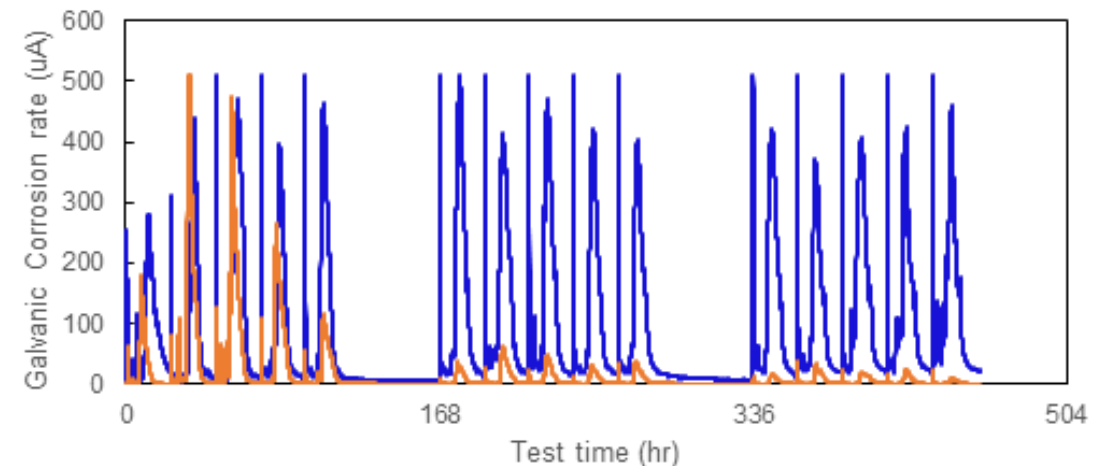
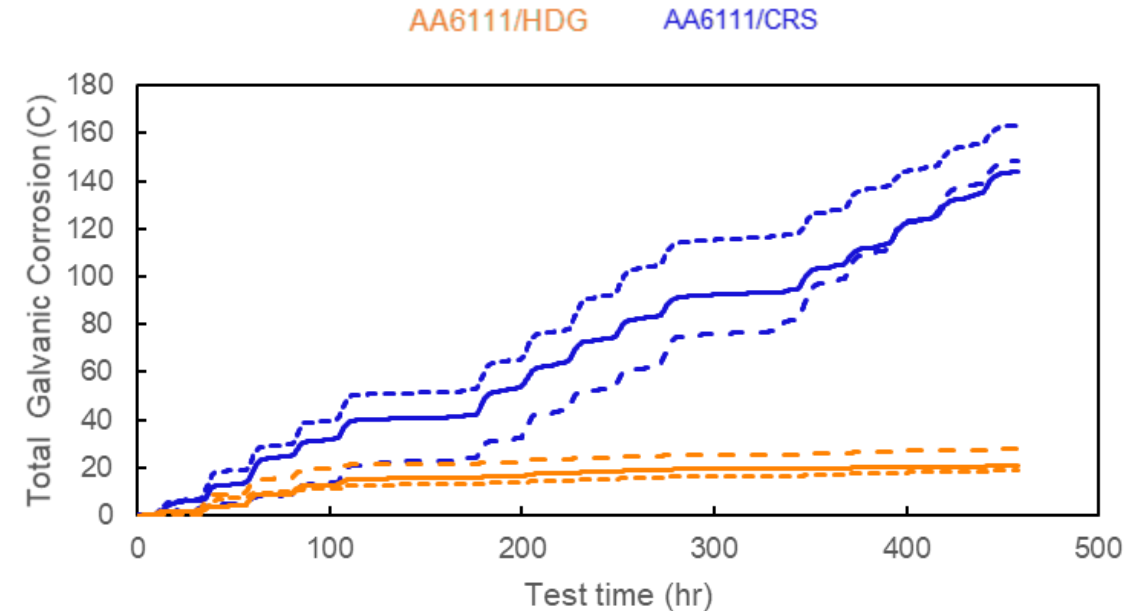
Galvanic Couple Evaluation

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

Galvanic Couple Evaluation

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

- 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

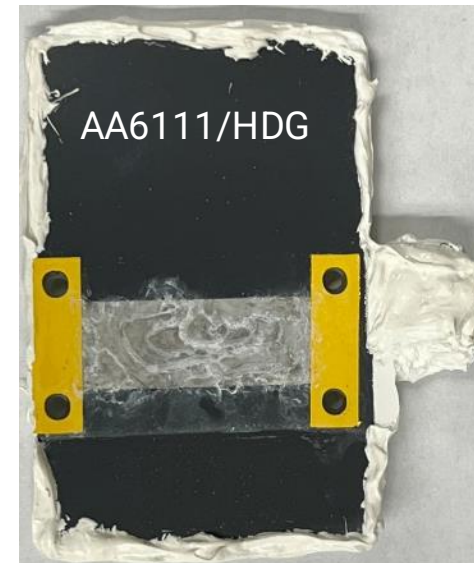
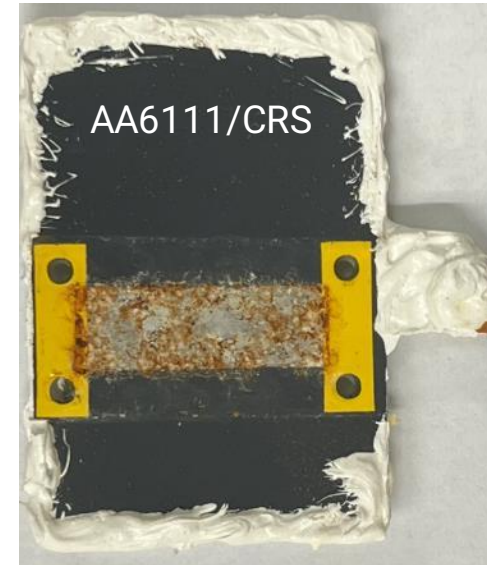


Galvanic Couple Evaluation

Component	Description
Base Coupon	AA6111 with 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

- 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



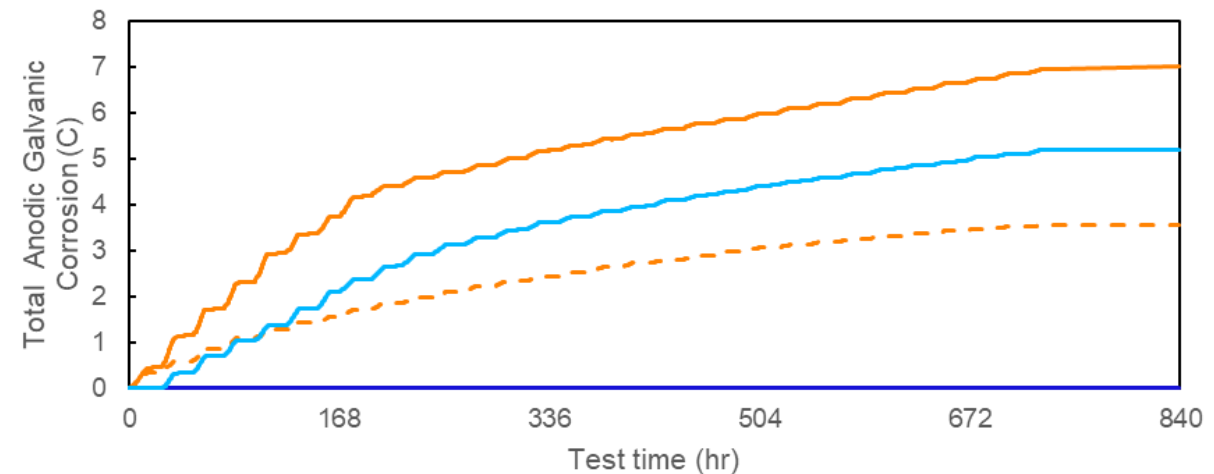
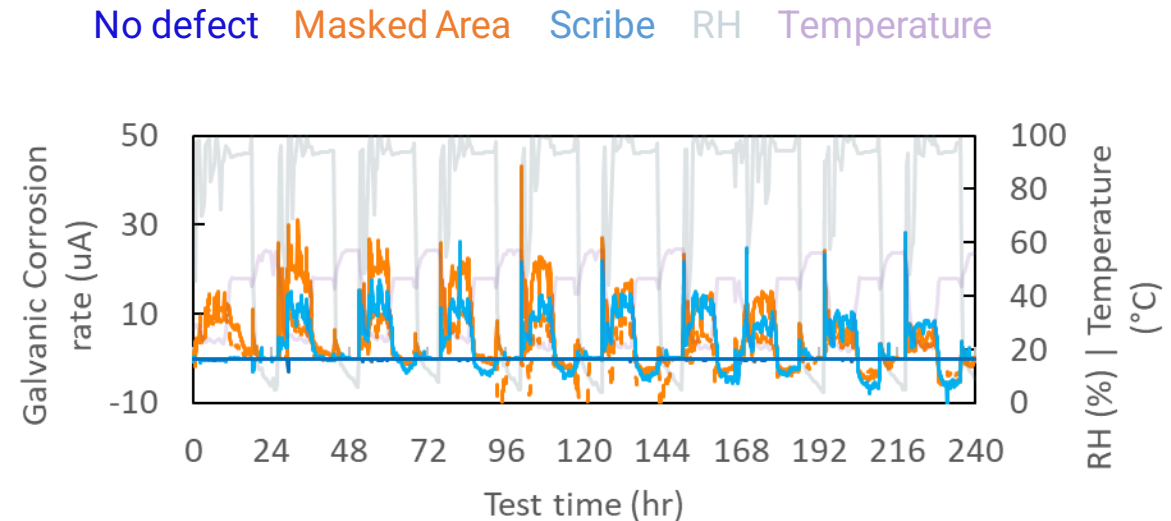
Defect Size Evaluation

Component	Description
Base Coupon	4130 steel with 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 with 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



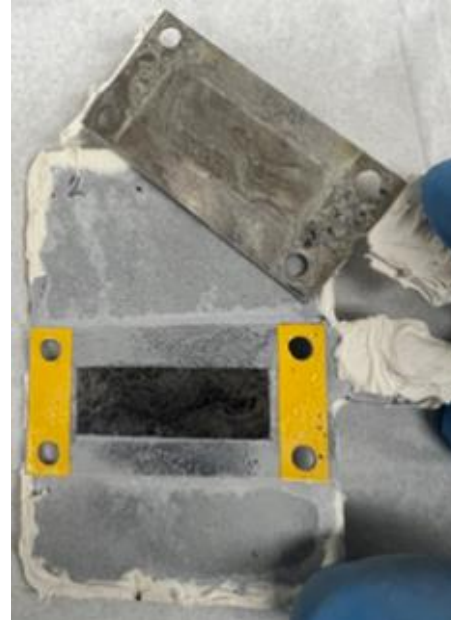
Defect Size Evaluation

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

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



No defect



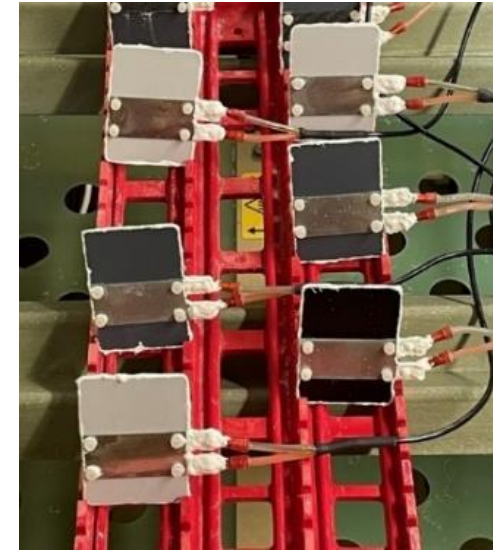
Masked Area



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



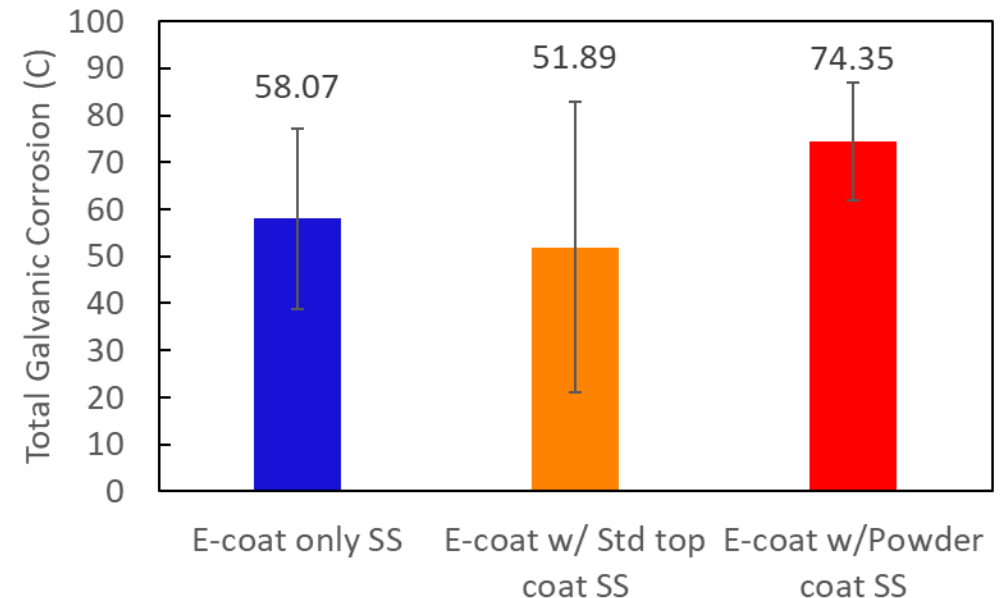
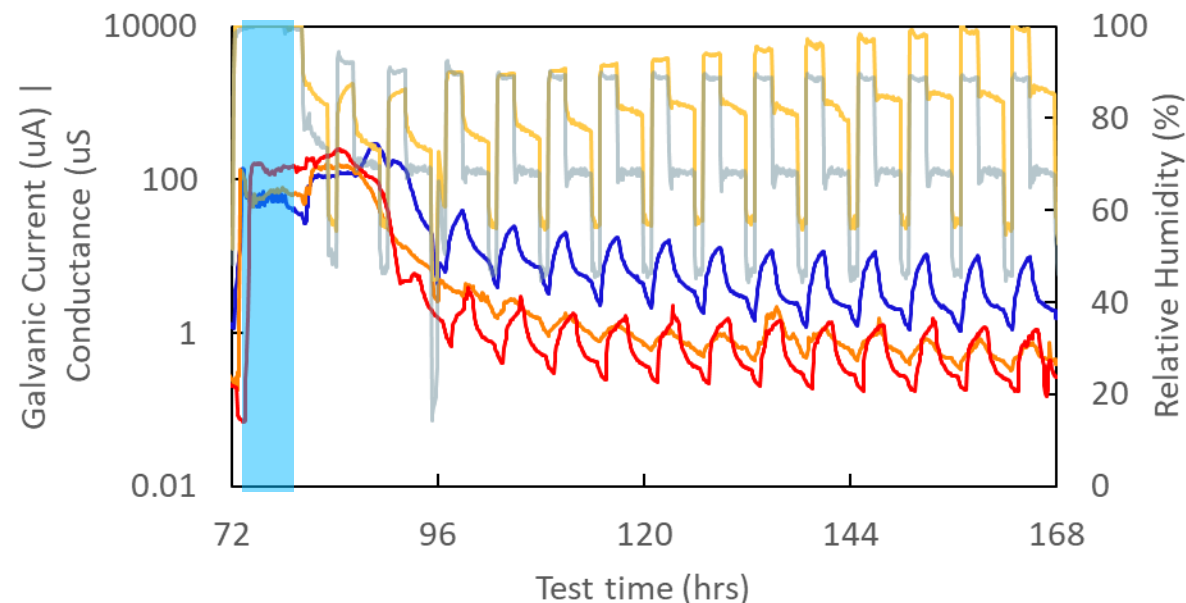
⁺MIL-PRF-85285

Topcoat Evaluation

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

- 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



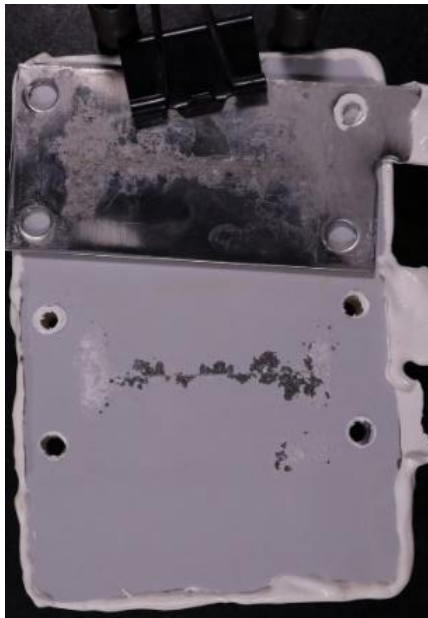
Topcoat Evaluation

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

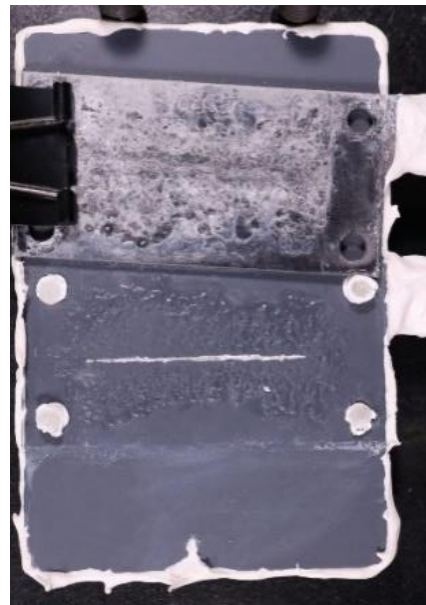
- Sustained elevated corrosion response to fog cycles before clear peaks are observed during humidity cycling during drying
- The addition of a topcoat over the e-coat did not affect the total corrosion
- → Similar amounts of blistering across samples

The MC ZRA system can monitor multilayer coating systems

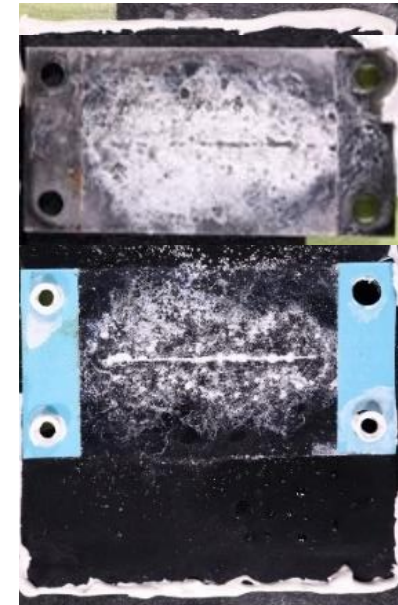
E-coat only w/ SS316



E-coat w/ Standard topcoat and SS316



E-coat w/ powder topcoat and SS316

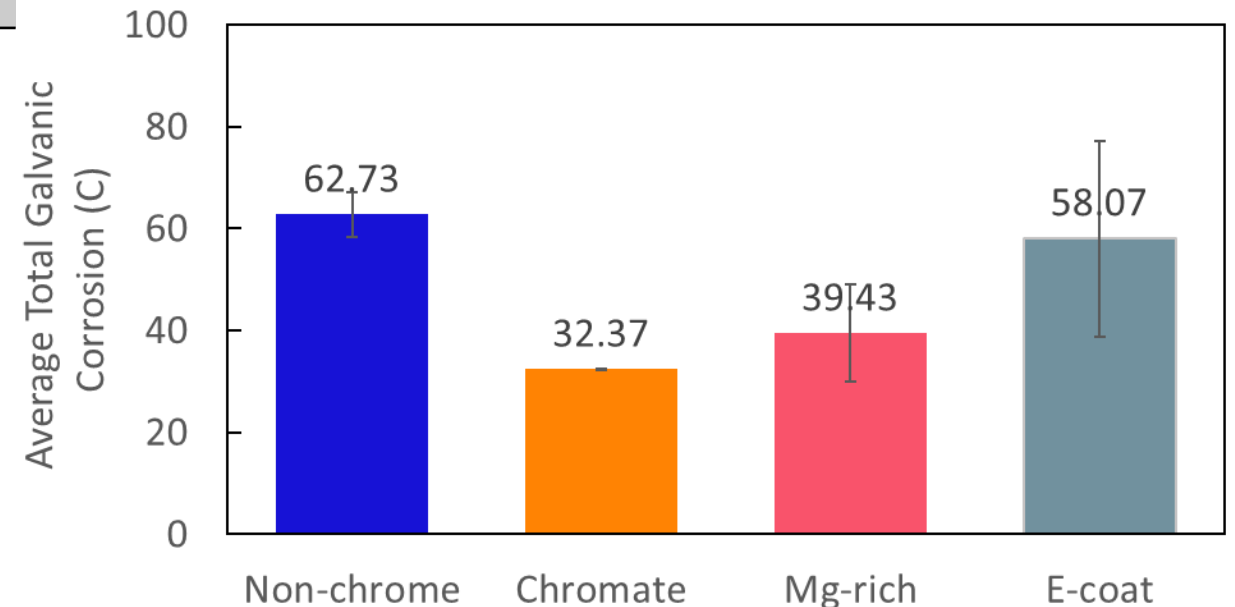


Aerospace Coating Comparison

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 MC ZRA system can differentiate between coatings including spray-applied and metal-rich coatings

- 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

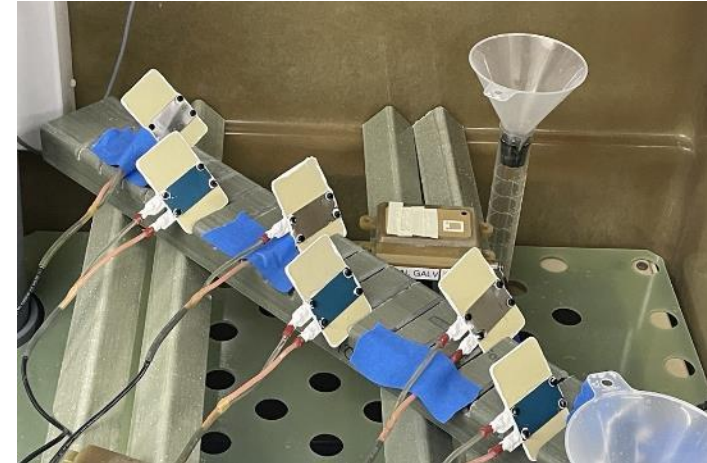


⁺MIL-PRF-23377 Ty I Class C2

[^]MIL-PRF-23377 Ty I Class N

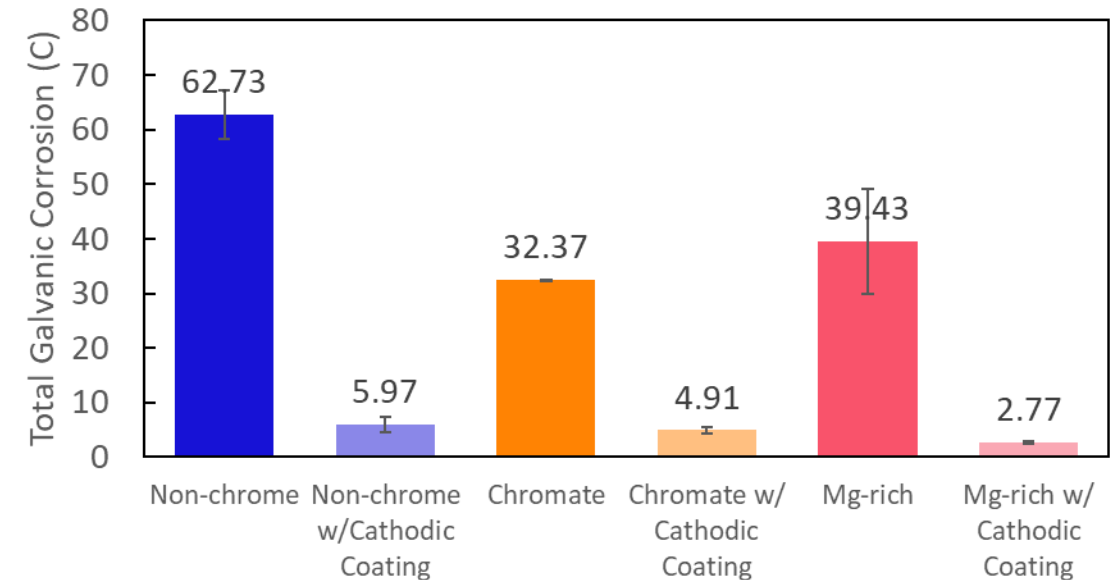
Cathodic Barrier Coating Evaluation

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



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



- 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

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

- 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

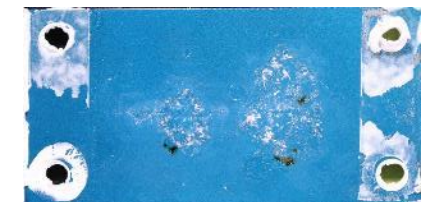
The barrier coating helped shut down cathodic reactions



Without a barrier coating



With the barrier coating



Conclusions

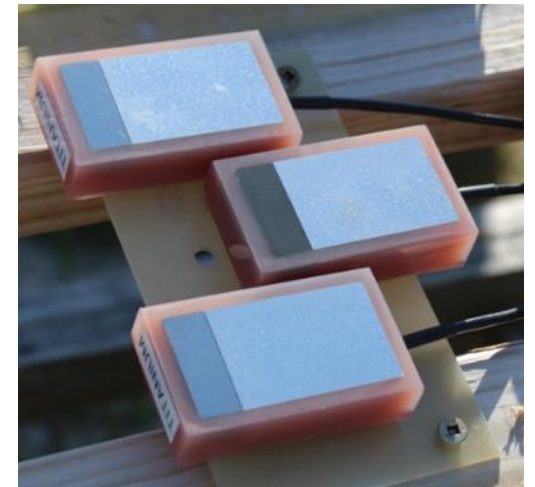
Conclusions and Moving Forward

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?

Vic Avance
Email: vic.avance@lunalabs.us