Corrosion Control in Carbon Fiber Reinforced Plastic (CFRP) Composite-Aluminum Closure Panel Hem Joints

Project ID: MAT131
Award DE-EE0007760

Brian Okerberg – Principal Investigator
PPG Industries, Inc.

June 20, 2018

Overview

Timeline

- Project start – 10/1/16
- Project end – 3/31/20
- Percent complete – 33%

Barriers addressed

- Corrosion evaluation of mixed material joints
- Predictive corrosion modeling
- High volume use of CFRP materials (automotive line)

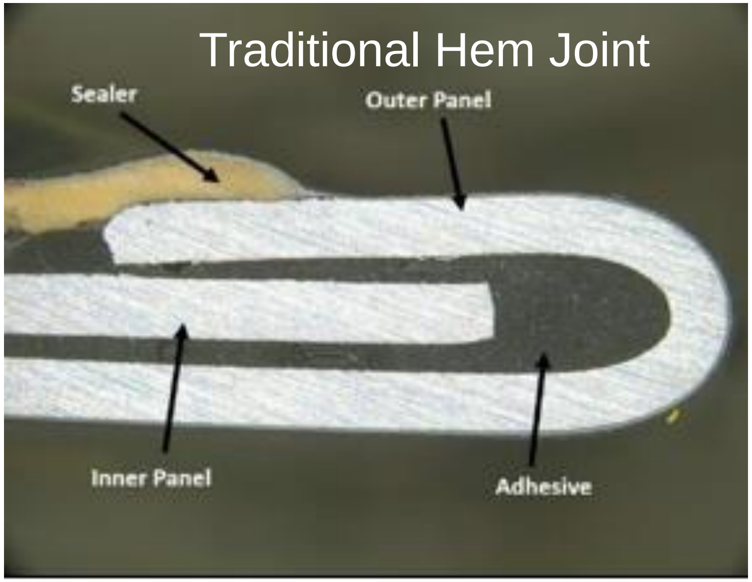
Budget

- Total project funding - $2,950,025
  - DOE share - $2,212,519
  - Contractor share - $737,506
- Funding for FY 2017 - $1,159,112
- Funding for FY 2018 - $1,153,345

Partners

Project Objectives

- Enable vehicle weight reduction replacing all-aluminum closure panels with carbon fiber reinforced polymer inner/aluminum outer (CFRP/Al) closures in a high-volume application
- Identify specific dissimilar material joining and or corrosion protection challenges and predictive models
- Develop novel technologies addressing these challenges to near-commercial readiness



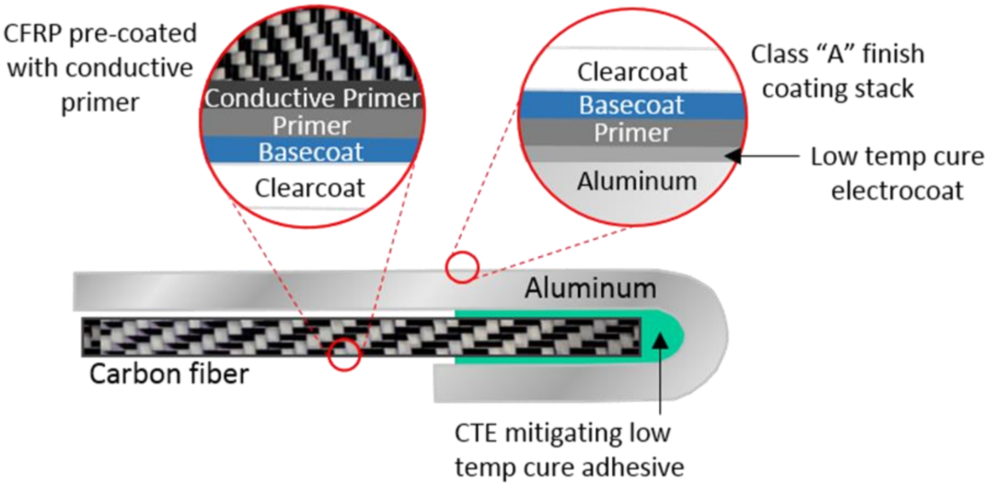


Image provided by Ford Motor Company

Objectives / Challenges

Technical Challenges

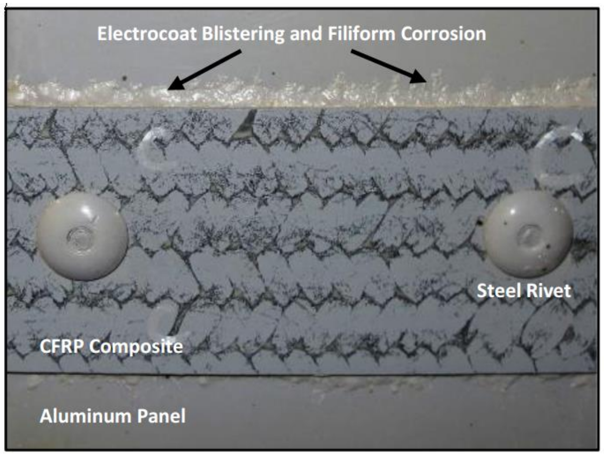


Image provided by Ford Motor Company

1. CFRPs are inherently cathodic to aluminum or other metals that could be present in the closure construction, setting up a corrosive galvanic cell.

2. A significant differential coefficient of thermal expansion (CTE) between CFRP and Al will impart dimensional stresses and displacement during the paint bake process.

3. Affordable CFRP matrix materials are not stable at current paint bake oven temperatures.

4. Conventional automotive coatings and adhesives are not compatible with CFRP or the required lower bake temperatures.

5. Predictive accelerated corrosion tests for CFRP/aluminum joints have not been determined.

Approach

Budget Period 1: Understanding Nature/Extent of Problem

- Understand the nature and extent of the corrosion problem
- Identify the susceptibility to galvanic corrosion and stress corrosion cracking
- Determine the level of conductivity that promotes electrostatic painting but not galvanic coupling
- Identify pathways to low-cure adhesives and coatings

Budget Period 2: Developing Solutions

- Develop prototype conductive primers, adhesives, and electrocoats
- Identify hem geometries to mitigate galvanic coupling and coefficient of thermal expansion (CTE) mismatches

Budget Period 3: Optimization and Validation

- Optimize and validate the solutions developed in BP 2
- Construct a surrogate aluminum outer/CFRP inner closure capable of passing Ford specifications and being processed through a typical paint shop operation

Budget Period 1 and 2 Milestones

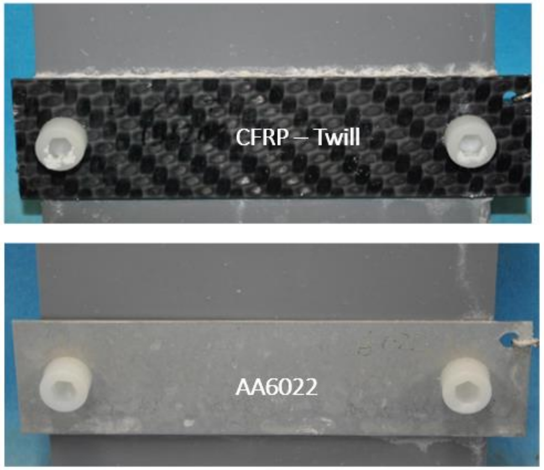
Milestone	Description	Status
Sample Preparation	Samples prepared and in corrosion testing.	Complete
Electrocoat & Adhesive formulas	At least one prototype electrocoat formula and one prototype adhesive formula achieving full cure at 10 minutes at 150°C while maintaining corrosion and lap shear strength on aluminum substrates.	Complete
Decision Point 3/31/2018	At least one electrocoat formula and adhesive formula is identified that meets lower cure temperature and strength requirements.	Complete

Milestone	Description	Status
Primer & Adhesive specifications	Electrocoat throwpower, appearance, and corrosion equal to control; Adhesive performance (lap shear strength, stress durability, viscosity and flow, toughness, and tensile strength) equal to control	In progress
Hem geometry	A final geometry is chosen based on the best performance in corrosion testing of various hem flange candidates.	In progress
Decision Point 3/31/2019	At least one electrocoat formula and adhesive formula is identified that meets lower cure temperature, strength, and other performance requirements.	

Technical Accomplishments - Corrosion

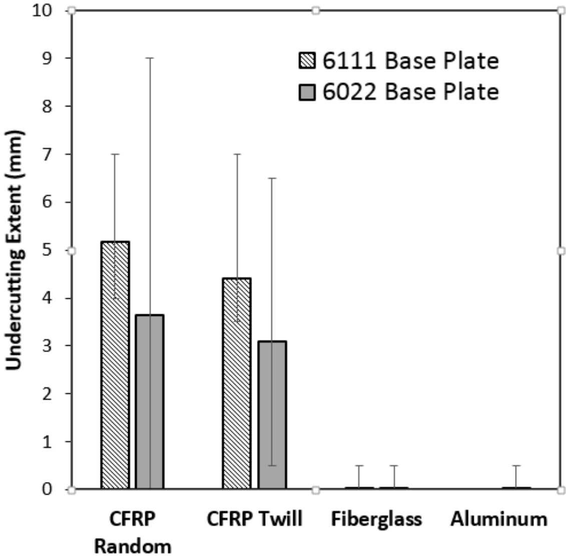
- Two types of CFRP: 1) Twill, continuous fiber – higher strength/stiffness, 2) Random/chopped fiber - less expensive, easier fabrication
- Cyclic corrosion testing shown to correlate well with in-field performance. Test track similar cycles but addition of driving cycle.

CFRP/Al



Al/Al

Panels on test track

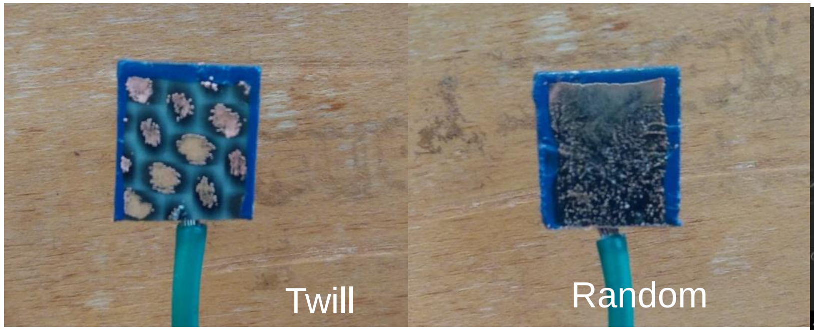


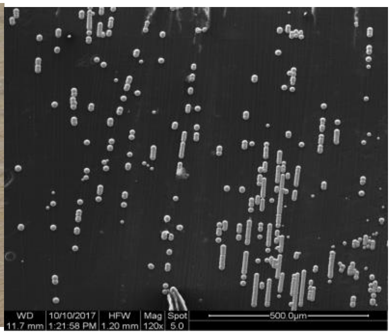
Significantly more corrosion in CFRP/Al joints, even for low Cu alloys

Increased corrosion in mixed material joints for automotive substrates

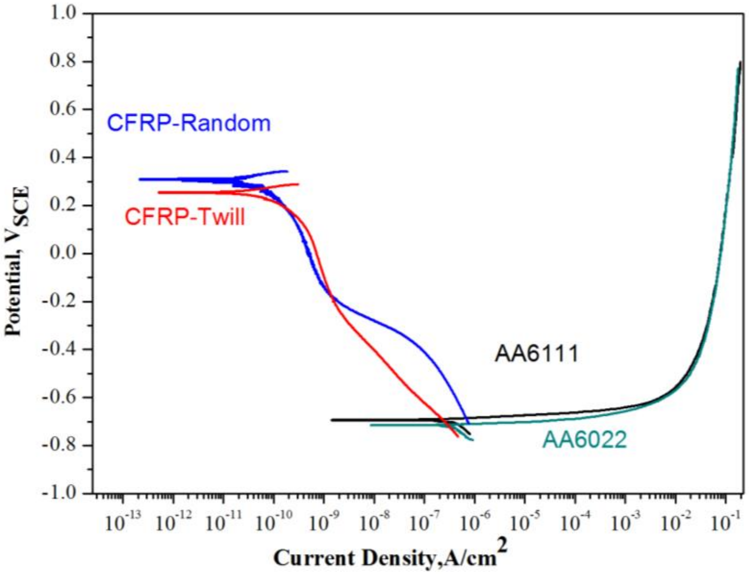
Images on this page provided by Ford Motor Company

Technical Accomplishments - Electrochemistry





Electrodeposition of Cu shows different electrochemical activity for different types of CFRP

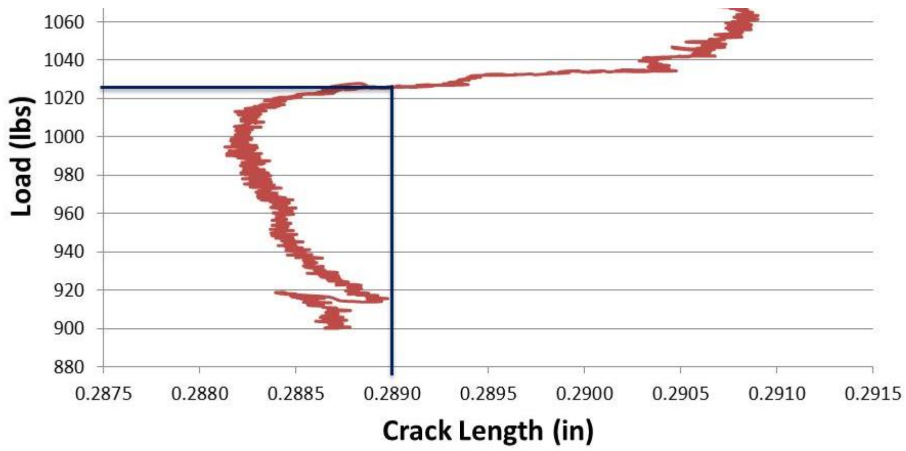


- Potentiodynamic polarization of AA6111, AA6022, CFRP-Random, CFRP-Twill is in aerated 5 wt% NaCl.
- Overlay of polarization curves shows that difference in OCPs between CFRPs and AA6xxx is around 900 mV.
- Cathodic current densities of CFRP Random and Twill differed by a factor of 5x.

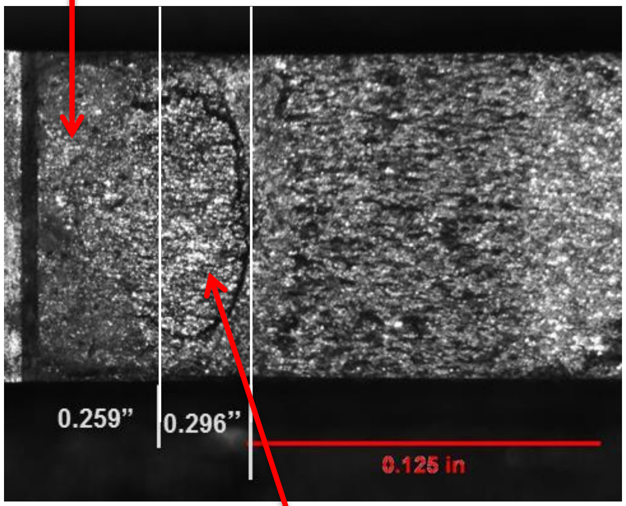
Differences observed in the electrochemical behavior of the substrate

Images on this page provided by The Ohio State University

Technical Accomplishments - SCC



Fatigue Pre-crack



Likely SCC Cracking Region

Completed baseline SCC testing on unpolarized AA6111-T8-like to show SCC initiates near K of 18-19 MPa√m

Images on this page provided by The Ohio State University

Technical Accomplishments – Low Cure Coatings

SYNTHESIS

- Cationic Electrocoat Resin
- Crosslinker Type

FORMULATION

- Catalyst Type (& loading)
- P/B
- Processing additives

LOW CURE E-COAT

10’@150°C (metal)

E-COAT PROCESS

- Al substrates - Al6111 (& Al6022)
- Pretreatment – standard phosphate
- Ecoat optimization – time/thickness
- Bake – 10’@150°C & 20’@175°C

ROUTINE E-COAT TEST

- CURE- Double acetone rub (DAR) test
  - TGA
  - Cure rheology
- Appearance
- Corrosion test (G-85 & L3190)

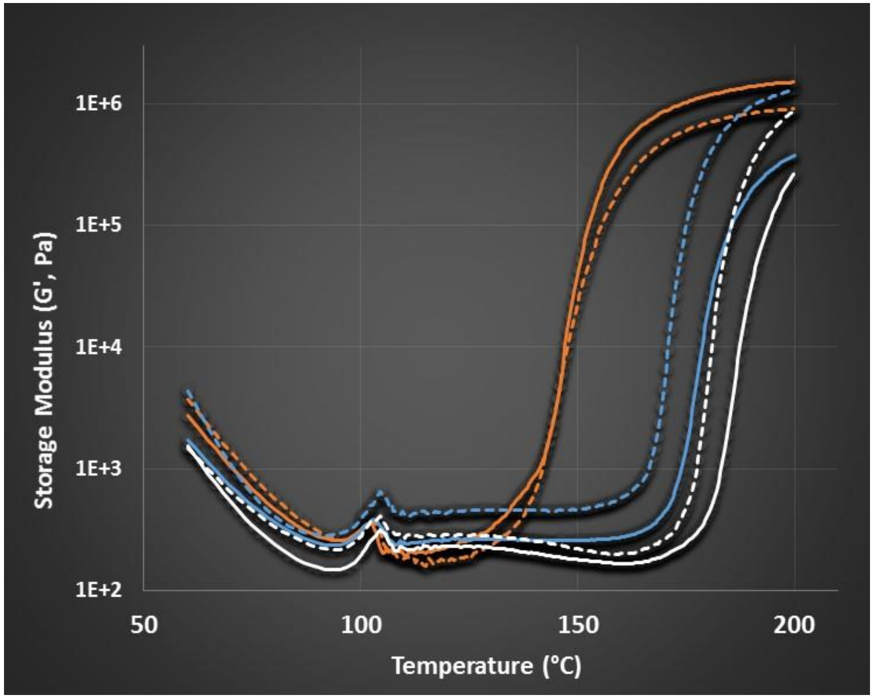
PPG

Technical Accomplishments – Low Cure Coatings

Formulation Variables

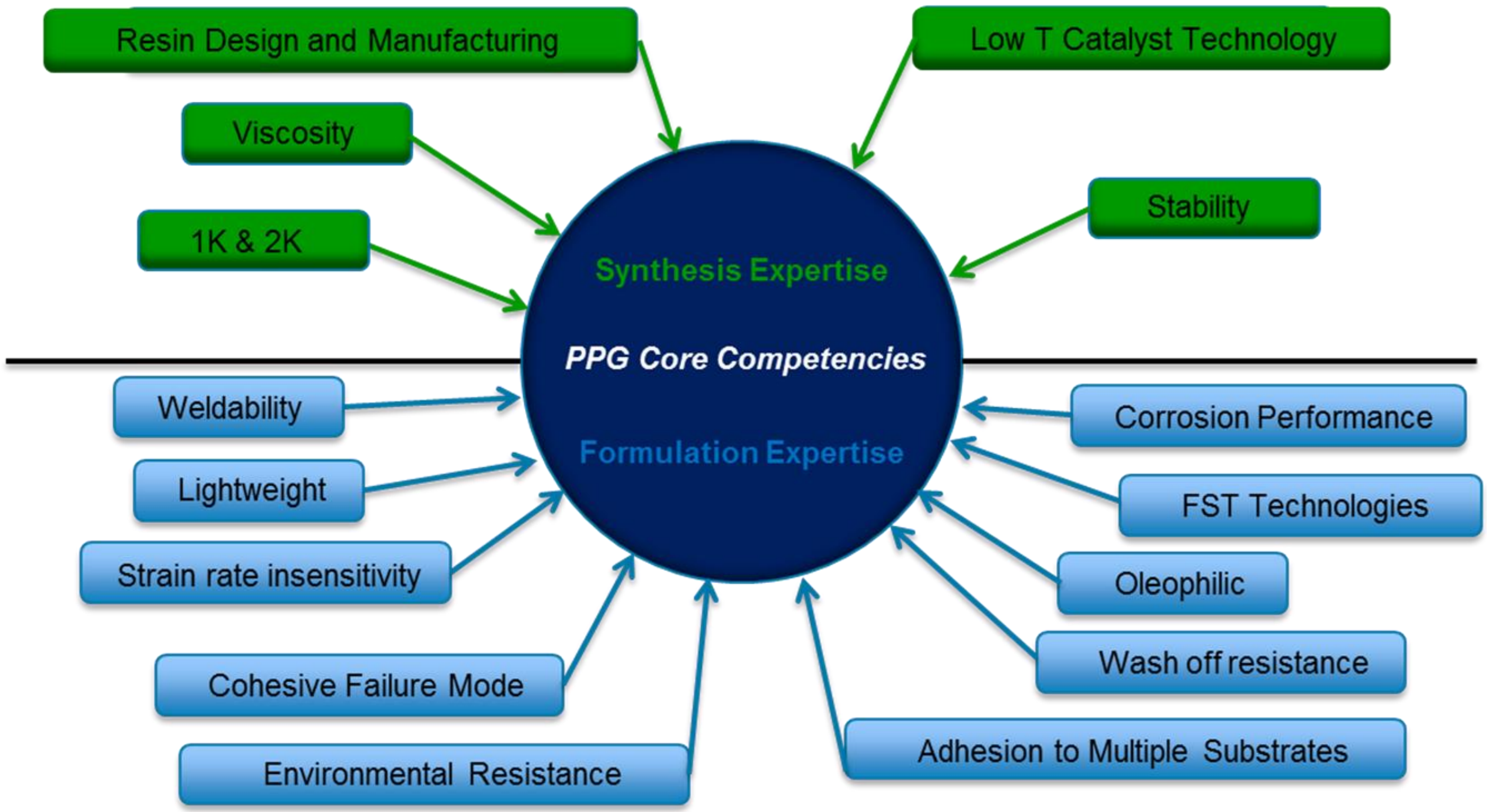
ID	FORMULATION VARIABLES			
	RESIN	XL	ADDITIVE	CATALYST
P1B	A	XL 1	C	
P2B	B		D	
P3	A	XL 2	C	E
P4	B		D	
P5	A	XL 3	C	
P6	B		D	
C1	A	XL 3	C	E

Coating Rheology



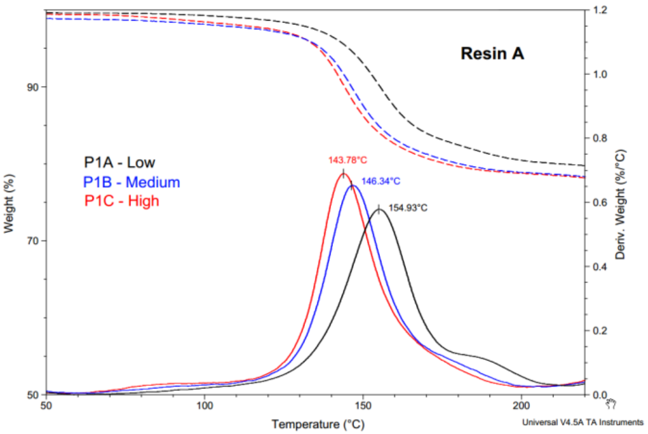
Formulations screened to identify to low temperature cure capability and other key properties (corrosion, appearance, etc.)

Technical Accomplishments – Low Cure Adhesives

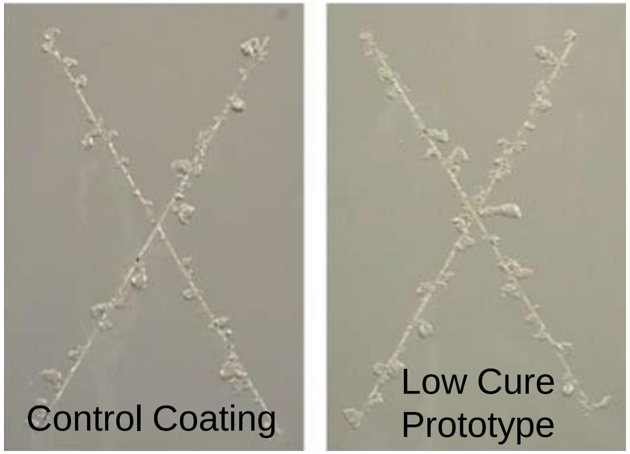


Synthesis and formulation approaches

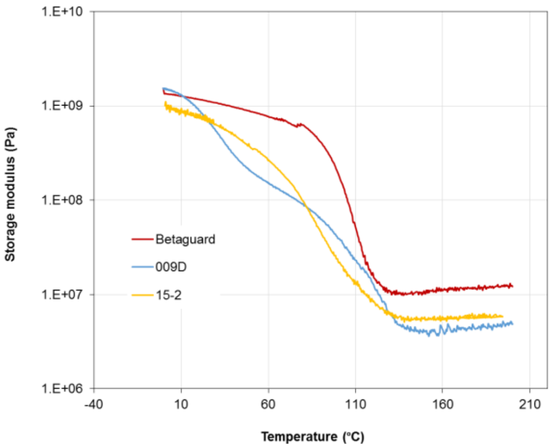
Technical Accomplishments – Low Cure Coatings



Low cure capable electrocoat identified (TGA)



Corrosion comparable to the control



Low cure capable adhesive identified

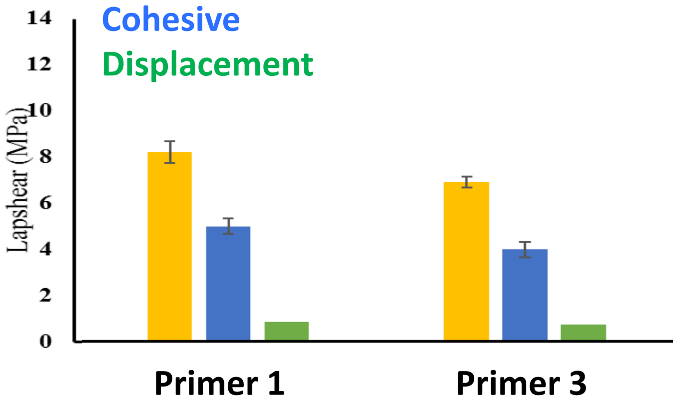
Low cure electrocoat and adhesives identified

Technical Accomplishments – Conductive Primers

Conductive primers are being investigated for impact on corrosion:

- Formulating primers of different conductivity to assess interplay between corrosion and paintability
- Preliminary samples sent to OSU for electrochemical evaluation
- Currently evaluating adhesion of primer/CFRP and primer/adhesive

Primer Type	Bake condition	DFT	wet resistivity	Sprayability
Primer 1	130°C-20'		29 kΩ	160
Primer 2	130°C-20'	1.0 mils	42 kΩ	< 85
Primer 3	130°C-20'		62 kΩ	< 85

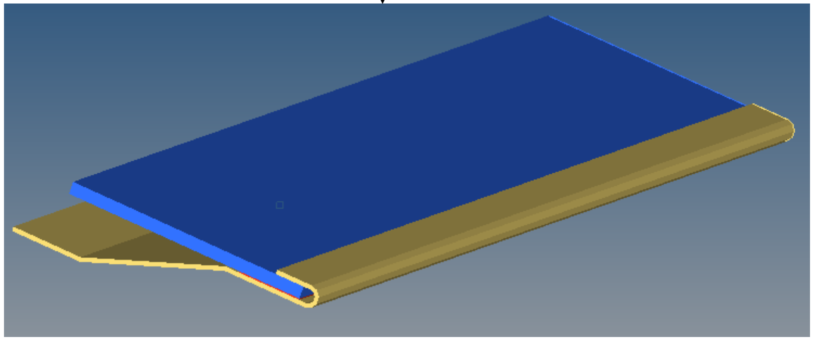


Technical Accomplishments – CTE Mismatch

The impact of differences in coefficient of thermal expansion (CTE) are being evaluated:

- Formulation and testing of low cure adhesives
- Mixed material coupons to experimentally measure stresses.
- Full hem joint geometry to model real-world stress state using CTE, and thermal cure profile (E’ vs. T)

Bowing of CFRP bonded (orange adhesive) to Al sheet (upper). Uncured panels w/o bowing (lower).



CAD geometry of hem coupon. Blue CFRP, yellow Al. (Adhesive not shown for clarity.)

Images on this page provided by Ford Motor Company

Responses to Previous Year Reviewers' Comments

This is the first review for this project.

Collaboration and Coordination with Other Institutions

PPG Industries, Inc.

- Providing samples of conductive primers to OSU for electrochemical evaluations
- Coating test coupons for corrosion evaluation at Ford

Ford Motor Company

- Providing substrate materials for testing
- Conducting track testing of coated samples
- Providing direction on electrochemical evaluations

The Ohio State University

- Measuring uniformity of conductivity of Ford CFRP substrate
- Conducting electrochemical evaluation of corrosion panels during corrosion testing

Remaining Challenges and Barriers

- Variability and different types of CFRP substrates create difficulties for reproducible corrosion testing
- CTE mismatch for large parts may be difficult to sustain
- Cost of low-cure materials might be prohibitive

Proposed Future Work

- Continue material development
  - Development of key electrocoat properties for application robustness
  - Improved adhesive behavior to mitigate CTE mismatch
  - Continued evaluation of impact of conductive primers on corrosion
- Evaluate alternate joint designs to understand impact on corrosion
- Continued galvanic characterization and assessment of hems or overlap coupons
- Further evaluation of impact of corrosion test conditions in mixed material joints

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

Summary

Objectives

- Implement the high-volume use of lightweight materials, such as CFRP and Al, to improve fuel economy for OEMs
- Develop predictive corrosion models for lightweight materials

Approach

- Benchmarking corrosion of CFRP/Al joints
- Develop predictive corrosion models for lightweight materials
- Screen technologies for low-cure response

Technical Accomplishments

- Confirmed increased corrosion of automotive CFRP/Al coupons
- CFRP type can influence extent of corrosion from an electrochemical standpoint
- Low cure electrocoat and adhesives were identified

Future Research

- Continue material development
- Further understanding of galvanic test methods for CFRP

Technical Back-Up Slides