Reducing Mass of Steel Auto Bodies Using Thin Advanced High-Strength Steel with Carbon Fiber Reinforced Epoxy Coating

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Presenter: Gabriel Ilevbare

Organization: INL and ORNL

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Project ID #: MAT144

Overview

Timeline

- Project start: April 2018
- Project end: April 2020
- Percent complete: 60%

Barriers

- Low Cost, High Volume Manufacturing
- Use of Multi-Material solutions
- Novel Design Approaches

Budget

- Total project funding
  - DOE share: $300,000
  - Contractor share: $339,000
- FY 2017 funding: $300,000
- FY 2018 funding: $0

Partners

- Diversitak (Rajan Eadara)
- ArcelorMittal (Michael Lizak)
- ORNL (C. David Warren)
- INL (Gabriel Ilevbare)
- Project lead: Rajan Eadara

Project ID #: MAT144

Relevance/Objectives

Objectives: Develop carbon fiber filled formulated epoxy composite materials which when applied to steel allow the use of lower thickness AHSS (down gauging) thus reducing component mass.

- A robotically dispensed paste applied with spray, swirl, or shovel applications
- Cures at 150ºC to 200ºC temperatures
- The material forms into a high modulus coating on steel substrates
- Target: closure panel materials 0.5 mm and 0.6 mm BP500
- Achieve the same structural performance while reducing the weight of the steel panel by down gauging
- >15% reduction in component mass
- No Corrosion issues

Impact: Reduction of component mass, and hence total auto body weight, leading to fuel savings

Project ID #: MAT144

Approach/Project Milestones

Project ID #: MAT144

- Year 1: Determine the best (performance and cost) fiber concentration, fiber size, fiber source, application method, application speed and cure temperatures.
  - ArcelorMittal: Part design, steel fabrication, corrosion performance.
  - Diversitak: Coating composition and application.
  - ORNL: Fiber selection, SEM analysis, CTE determination, Coating Evaluation.
  - INL: Corrosion performance at coupon and full scale levels.
- Year 2: Characterize corrosion performance and apply technology to real parts for performance evaluation

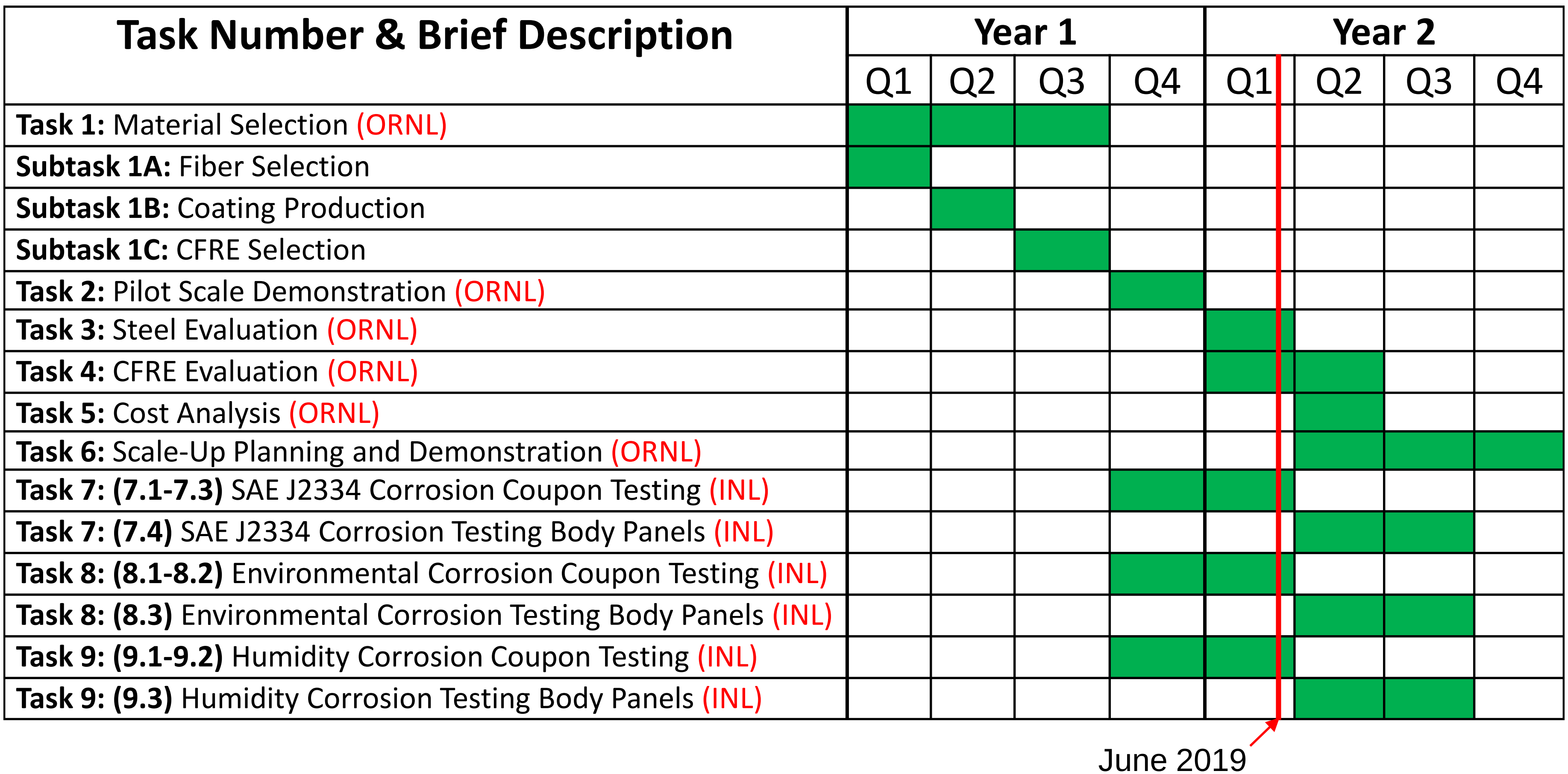
Task/MS	Milestone Description	Due
1	Delivery of fiber to Diversitak	**April 2018**
2	Demonstration panels produced and fiber distribution determined. Metric a 15% reduction in sheet mass/ square unit area with equivalent stiffness.	**December 2018**
3	Application process set-up and demonstration of the pilot scale unit.	**April 2019**
4	Industry test data quantifying adhesion and listing any deficiencies.	June 2019
5	Test data comparing the CFRE coated steel with uncoated steel.	October 2019
6	Final Project Report and commercialization plan.	April 2020

Key: **Milestone Completed**

Approach/Project Milestones (2)

Project ID #: MAT144

Task/MS	Milestone Description (Continued)	Due
7	Corrosion assessment of coupons and body panels SAE J2334	December 2019
8	Environmental corrosion assessment of coupons and body panels	December 2019
9	Humidity corrosion assessment of coupons and body panels	December 2019



Technical Accomplishments (Prior Year)

Optimal Carbon Fiber Reinforced Epoxy Chemistry and Application

- No read through
- Minimal coating shrinkage
- Low coefficient of thermal expansion
- No flaking or loss of adhesion
- Improved dent resistance
- Oil canning resistance with marked stiffness increase and low noise transmittal with CFRE coatings
- E-coat compatible and Weldable
- Fiber type and critical volume fraction achieved for optimal performance
- No morphology change in thermal cycling
- No measurable movement, displacement or wash off on application
- Robotically spray, swirl or shovel application
- 1-2 mm thickness achievable on application
- Mass reduction potential has been demonstrated
- Project is well ahead of schedule

Technical Accomplishments and Progress:

Results/Observations (New Work)

Methodology: Corrosion Testing (1)

Corrosion testing involves 550 test samples made from a high strength steel base with a CFRE coating. Samples will be subjected to three corrosion test protocols:

- **SAE J2334 Cyclic Corrosion Test**
  - Provides correlation to severe corrosive field environments with respect to cosmetic corrosion
  - Three steps with a 24-hr cycle
    - *Humid Cycle:* 100% RH at 50°C for 6-hrs. (Q-Fog Salt Spray Chamber)
    - *Salt Spray Cycle:* Aerated salt solution sprayed throughout chamber for 0.25-hrs. Test solution is comprised of 0.5% NaCl, 0.1% $CaCl_2$, and 0.07% $NaHCO_3$. (Q-Fog Salt Spray Chamber)
    - *Dry Off Cycle:* 50% RH at 60°C for 17.75-hrs. (Environmental Chamber)

- **Humidity Resistance Test FLTM BQ 104-02**
  - Determines the resistance to humidity of automotive components
  - Single step test at 95% RH, 38°C for 24-hrs.

FLTM- Ford Laboratory Test Method; SAE- Society of Automotive Engineers

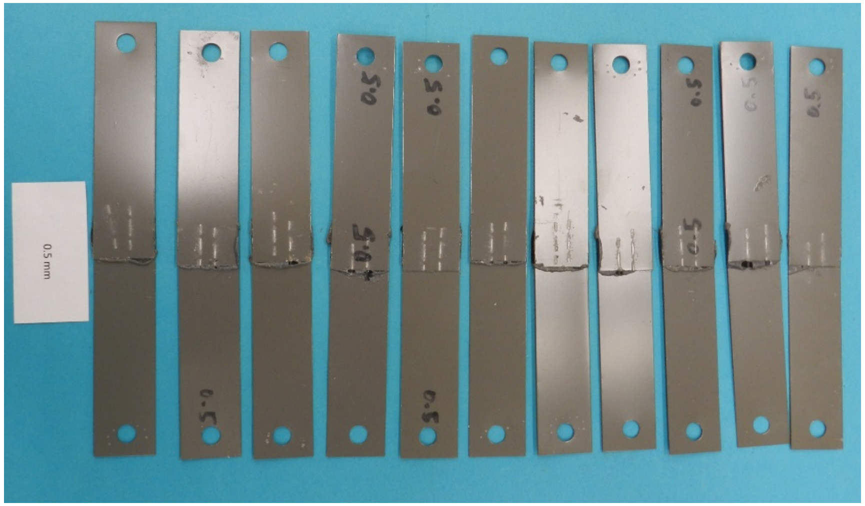
Methodology: Corrosion Testing (2)

- **Environmental (Freeze/Thaw) Cycling Test FLTM BQ 104-07 (Procedure 11)**
  - Determines the resistance to freeze/thaw cycling of automotive components
  - Comprised of six steps which comprise (one 24-hr cycle).
    - Dwell at 90°C for 3-hrs.
    - Ramp down to -40°C in 2-hrs.
    - Dwell at -40°C for 3-hrs.
    - Ramp to 38°C and 95% RH in 1-hr.
    - Dwell at 38°C and 95% RH for 14-hrs.
    - Ramp to 90°C in 1-hr.

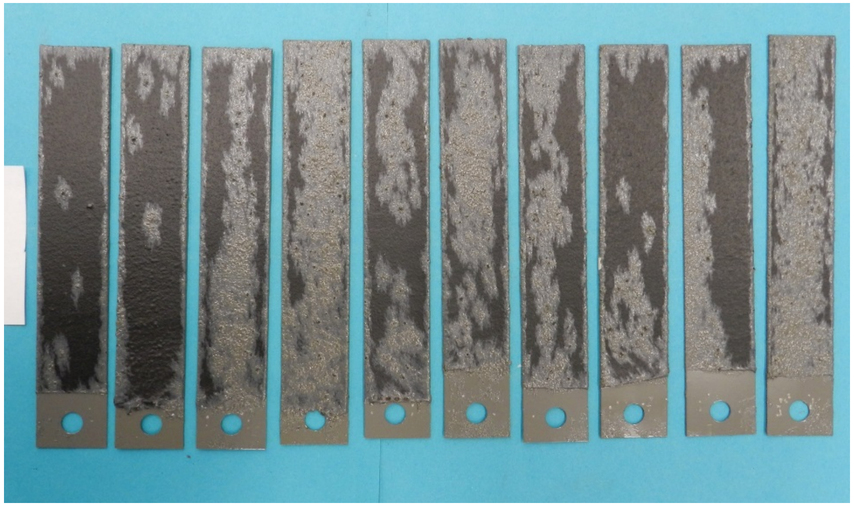
FLTM- Ford Laboratory Test Method

Test Coupons- Pre-Test

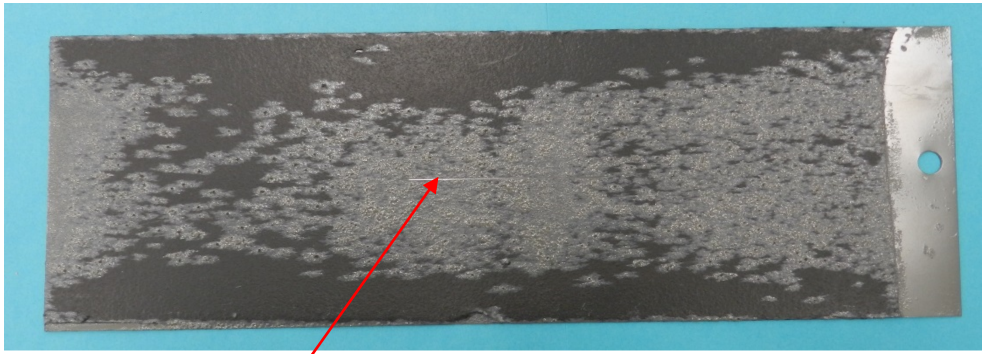
Lap Shear Coupons



Flexural Strength Coupons



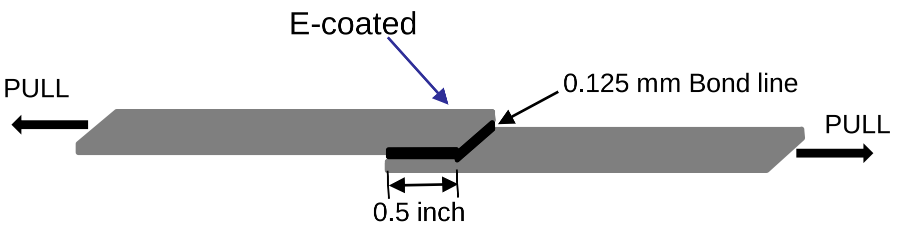
Corrosion Evaluation Coupon



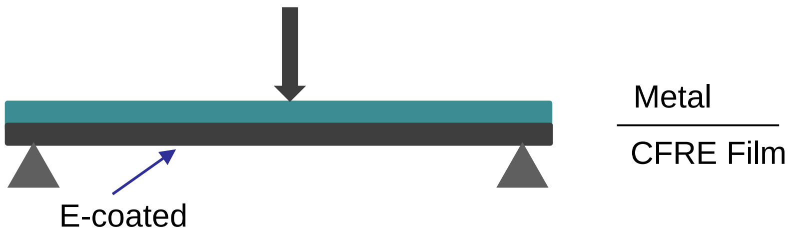
Scribe line machined through coating per SAE J2334
(No scribe lines on other test method coupons)

SAE J2334 Test Matrix

1. **100 Total Lap Shear Coupons**; 1” x 4” base metal with 0.5” overlap.
   - DP500 steel used as base metal, both 0.6 mm and 0.5 mm thick.
   - Coupon sets exposed to 4, 8, 20, 30, and 40 cycles. Completed
2. **100 Total Flexural Strength Coupons**; 1” x 6” with 0.5 mm thick CFRE coating.
   - DP500 steel used as base metal, both 0.6 mm and 0.5 mm thick.
   - Coupon sets exposed to 4, 8, 20, 30, and 40 cycles. Completed
3. **50 Corrosion Evaluation Coupons**; 4” x 12”, with 0.5 mm thick CFRE coating.
   - DP500 steel used as base metal, both 0.6 mm and 0.5 mm thick.
   - Coupon sets exposed to 4, 8, 20, 30, and 40 cycles. In Progress



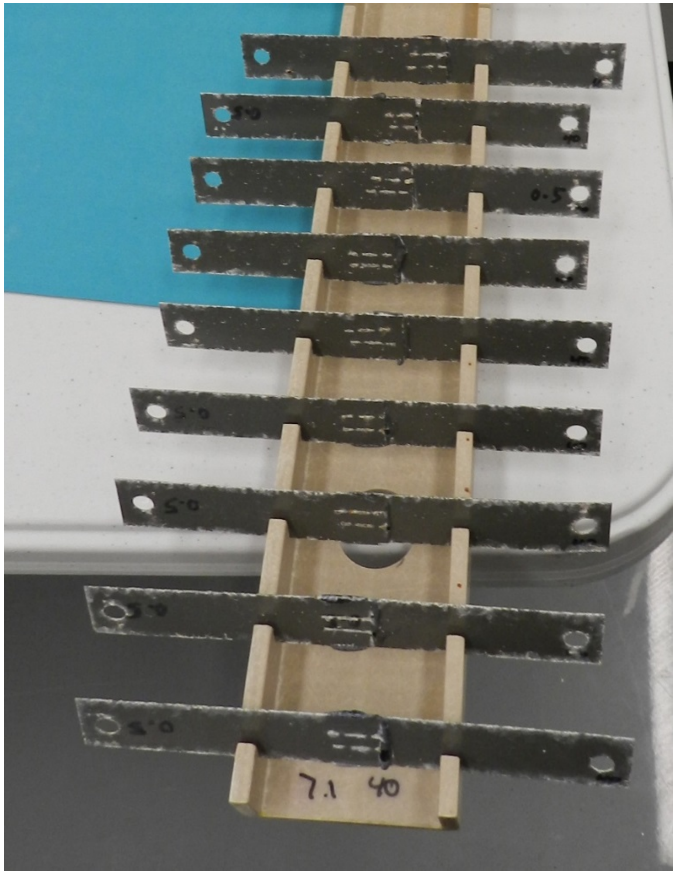
Lap Shear Tensile Test Specimen
Tests adhesion along the plane of adhesion



Flexural Strength Test Specimen
Measures highest stress experienced within the coating at yield point

SAE J2334 Post-Test Coupon Observations

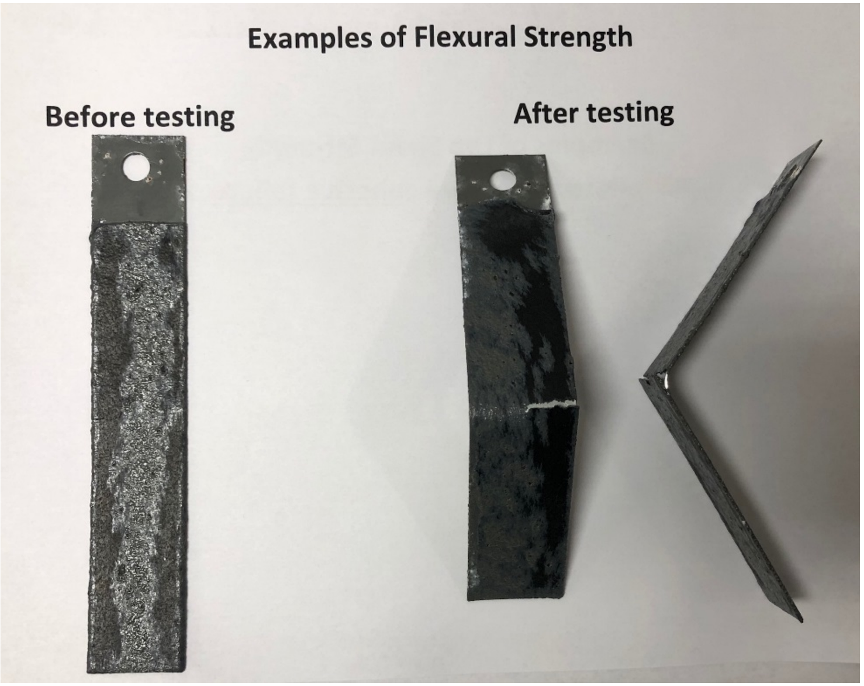
- No corrosion observed in the lap joints of the lap shear specimens
- No corrosion observed on coatings on the flexural specimens
  - Exceptions: Corrosion on bare metal surfaces where coating was thin or absent

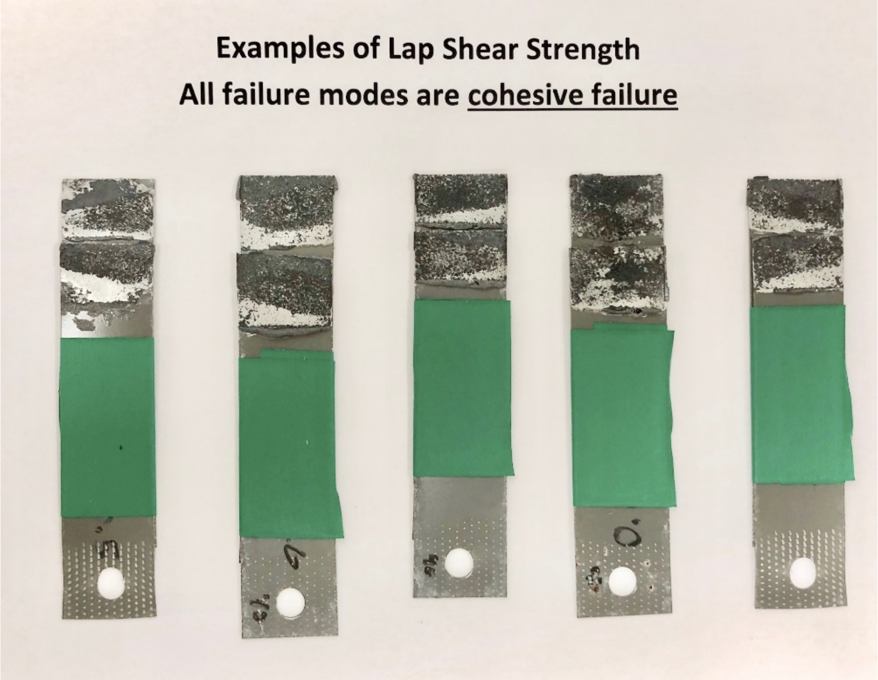


Post-Test Lap Shear (40 Cycle)

20 Cycle Post Test Flexural Strength

SAE J2334 Post-Test Coupon Observations





Examples of Flexural Strength Specimens Before (Left) and After Right) Testing

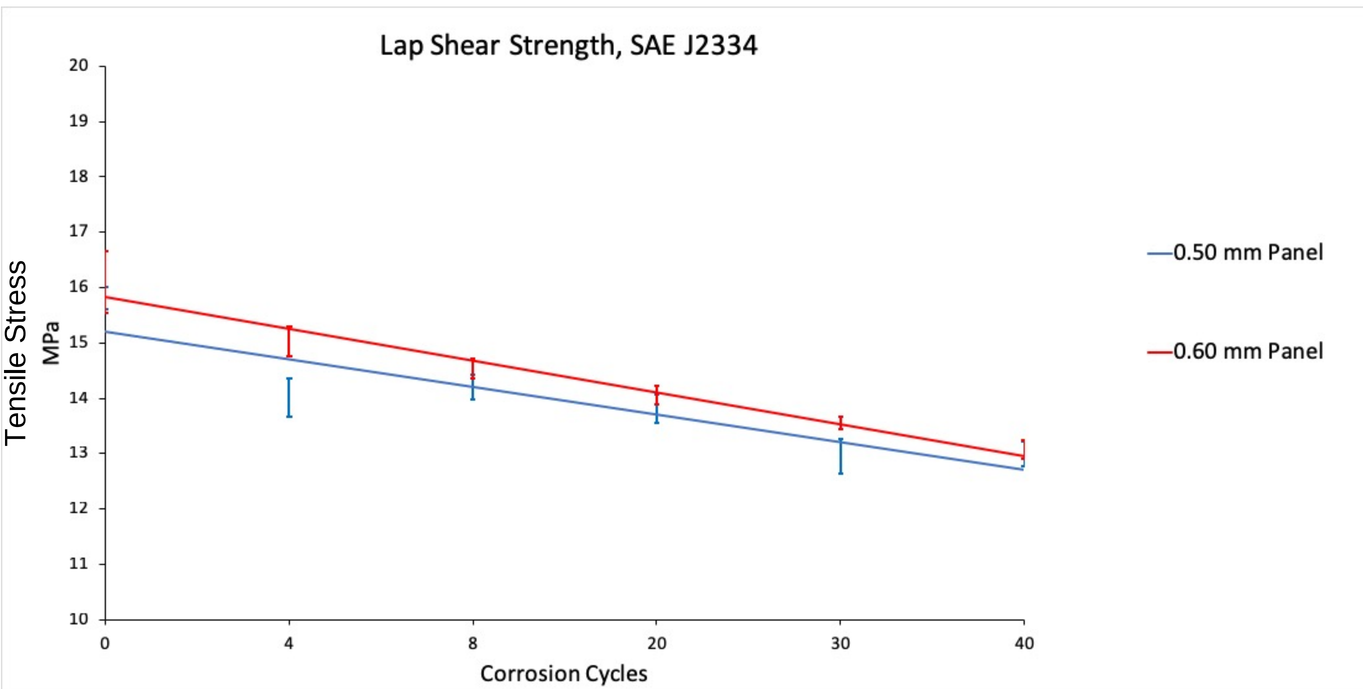
Examples of Lap Shear Strength Specimens After Testing
All Failure Modes are <u>Cohesive Failure</u>

SAE J2334 Test Results

- Coating adhesion (lap shear tests) decreases with number of cycles up to ~16% at 40 cycles

Lap Shear (corrosion cycling), tensile stress at break (MPa)

Panel Thickness	Control (0 cycles)	4 cycles	8 cycles	20 cycles	30 cycles	40 cycles
0.5mm	15.80	14.01	14.20	13.81	12.95	13.00
0.6mm	16.10	15.03	14.54	14.06	13.56	13.07



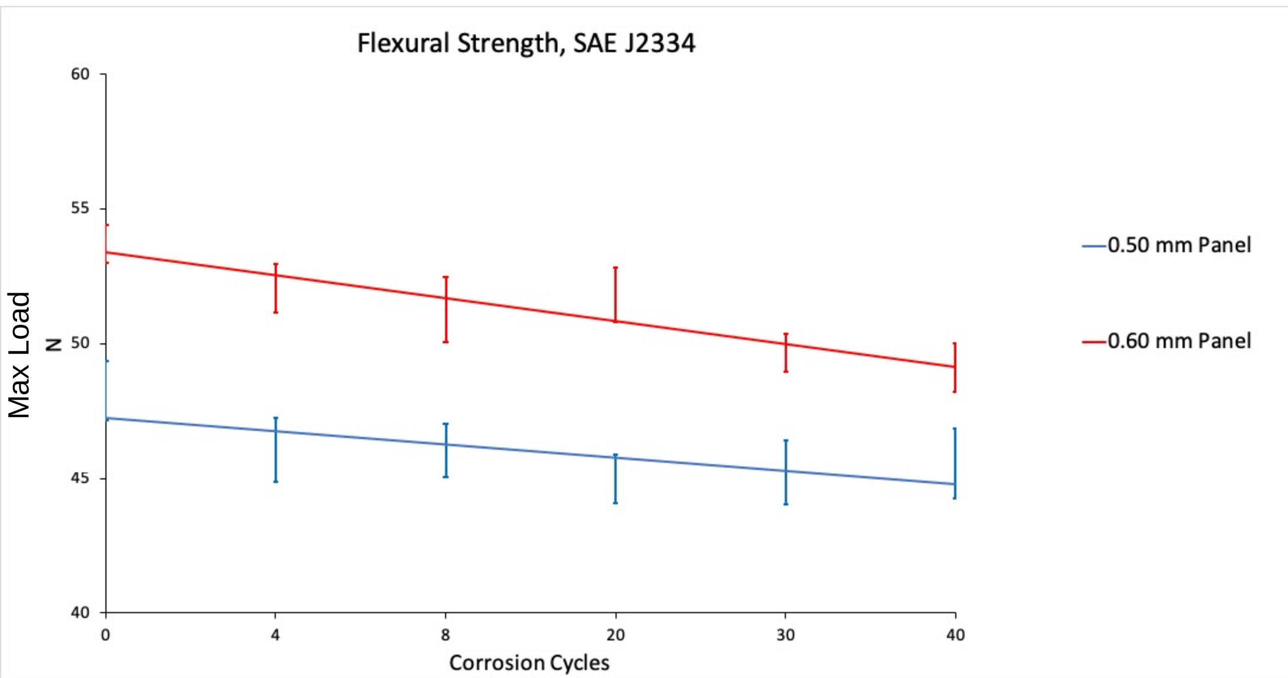
Coating Tensile Stress at Yield Point as a Function of Corrosion Cycles

SAE J2334 Test Results

- Flexural strength decreases with number of cycles up to about ~8% at 40 cycles

Flexural Strength (corrosion cycling), max load(N)

Panel Thickness	Blank	Control (0 cycles)	4 cycles	8 cycles	20 cycles	30 cycles	40 cycles
0.5mm	21.83	48.27	46.06	46.04	45.00	45.23	45.56
0.6mm	32.44	53.73	52.08	51.28	51.82	49.65	49.10



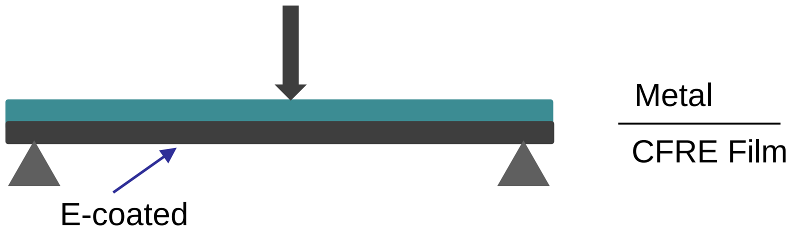
Flexural Strength at Yield Point as a Function of Corrosion Cycles

- No results for corrosion tests (4” × 12” panels) available (In-progress)

Humidity Resistance Test Matrix

1. 100 Total Flexural Strength Coupons; 1” x 6” with 0.5 mm thick CFRE coating.
   - DP500 steel used as base metal, both 0.6 mm and 0.5 mm thick.
   - Coupon sets exposed to 4, 8, 20, 30, and 40 cycles. Completed

2. 50 Corrosion Evaluation Coupons; 4” x 12”, with 0.5 mm thick CFRE coating.
   - DP500 steel used as base metal, both 0.6 mm and 0.5 mm thick.
   - Coupon sets exposed to 4, 8, 20, 30, and 40 cycles. In Progress



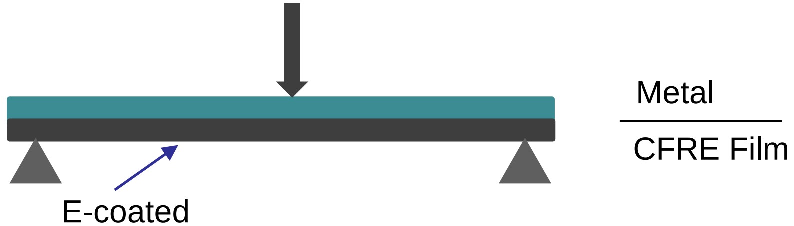
Flexural Strength Test Specimen
Measures highest stress experienced within the coating at yield point

FLTM BQ-104-02

Environmental Cycling Test Matrix

1. 100 Total Flexural Strength Coupons; 1” x 6” with 0.5 mm thick CFRE coating.
   - DP500 steel used as base metal, both 0.6 mm and 0.5 mm thick.
   - Coupon sets exposed to 4, 8, 20, 30, and 40 cycles. Completed

2. 50 Corrosion Evaluation Coupons; 4” x 12”, with 0.5 mm thick CFRE coating.
   - DP500 steel used as base metal, both 0.6 mm and 0.5 mm thick.
   - Coupon sets exposed to 4, 8, 20, 30, and 40 cycles. In Progress



Flexural Strength Test Specimen
Measures highest stress experienced within the coating at yield point

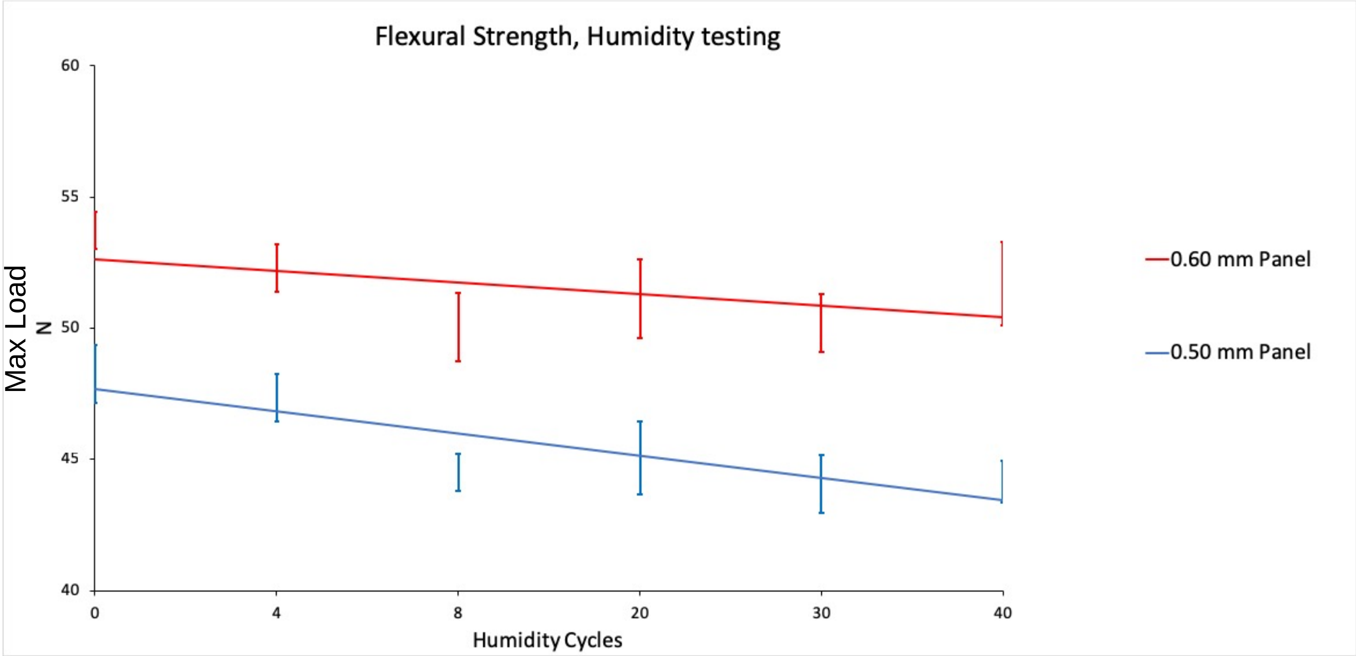
<u>FLTM BQ-104-07 (Procedure 11)</u>

Humidity Resistance Testing

- Flexural strength decreased with number of cycles up to about ~8% at 40 cycles for both tests

Flexural Strength (Humidity testing), max load(N) (FLTM BQ 104-02)

Panel Thickness	Blank	Control (0 cycles)	4 cycles	8 cycles	20 cycles	30 cycles	40 cycles
0.5mm	21.83	48.27	47.36	44.51	45.05	44.06	44.17
0.6mm	32.44	53.73	52.31	50.06	51.11	50.21	51.70



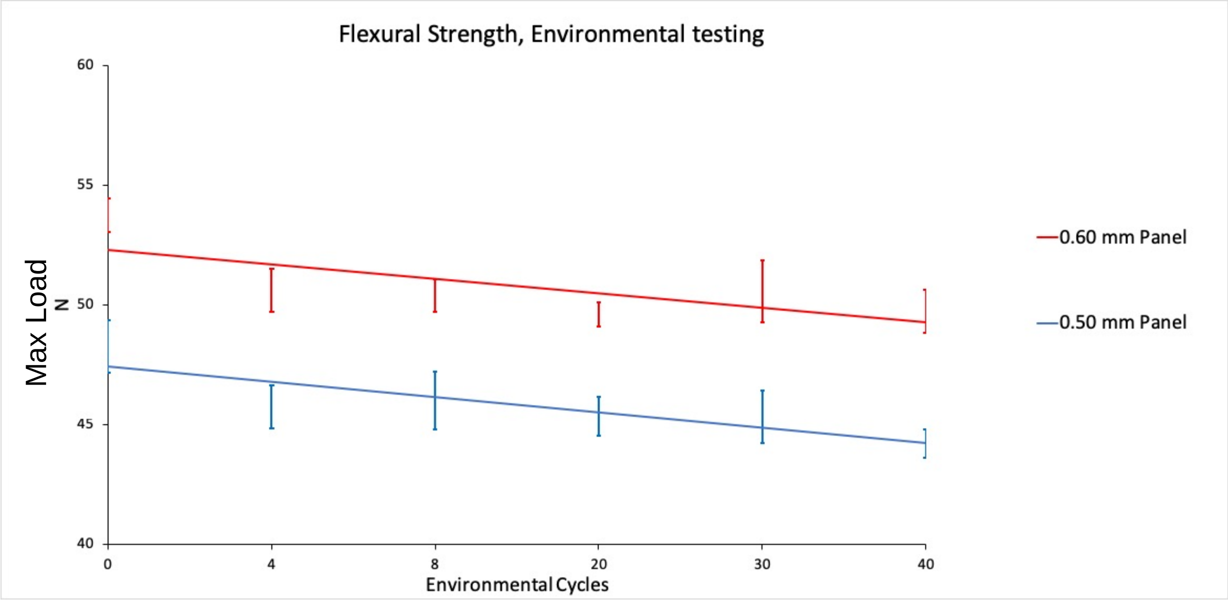
Flexural Strength at Yield Point as a Function of Humidity Cycles

Environmental Cycling Testing

- Flexural strength decreased with number of cycles up to about ~8% at 40 cycles for both tests

Flexural Strength (Environmental cycling), max load(N) (FLTM BQ 104-07)

Panel Thickness	Blank	Control (0 cycles)	4 cycles	8 cycles	20 cycles	30 cycles	40 cycles
0.5mm	21.83	48.27	45.75	45.99	45.34	45.30	44.21
0.6mm	32.44	53.73	50.62	50.38	49.59	50.55	49.72



Flexural Strength at Yield Point as a Function of Environmental (Freeze/Thaw) Cycles

- No results for corrosion tests (4” × 12” panels) available (In-progress)

Responses to Previous Year Reviewers' Comments

- None

Collaboration and Coordination with Other Institutions

- **Diversitak:** Coating composition and application (**<u>Lead Organization</u>**)
- **ArcelorMittal:** Part design, steel fabrication, corrosion performance.
- **ORNL:** Fiber selection, SEM analysis, CTE determination, Coating Evaluation.
- **INL:** Corrosion performance at coupon and full scale levels.

Proposed Future Research

Now that a final formulation has been determined:

- Complete Panel Level SEM Evaluation of Panels (2018)
- Complete CTE evaluation in each of three directions. (2018)
- Begin Corrosion Testing of Panels (2019)
- Design Production System for Application (2018)
- Construct Production System (2019)
- Integrate Material Property information into Design Models (2019)
- Produce Component Door Parts for Full Scale Testing (2019-2020)
- Conduct Component Full Scale Testing (2019)
- Corrosion Testing of Door Parts (2019-2020)
- Conduct Cost and Mass Study (2019-2020)

Any proposed future work is subject to change based on funding levels

Summary Slide

- No corrosion observed in the lap joints of the lap shear specimens
- No corrosion observed on coatings on the flexural specimens.
  - Exceptions: Corrosion on bare metal surfaces where coating was thin or absent
- J2334 Tests:
  - Coating adhesion (lap shear tests) decreases with number of cycles up to ~16% at 40 cycles
  - Flexural strength decreases with number of cycles up to about ~8% at 40 cycles
- Humidity and Environmental Testing
  - Flexural strength decreased with number of cycles up to about ~8% at 40 cycles for both tests

Technical Back-Up Slides

Test Coupons

- Lap Shear Coupons shown in QFog Cyclic Chamber: