Effect of Surface Contamination on Composite Bond Integrity and Durability

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Effect of Surface Contamination on Composite Bond Integrity and Durability

- **Motivation and Key Issues**
  - Past research has focused on determining/understanding acceptable performance criteria using the initial bond strength of composite bonded systems.
  - There is significant interest in assessing the durability of composite bonded joints and the how durability is affected by contamination.
- **Objective**
  - Develop a process to evaluate the durability of adhesively bonded composite joints
  - Investigate **undesirable bonding conditions** by creating scalable and repeatable weak bonds.
  - Investigate a means to mitigate the undesirable conditions via surface preparation methods.
  - Support CMH-17 with the inclusion of content for bonded systems

Effect of Surface Contamination on Composite Bond Integrity and Durability

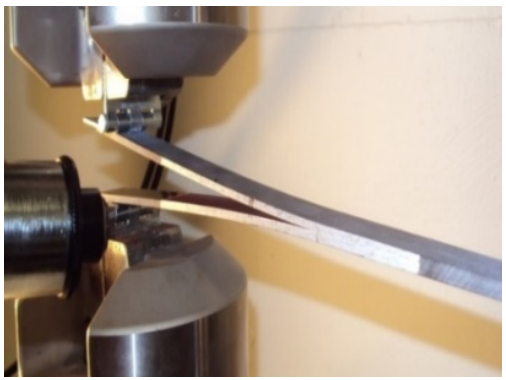
- **Principal Investigators**
  - Dwayne McDaniel, Ben Boesl

- **Students**
  - Gabriela Gutierrez-Duran, Brian Hernandez, Julie Dubon, Mauricio Pajon

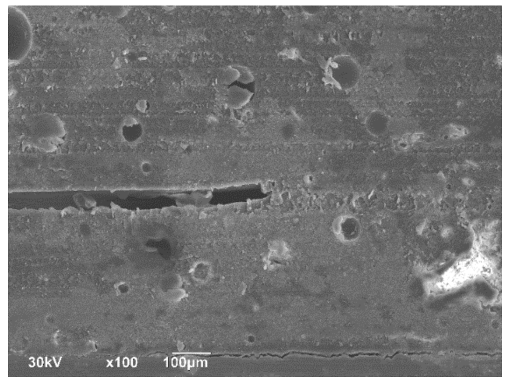
- **FAA Technical Monitor**
  - Ahmet Oztekin

- **Industry Participation**
  - Exponent, 3M, Embraer, BTG Labs

Research Tasks FY18-19



Investigation of contaminated bondlines on the macro scale



Investigation of contaminated bondlines on the micro scale

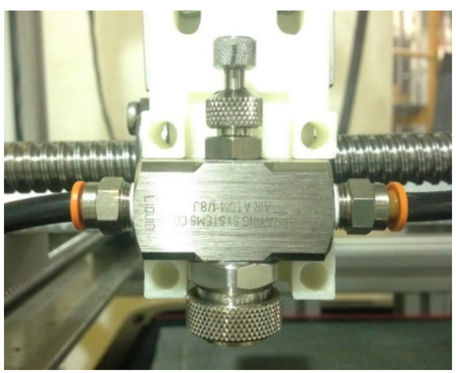
5.9 ASSEMBLY PROCESSES

Assembly processes are not conventionally covered within composite material characterization, but can have a profound influence on the properties obtained in service. As seen with test coupons, edge and hole quality can dramatically affect the results obtained. While these effects are not usually covered as material properties, it should be noted that there is an engineering trade off between part performance and the time and effort expended toward edge and hole quality. These effects need to be considered along with the base material properties.

Support of CMH-17 Handbook

Road Map of Contamination Studies
Discrete vs Continuous Approaches

Discrete Method	Static	Exposed	Fatigue	Exposed & Fatigue
Baseline	DCB	DCB	DCB	DCB
1 mm (0 kg)	DCB	DCB	DCB	DCB
1 mm (22 kg)	DCB	DCB	DCB	DCB
3 mm (0 kg)	DCB	DCB	DCB	DCB



Continuous Method	Static	Exposed	Fatigue
Baseline	DCB	**DCB**	**DCB**
~10%	DCB	**DCB**	**DCB**
~50%	DCB	**DCB**	**DCB**
~75%	DCB	**DCB**	**DCB**

Materials

- **Material type and curing procedure for specimens:**

  Unidirectional carbon-epoxy system, film adhesive, secondary curing bonding and contaminants.

- **Materials utilized:**
  - Toray P 2362W-19U-304 T800 Unidirectional Prepreg System (350F cure)
  - 3M AF 555 Structural adhesive film (7.5x2 mills, 350F cure)
  - Precision Fabric polyester peel ply 60001
  - Frekote 700-NC from Henkel Corporation

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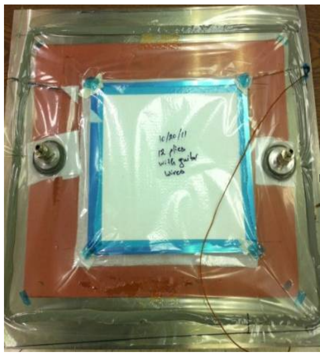
Manufacturing of Bonded Systems

Fabrication of Laminates



Laminate Cure

(Cure Cycle @350F)

Bonding of Laminates

Adhesive Cure

(Cure Cycle @350F)

Preparing/Cutting Samples

Adhesive Bond Strength Testing

KEY QUESTION

What happens to bonded joint's strength when contamination occurs, if known can it be mitigated?

CAUSES

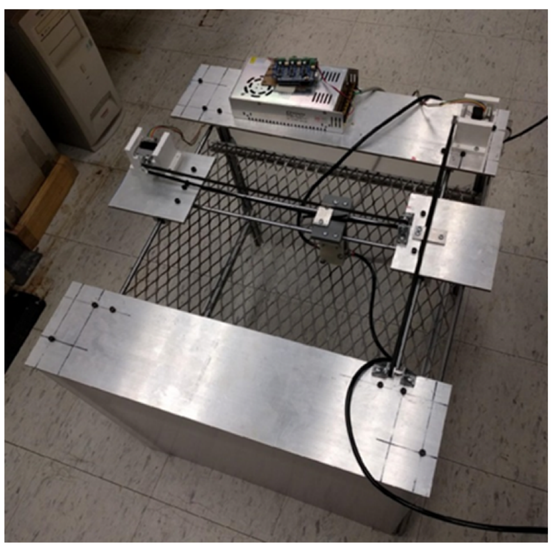
Contamination can occur in a manufacturing setting from oil on hands, mold release, leakage/spillage, etc.

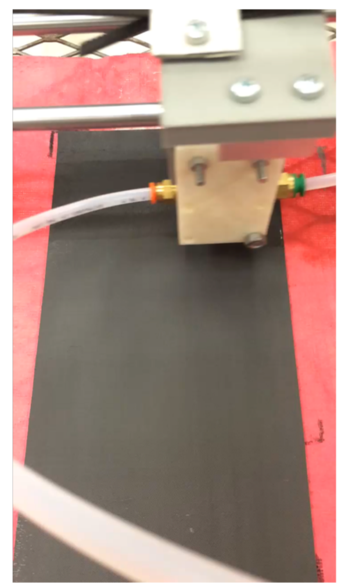
Contamination Approach

GOAL - Develop a process to create a scalable and repeatable weak bond via bondline contamination.

Contaminant – Frekote release agent

- Developed a station that can uniformly spray contaminant – vary nozzle size and spray rates
- Potential for creating a scalable weak bond by adjusting concentration of Frekote
- Total amount of contaminate applied is measured using an analysis of pre- and post- weight measurement.



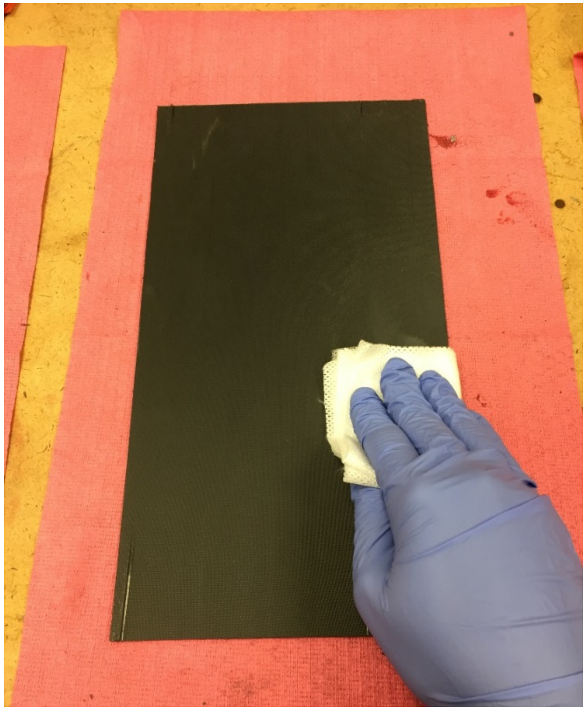


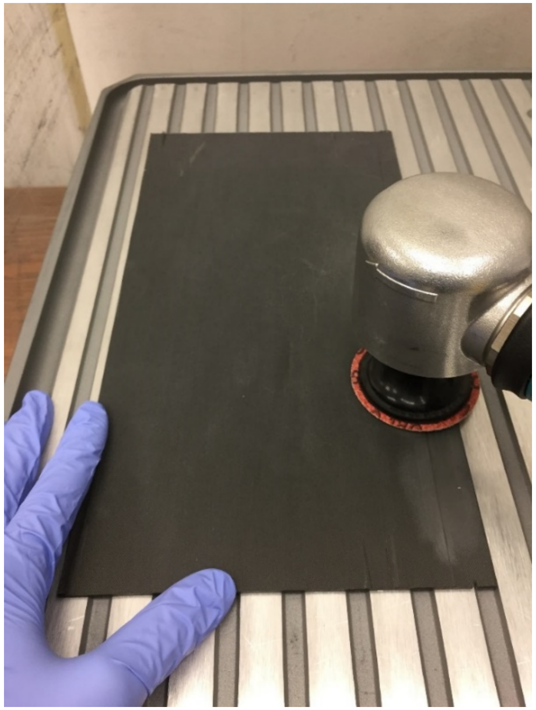
Calibration of Contamination Levels

- Calibration of the contamination levels is important in order to be able to trace back the amount of contaminant used and relate that amount to the strength of the weak bond created
  - This enables us to determine the different bond strengths that can be created from different amounts of contaminant
- Adjusting spray speeds and mass measurements of the contaminant on a 1” x 1” section of a panel, allows for the determination of the strength of the weak bond
- **Procedures**
  - Modify the spray speed according to the amount of mass desired
    - Fast speeds: less mass
    - Slow speeds: more mass
  - Weigh a 1” x 1” section of a panel before spraying contaminant
  - Spray contaminant and weigh it again
  - Continue process until desired mass is reached

Mitigation Procedures

- **GOAL -** Develop a process to mitigate the influence of contamination of the bondline
- Two methods of mitigation
  - ***Solvent Wipe -*** Attempt to remove contaminate off of surface with soaked cloth
  - ***Sanding of Material -*** Actively remove material using abrasive

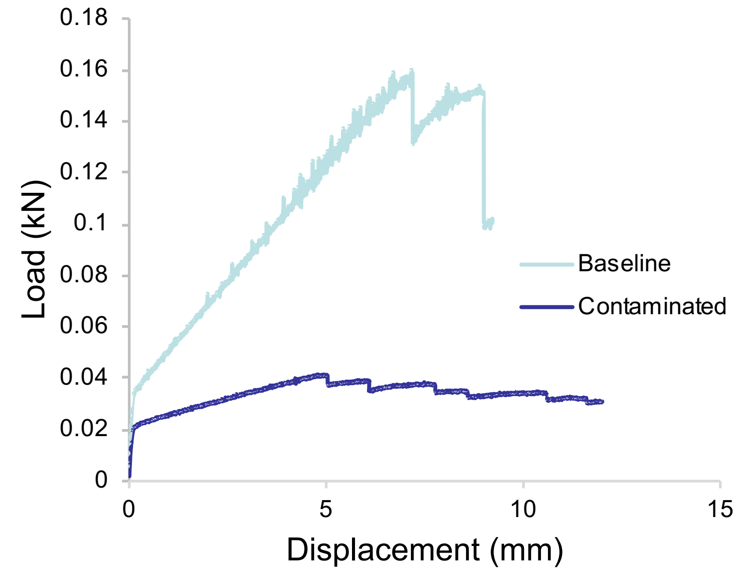


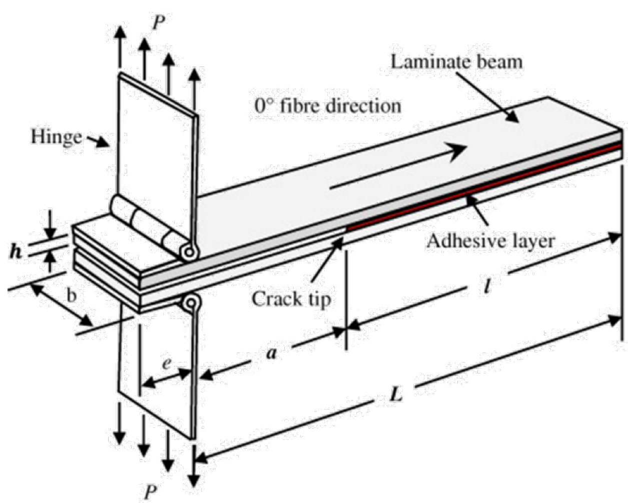


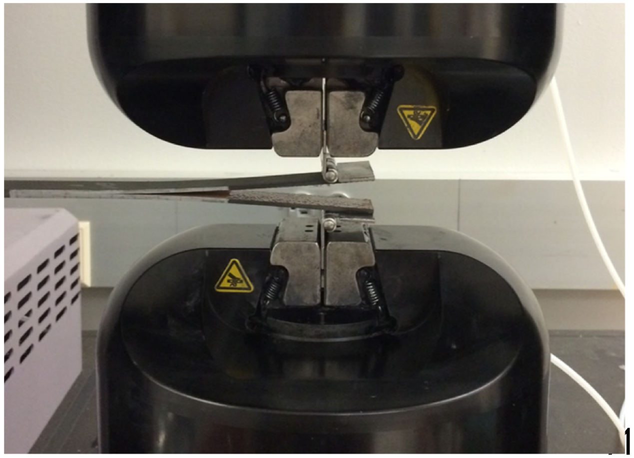
Bond Quality Evaluation

- Dual Cantilever Beam Testing
  – Measures interlaminar fracture toughness
- Fracture toughness provides a measure of composite strength
  – The critical energy a material may absorb before failure and resistance to delamination

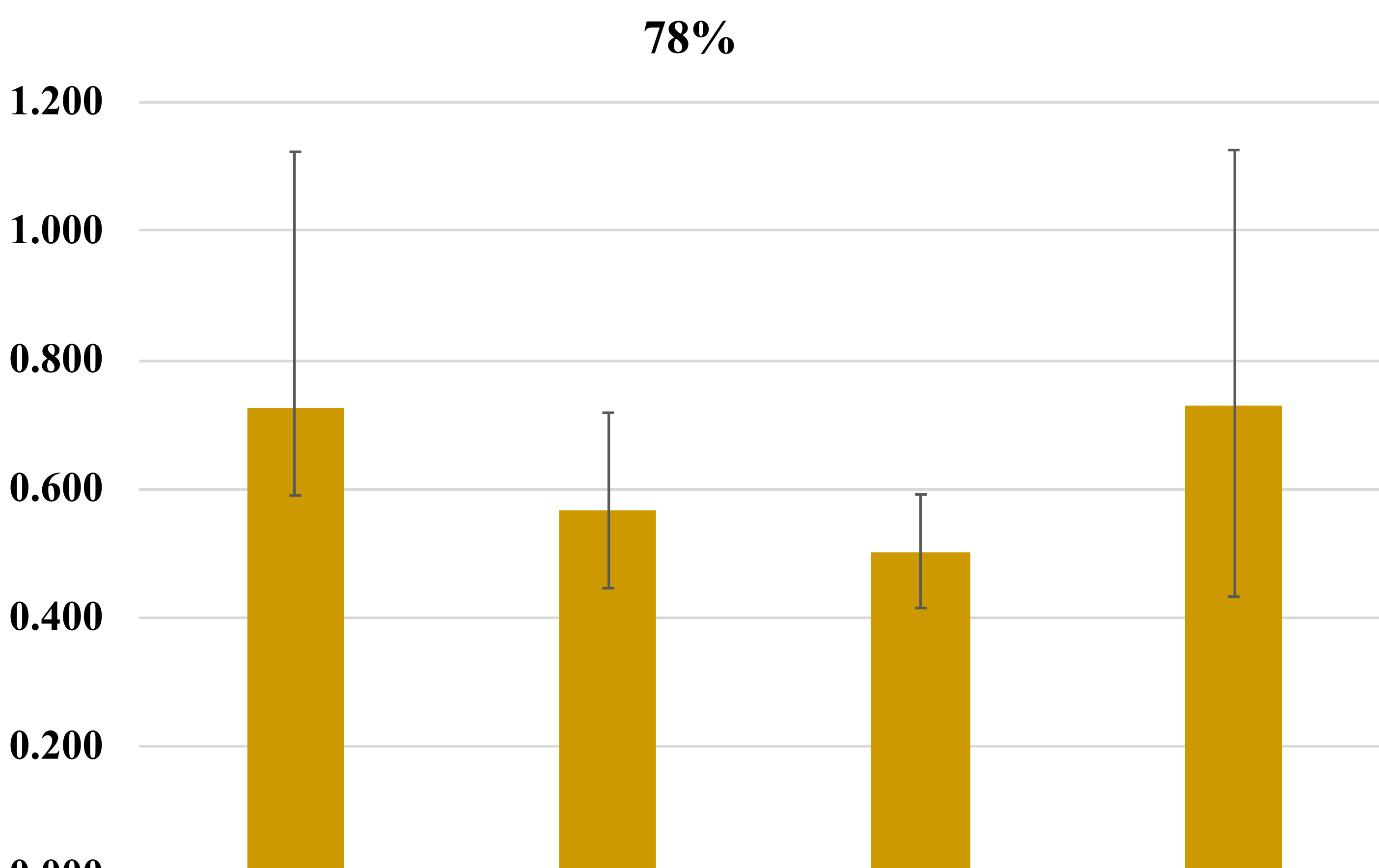
  – $G_{1C} = \frac{3P\delta}{2b(a+|\Delta|)}$
- Use of MTS machine to measure displacement







Results of Mitigation Approaches



	Baseline	Cont	Wipe	WSW
78%	0.726	0.565	0.500	0.728

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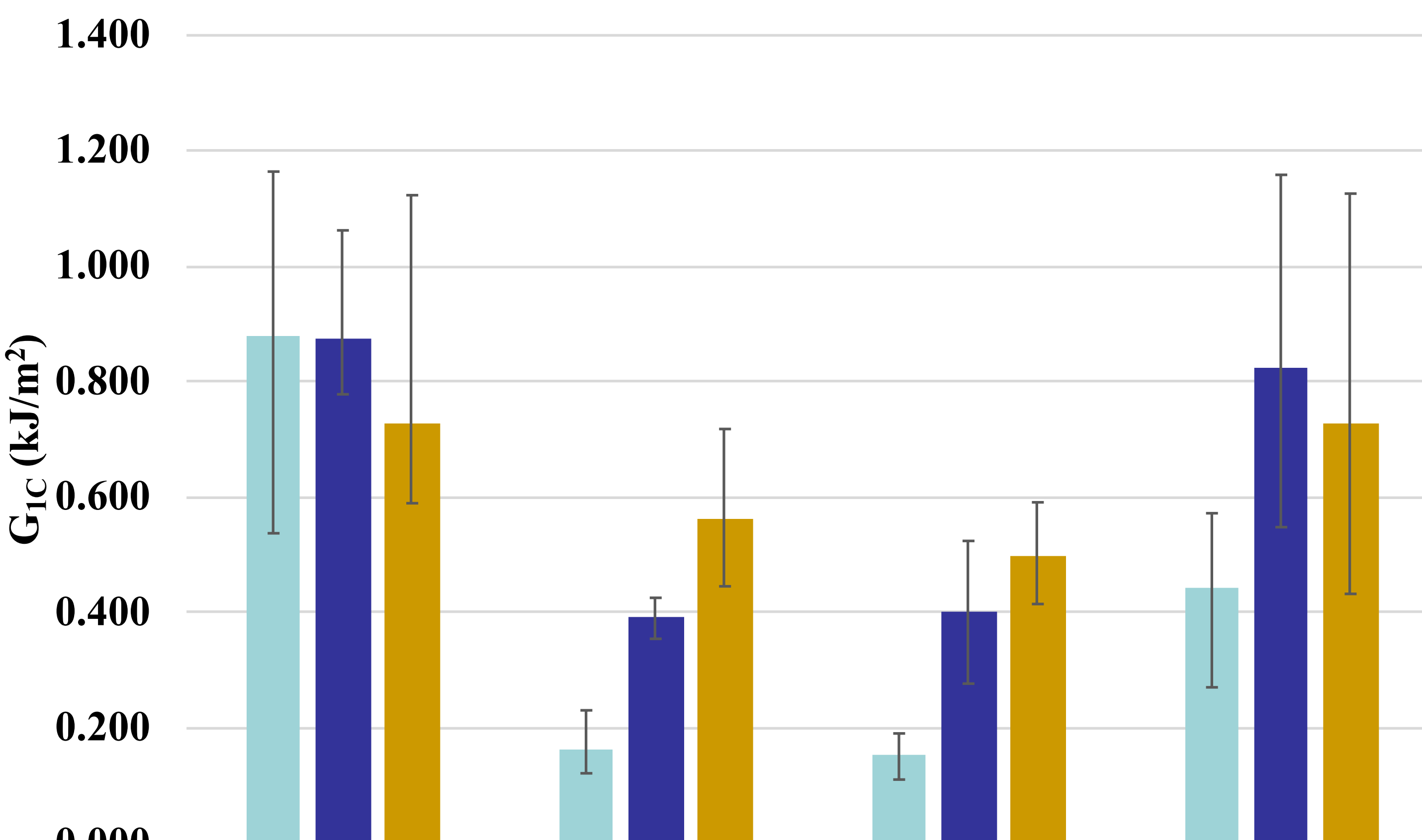
Summary of Mitigation Results



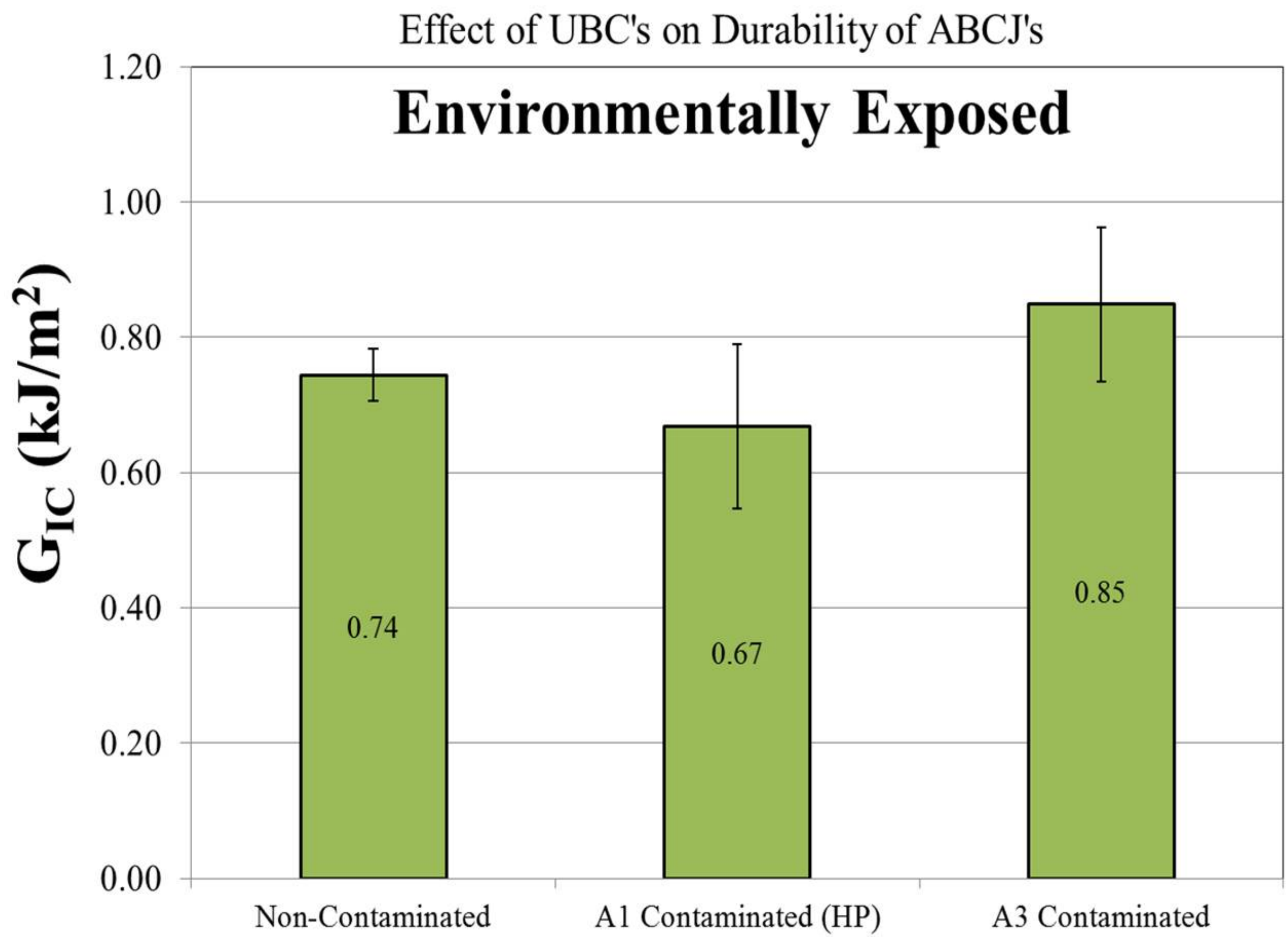
	Baseline	Cont	Wipe	WSW
19%	0.879	0.165	0.154	0.445
45%	0.873	0.394	0.403	0.822
78%	0.726	0.565	0.500	0.728

Durability Characterization – Environmental Aging

- Why is it important?
  - Composite laminates not only go through contamination effects but are also exposed to other conditions when they've been placed on the plane
- Specimens are environmentally aged in a Thermotron 2800 Environmental chamber in an unstressed condition
  - Specimens are subjected to harsh environments i.e. controlled temperature and humidity conditions at 70°C and 95% RH
    - The fluid selected for the aging process is di-ionized water

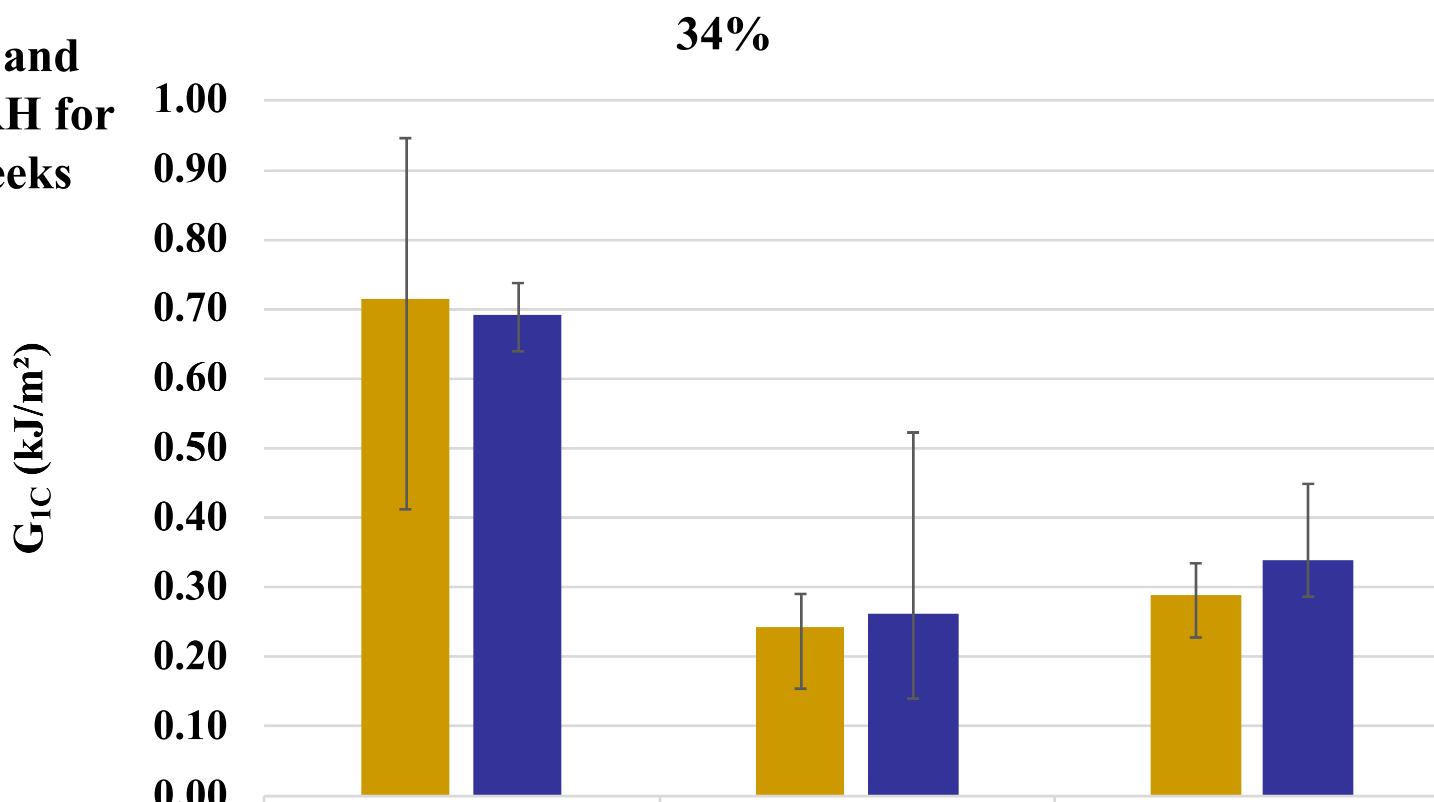
Durability Results - Stamp approach

70 C and 95% RH for 4 Weeks



Durability Results – Uniformly Sprayed Approach

70 C and 95% RH for 4 Weeks



	Baseline	Contaminated	WSW
Unexposed	0.72	0.24	0.29
Exposed	0.69	0.26	0.34

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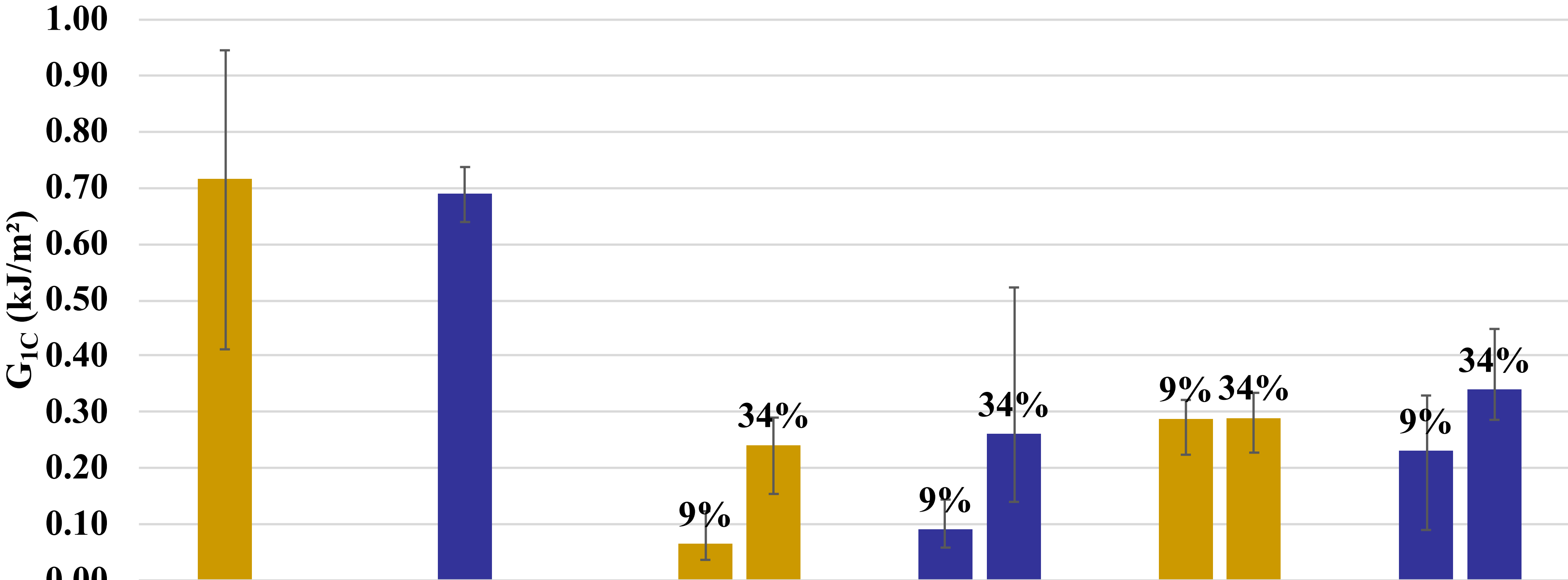
Summary of Durability Results



	Baseline Unexposed	Baseline Exposed	Contaminated Unexposed	Contaminated Exposed	WSW Unexposed	WSW Exposed
9%	0.72	0.69	0.07	0.09	0.29	0.23
34%			0.24	0.26	0.29	0.34

Failure Modes – Uniformly Sprayed Approach (Baseline)

Unexposed

Exposed

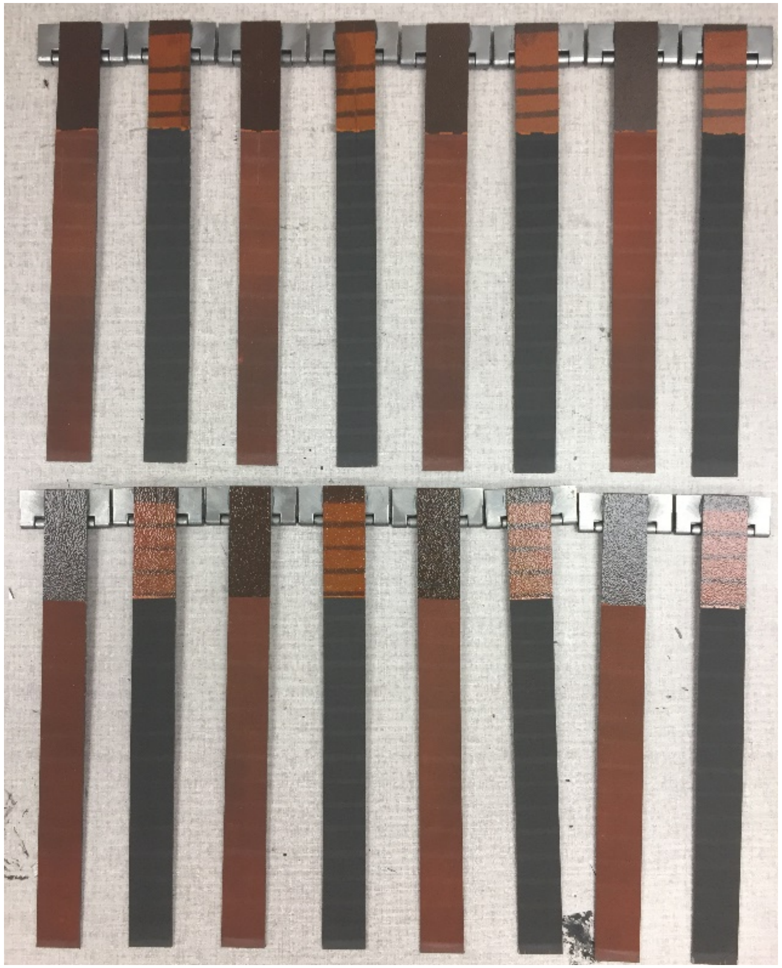
Failure Modes – Uniformly Sprayed Approach (Contaminated)

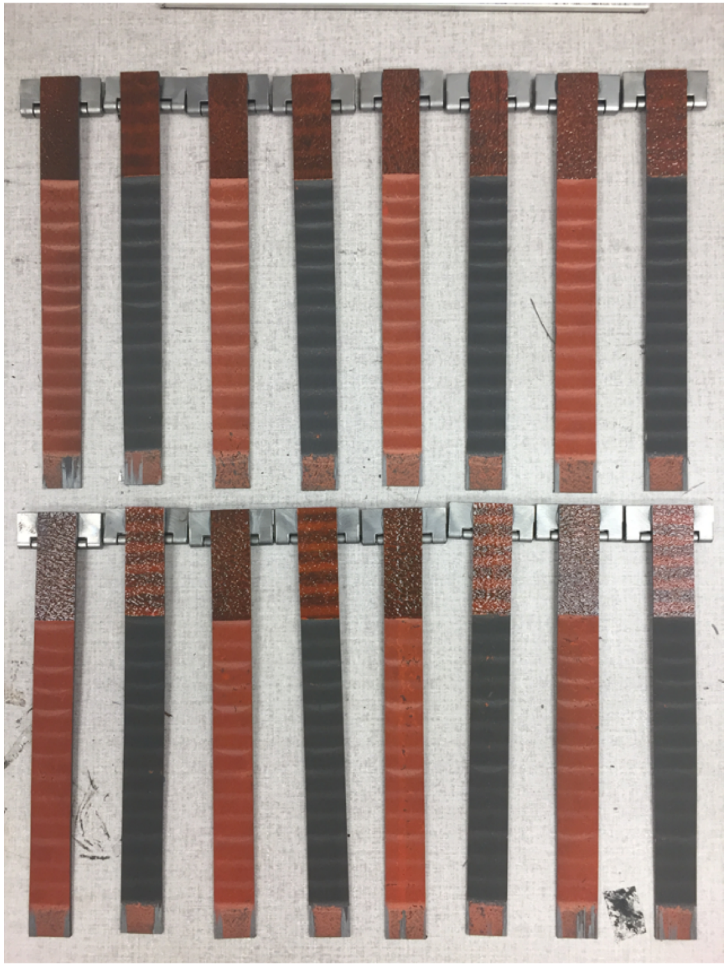
9%

34%

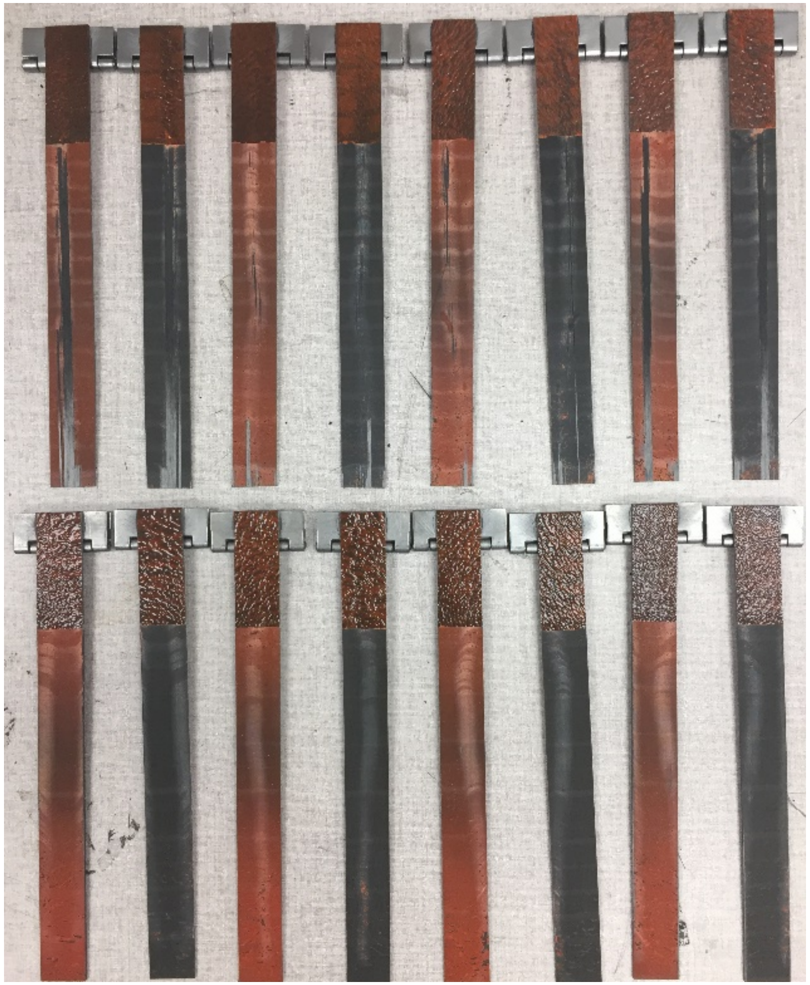
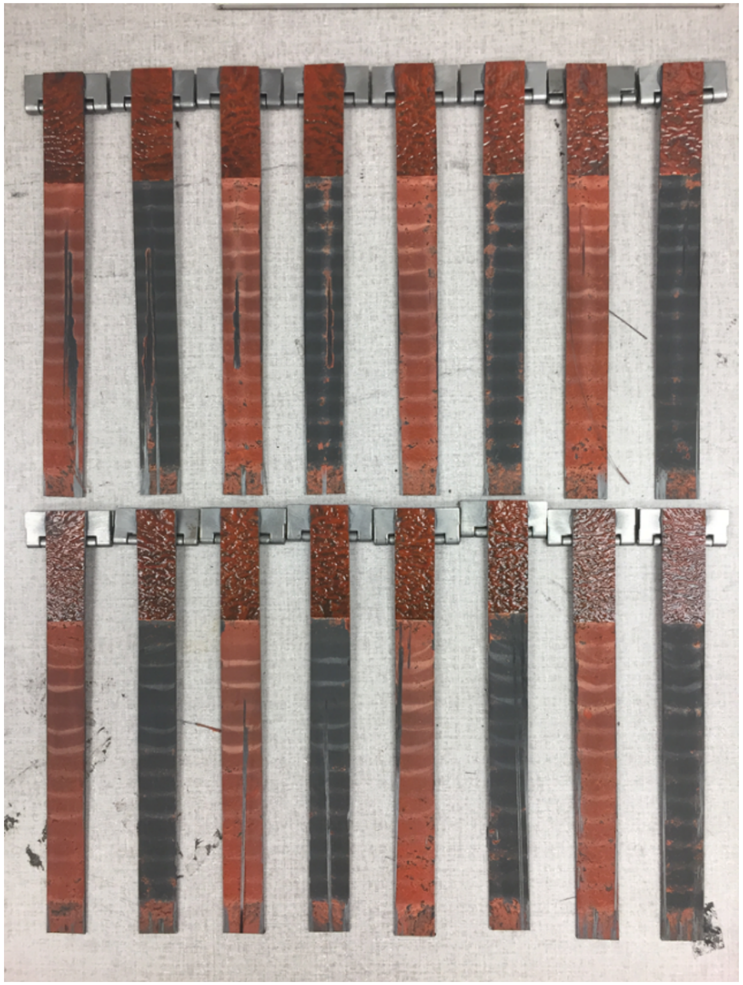
Unexposed

Exposed





Failure Modes – Uniformly Sprayed Approach (Wipe Sand Wipe)

	9%	34%
Unexposed		
Exposed		

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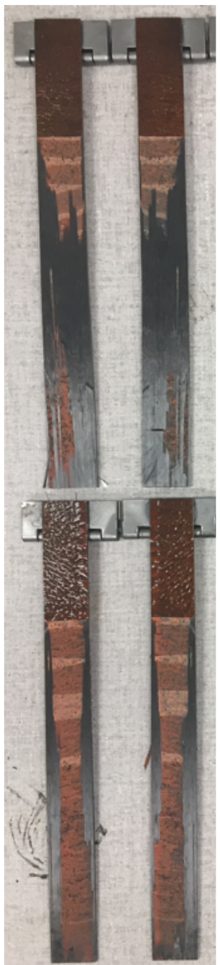
Failure Modes – Uniformly Sprayed Approach

Baseline



Contaminated

9%

34%

Wipe Sand Wipe

9%

34%

Unexposed

Exposed

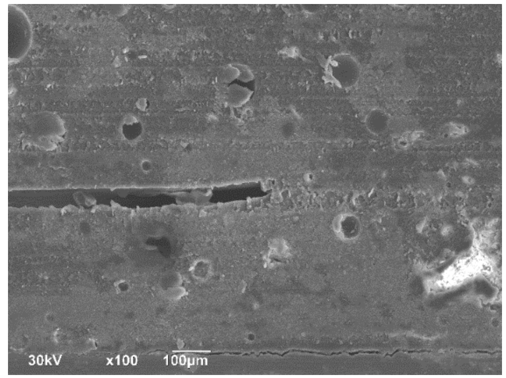
Summary

- A contamination procedure was developed using and Frekote to develop a scalable and repeatable weak bond. The weak bonds can be used to evaluate surface prep techniques and potentially NDI methods.
- Repeatable weakened bonds were obtained using a customized contamination rig for three levels of contamination (~10, ~50 and 75% bond strength).
- Mitigation approaches included solvent wiping and solvent wiping/sanding/solvent wiping. Results from these tests indicated that wiping alone did not improve the bond strength, however, there was significant improvement with the wiping/sanding/solvent wiping.
- Durability of both contaminated samples and contaminated with mitigation approaches were evaluated with both static loading and environmental exposure. There was no apparent combination effect from samples both contaminated and exposed.

Research Tasks FY18-19

Investigation of contaminated bondlines on the macro scale

Contaminated DCB coupons and coupons treated with the mitigation methods will be exposed to fatigue loading to determine effects on durability.



Investigation of contaminated bondlines on the micro scale

In-situ testing will be used to evaluate aspects of failure that include, environmental exposure, contamination and bondline thickness. Efforts will also be made to quantity the fracture toughness using DIC to estimate the strain field around the crack tip.

Chapter 5 Materials and Processes - The Effect of Variability on Composite Properties

5.9 ASSEMBLY PROCESSES

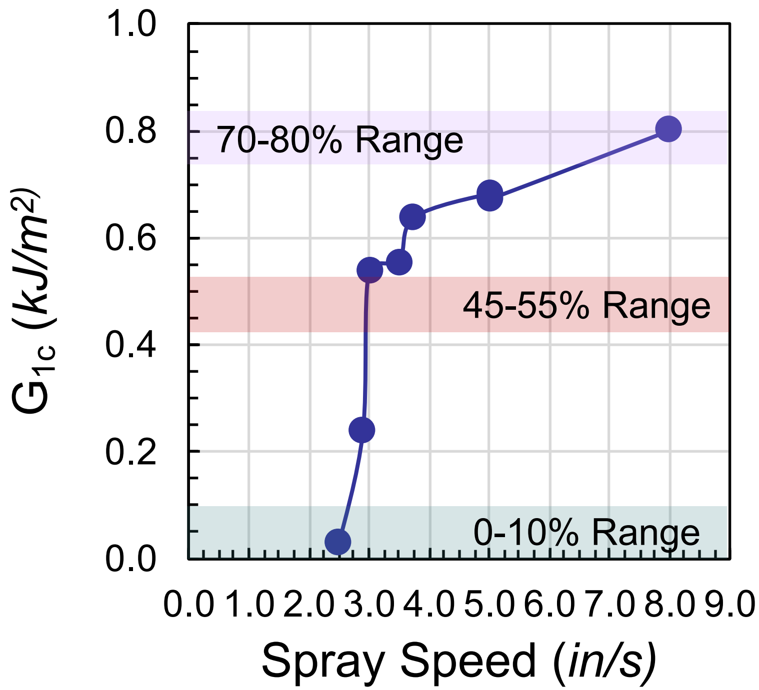
Assembly processes are not conventionally covered within composite material characterization, but can have a profound influence on the properties obtained in service. As seen with test coupons, edge and hole quality can dramatically affect the results obtained. While these effects are not usually covered as material properties, it should be noted that there is an engineering trade off between part performance and the time and effort expended toward edge and hole quality. These effects need to be considered along with the base material properties.

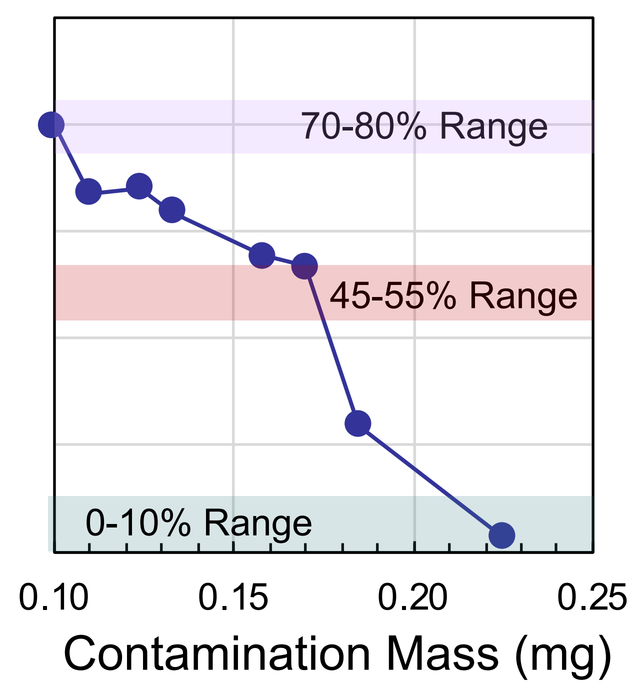
Support of CMH-17 Handbook

Content on bond testing and quality as well as materials will be assembled, organized and submitted for review for CMH-17.

Questions?

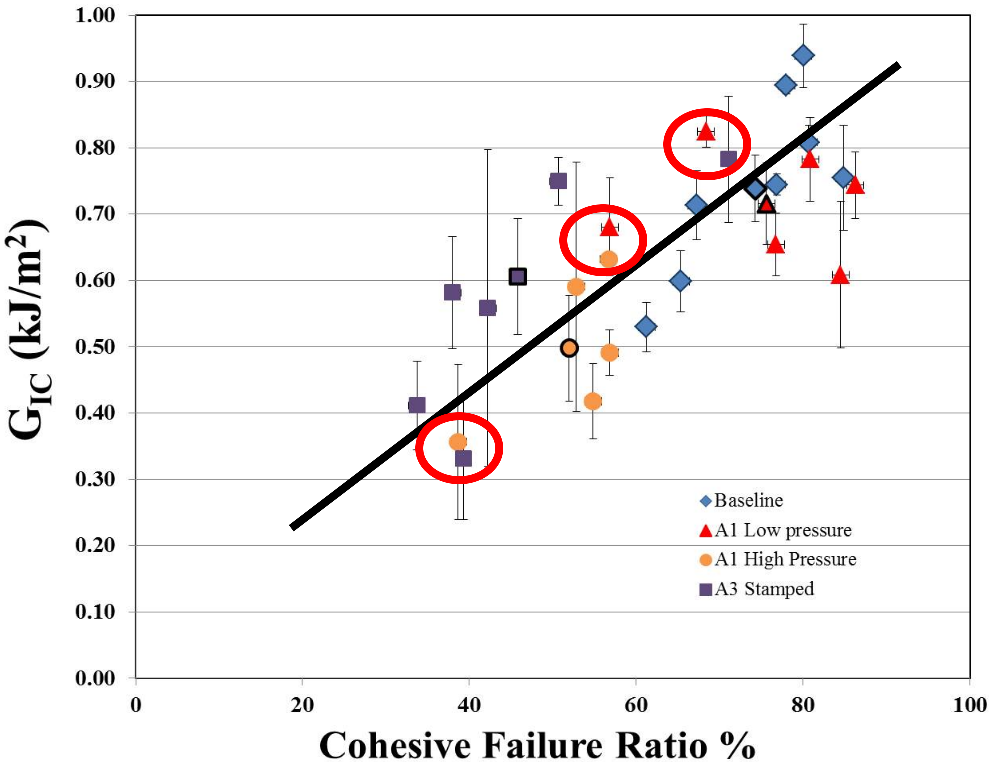
Contamination Results

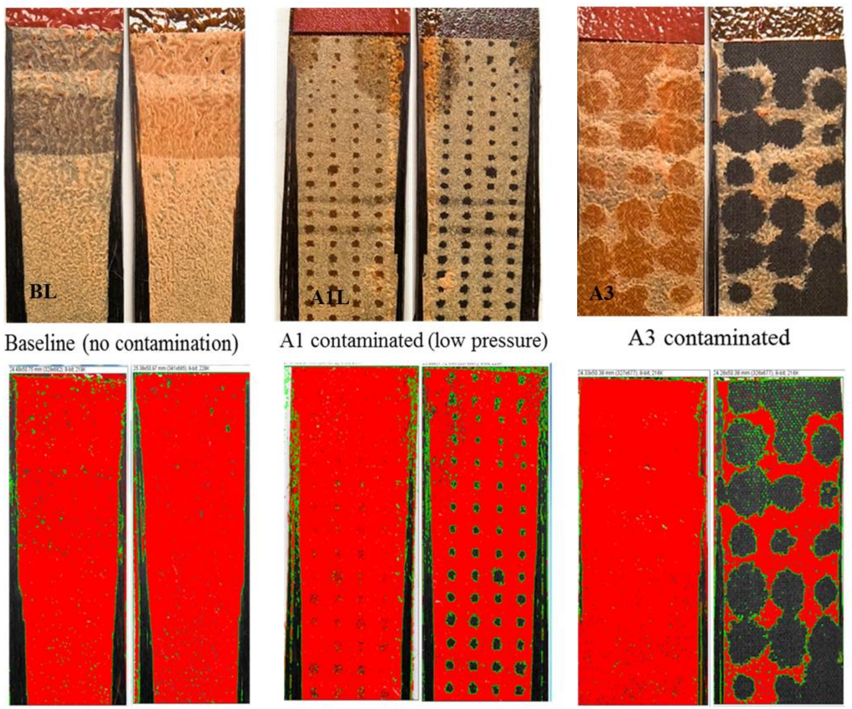




Previous Contamination Efforts
Discrete Methods – DCB Testing

Create scaled bond strength – vary contamination size and area





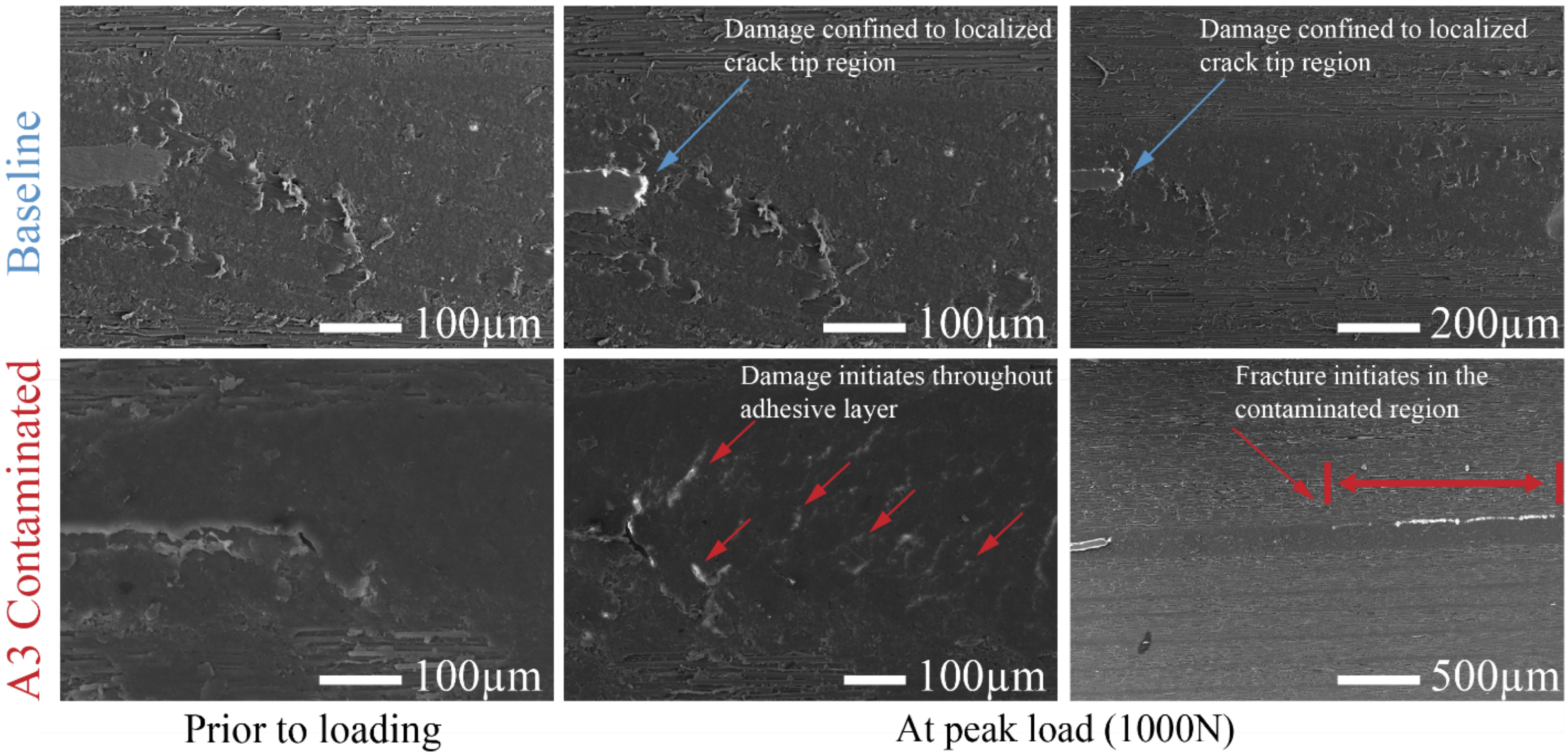
18% Drop in G_{IC} per 10% decrease in cohesive ratio

Contamination was modeled as circular cracks

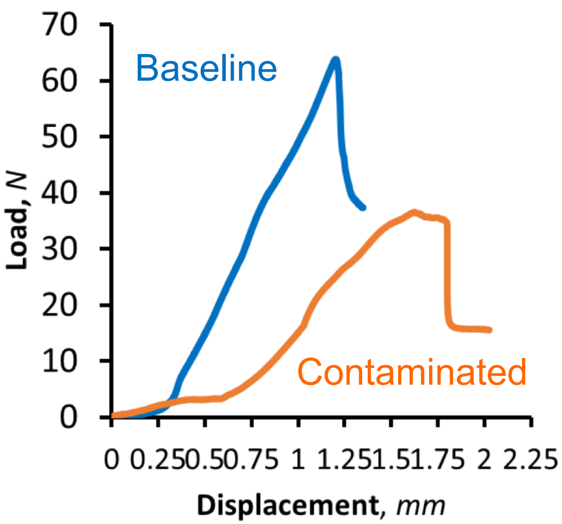
No significant effects of contaminate sizing, area was the dominate parameter.

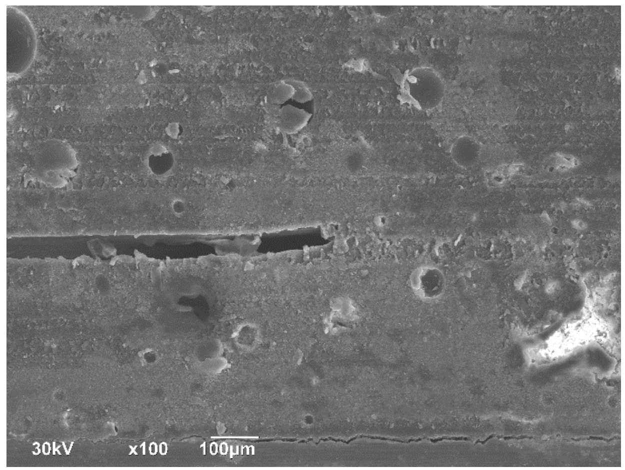
Previous Contamination Efforts

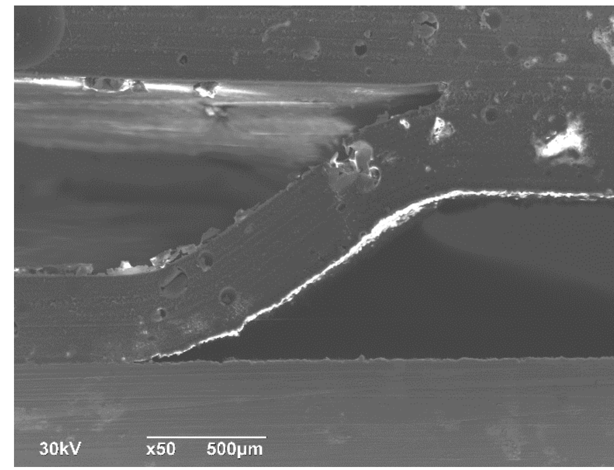
Discrete Methods – μENF Testing



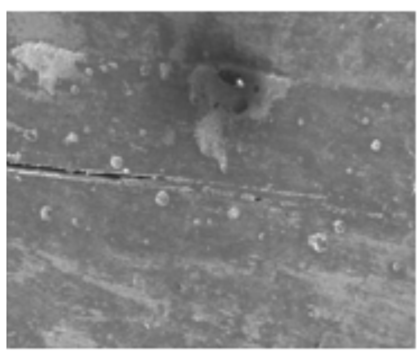
In-situ Testing
Summary of Mechanisms

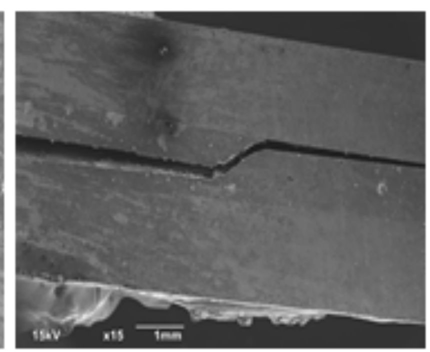


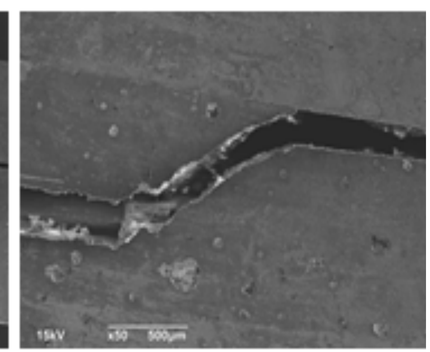




Advantages of Testing
Combined load-displacement with high magnification imaging can reveal the mechanisms of fracture. DIC can capture quantitative information (strain) as a function of processing.

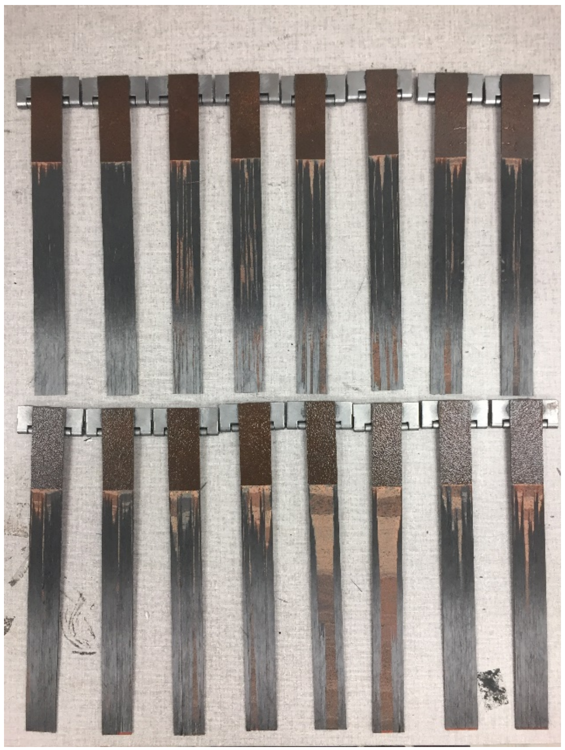




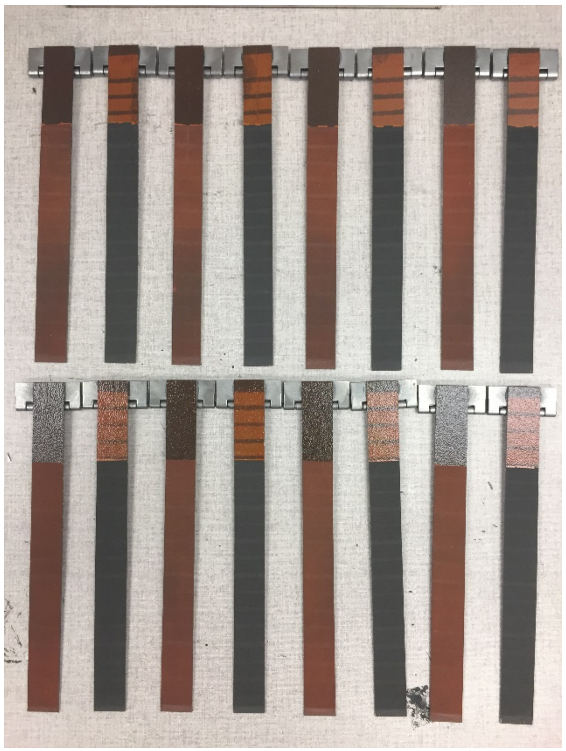


Failure Modes – Uniformly Sprayed Approach (13%)

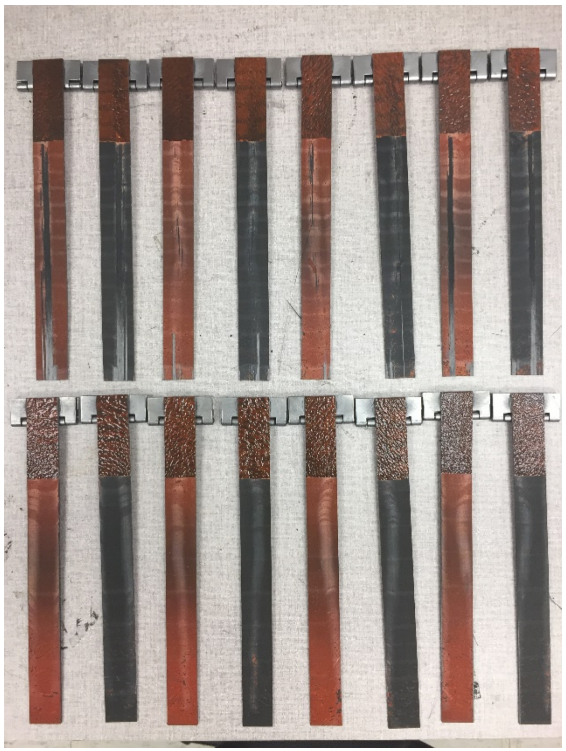
Baseline | **Contaminated** | **Wipe Sand Wipe**



Unexposed



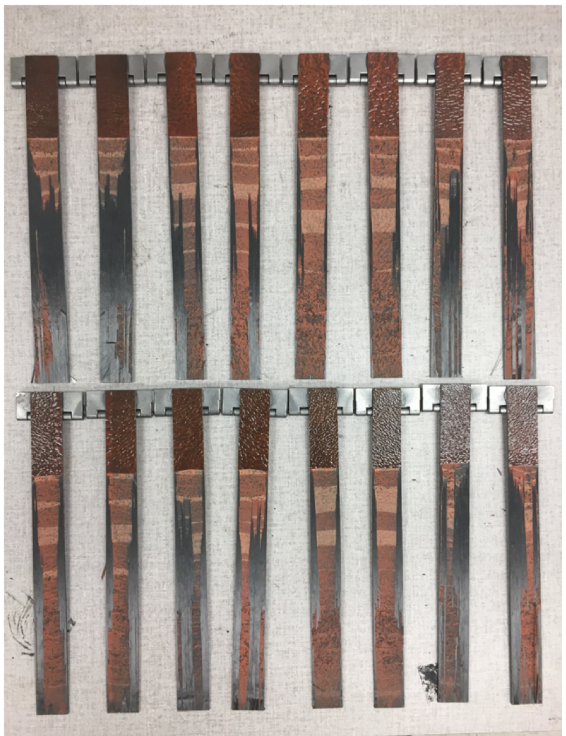
Exposed

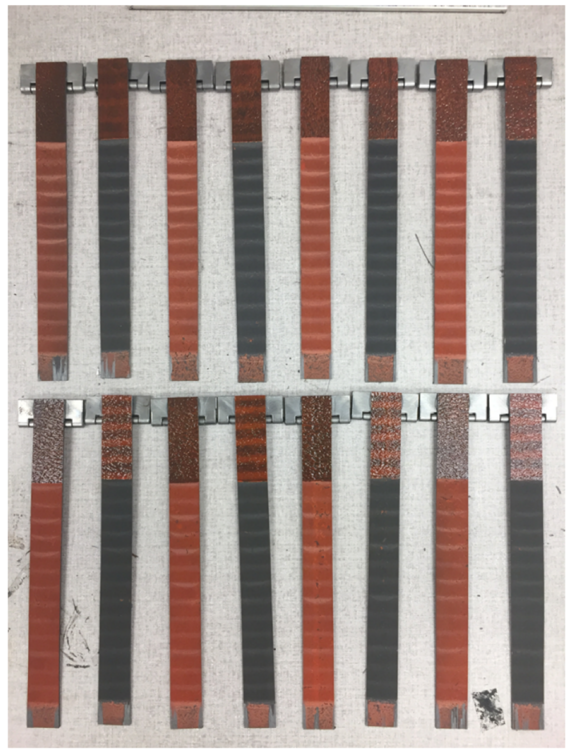


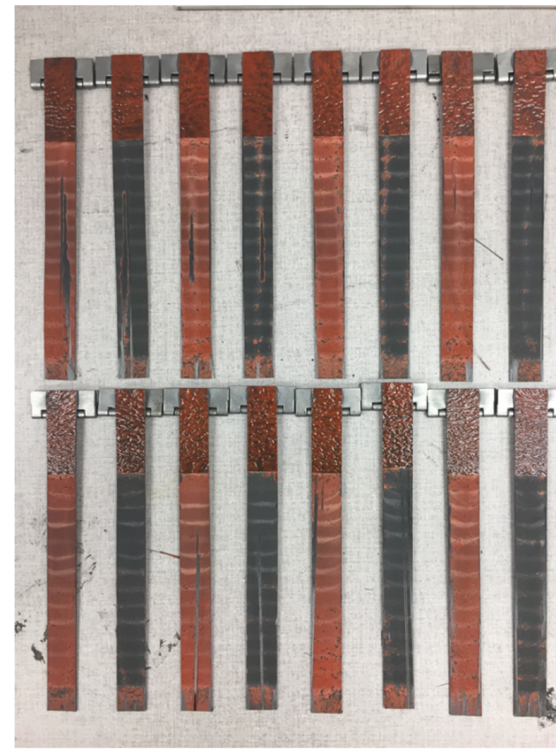
Failure Modes – Uniformly Sprayed Approach (40%)

Baseline	Contaminated	Wipe Sand Wipe

Unexposed







Exposed