Effect of Surface Contamination on Composite Bond Integrity and Durability

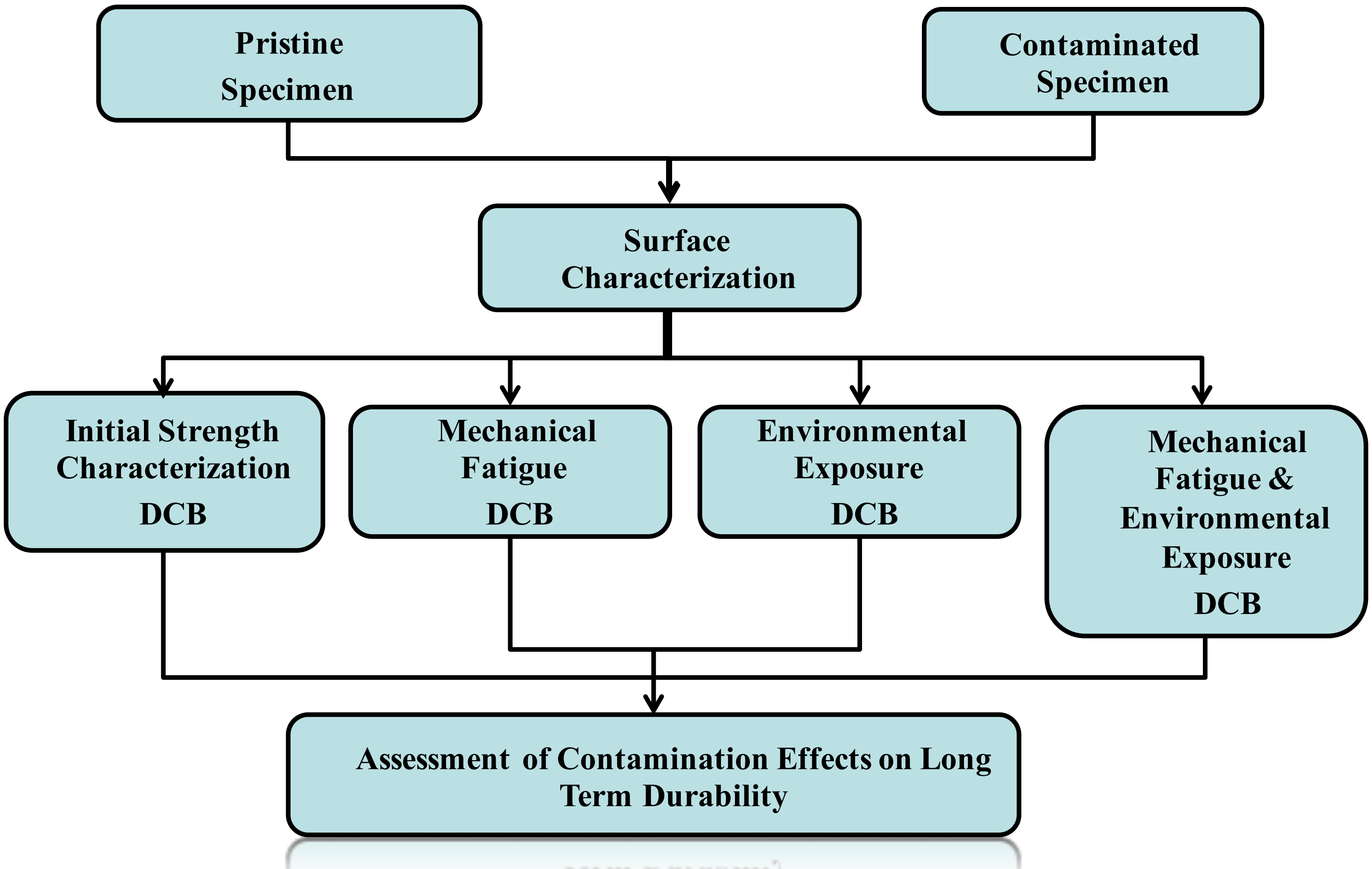
Dwayne McDaniel, Benjamin Boesl,
Vishal Musaramthota, Shervin Tashakori
Florida International University

Contact: mcdaniel@fiu.edu Ph: (305) 348-6554

Composite Bond Integrity/Long-Term Durability of Composite Bonds

- **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 effected by contamination.
- **Objective**
  - Develop a process to evaluate the durability of adhesively bonded composite joints
  - Investigate **undesirable bonding conditions** by characterizing the initial performance at various contamination levels
  - Characterize the durability performance of the system using the same contamination levels
  - Support CMH-17 with the inclusion of content for bonded systems

Durability Assessment Procedure



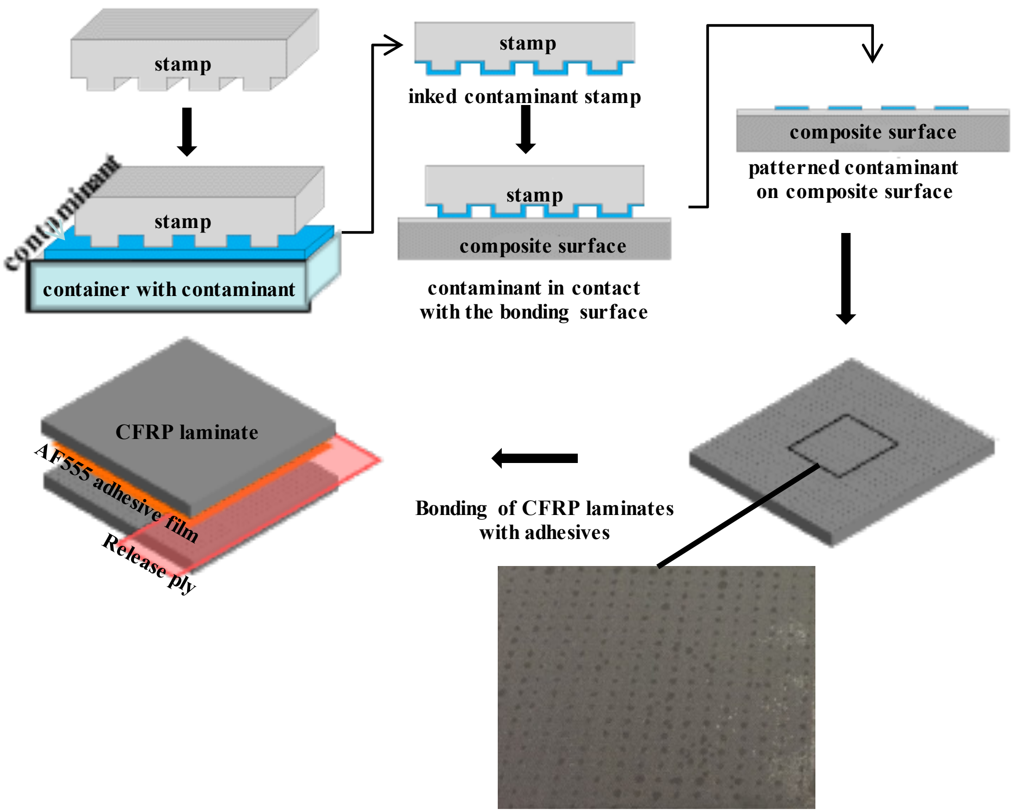
Bonding System Materials

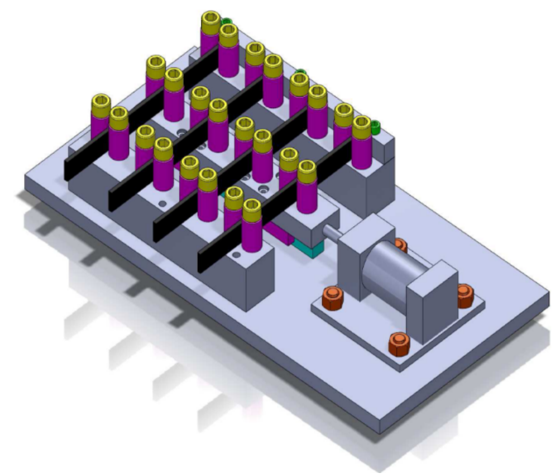
- Material type and curing procedure for specimens: unidirectional carbon-epoxy system, film adhesive, secondary curing bonding and contaminants.

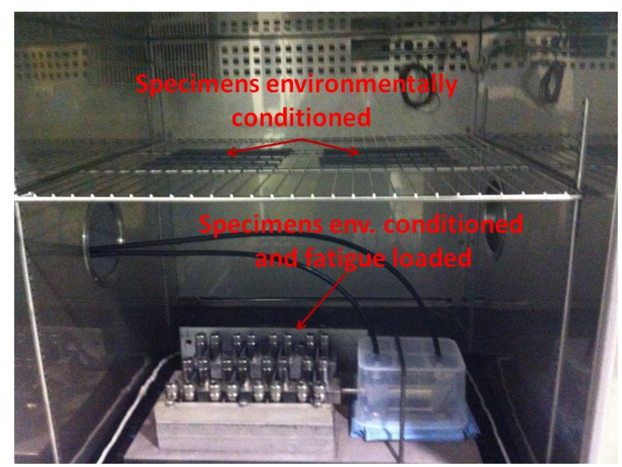
- Materials utilized:
  - Toray P 2362W-19U-304 T800 Unidirectional Prepreg System (350F cure)
  - 3M AF 555 Structural adhesive film (7.5x2 mills, 350F cure)
  - Precision Fabric polyester peel ply 60001
  - Freekote 700-NC from Henkel Corporation

- Specimen Conditioning:
  - Environmental Chamber : 50° C, 95% RH, for 8 weeks and 1.5 years
  - Fatigue Loading: 3 point bending arrangement, 1 inch double amplitude, 2.6 million cycles

Fatigue Fixture and Contamination Procedure





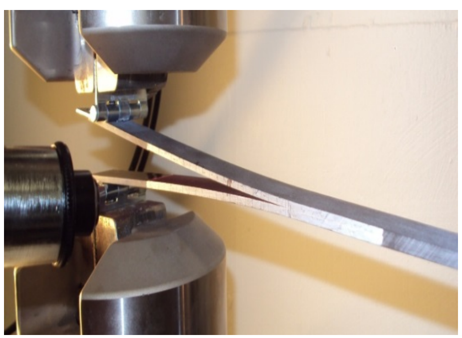


- Stamp Procedure
- Fixture Loaded in Environmental chamber

Assessment of Bond Quality

Double Cantilever Beam (DCB) tests are conducted to determine the adhesive critical energy release rate (G_{IC}).

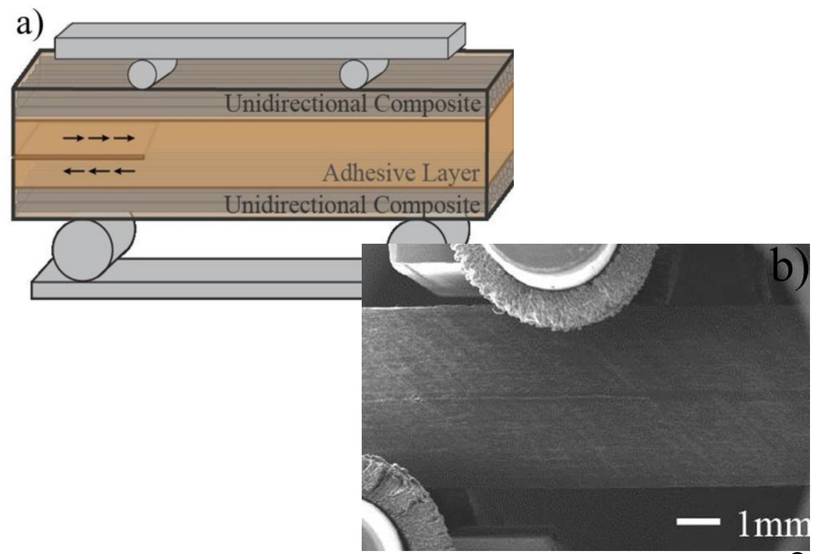
Reveals data for the energy release rate, crack propagation mechanism and provide the dominant mode of failure



Configuration: Loading rate - 5.0 mm/min in the direction perpendicular to the specimen from one of the edges

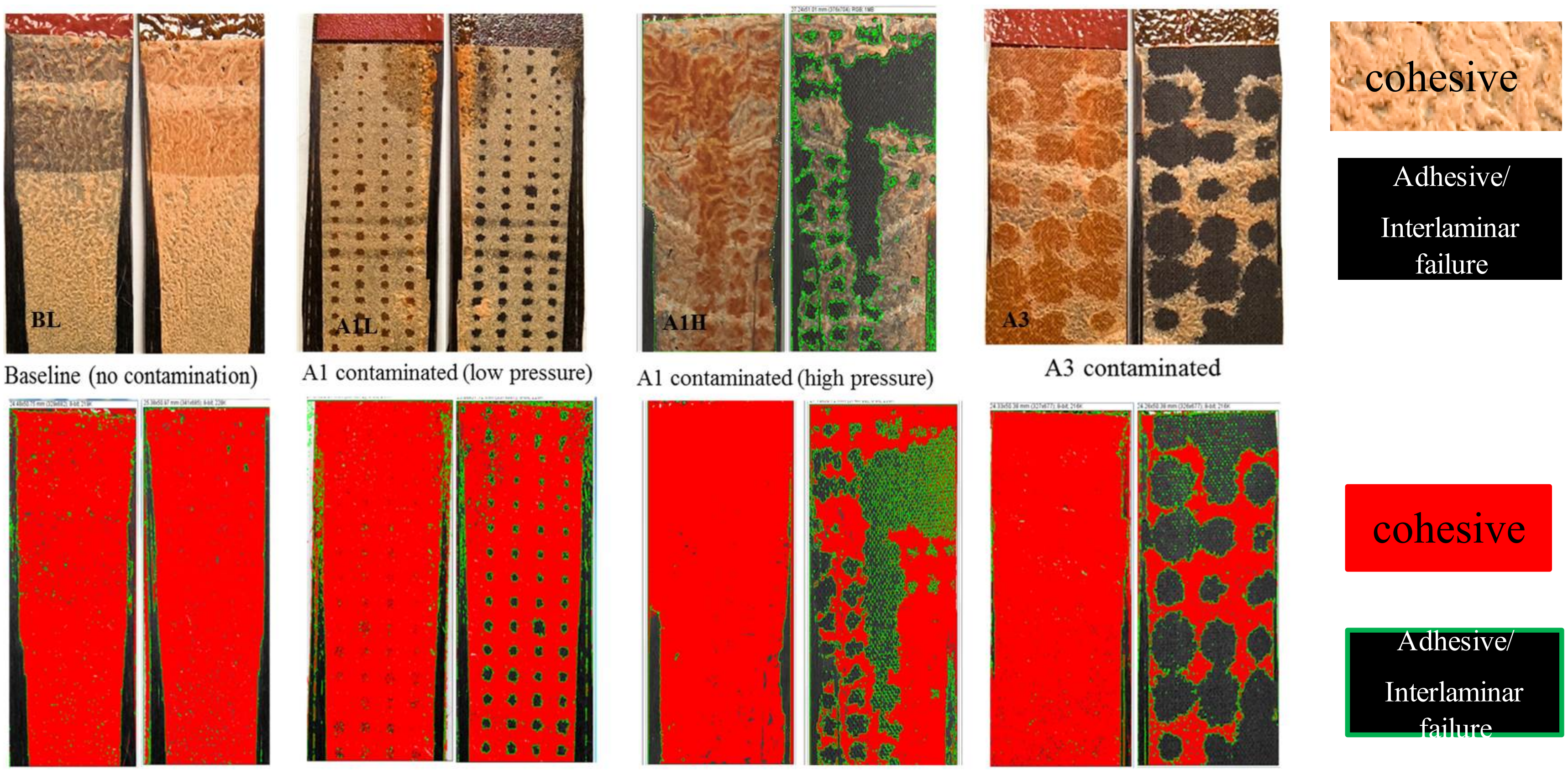
End Notch Flexure (ENF) tests are conducted *in-situ* to determine the initiation and propagation of damage.

Reveals mechanisms of damage propagation via crack growth progression and crack opening profiles.



Quantification of Modes of Failure

Image J software was utilized to quantify failure modes

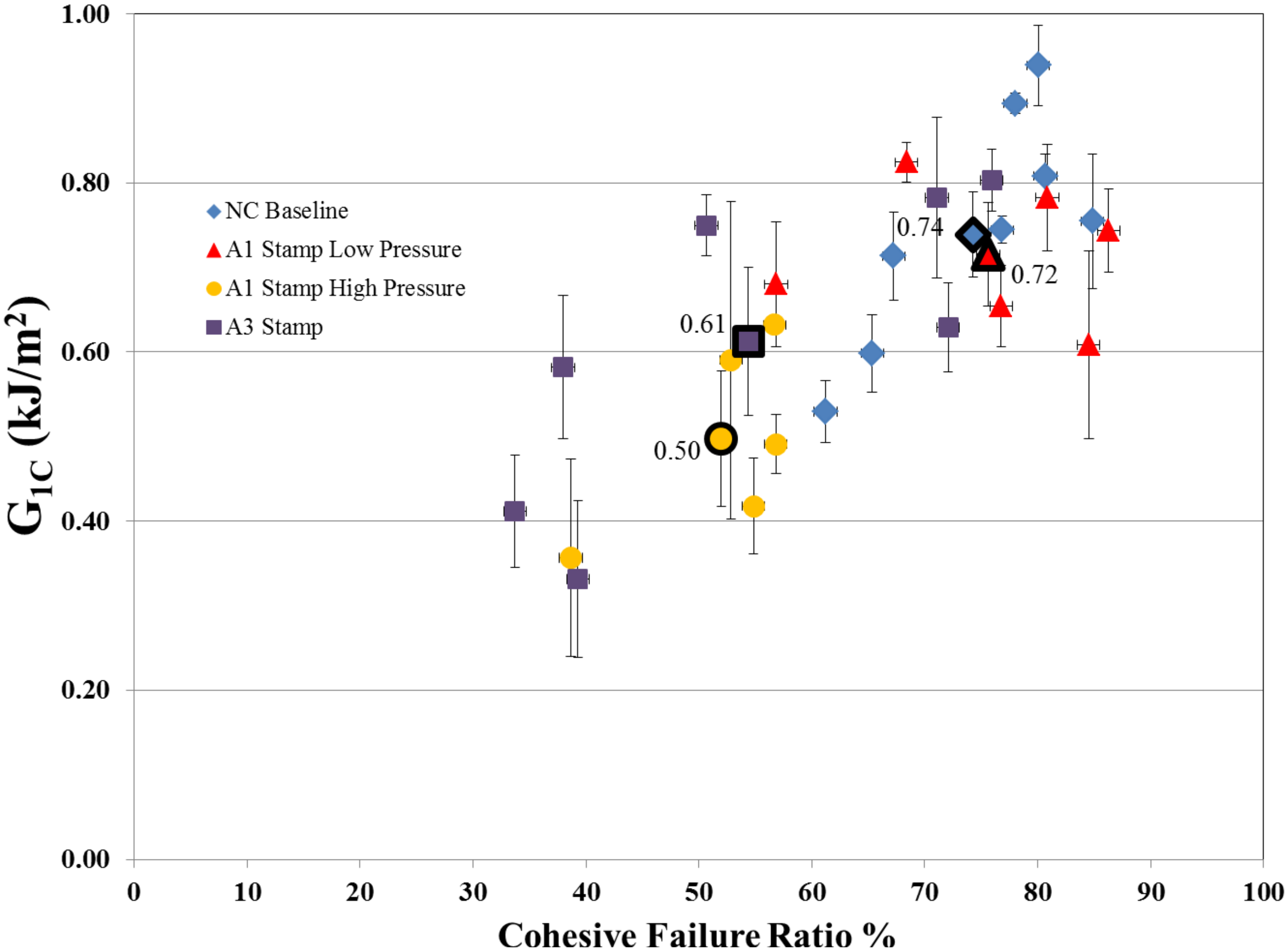


Recent Results

- Mode of failure analysis and how that correlates with bond quality
- Assessment of damage initiation and propagation using *in situ* microscopy
- Analytical modeling of a contaminated bondline using Linear Elastic Fracture Mechanics (LEFM).

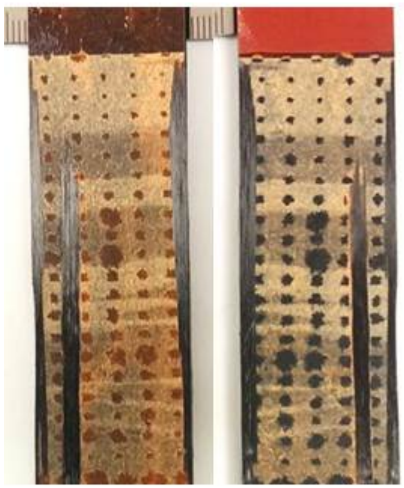
Bond Quality Assessment

Dual Cantilever Beam (DCB) Specimen



Bond Quality Assessment

Dual Cantilever Beam (DCB) Specimen



A1L-06

G_{1C} - 0.78 kJ/m^2
COH % - 68.38

A3-05

G_{1C} - 0.78 kJ/m^2
COH % - 71.07

Varying Stamp Size

Similar Cohesive Area

Similar Bond Quality

A3-05

G_{1C} - 0.78 kJ/m^2
COH % - 71.07

A3-07

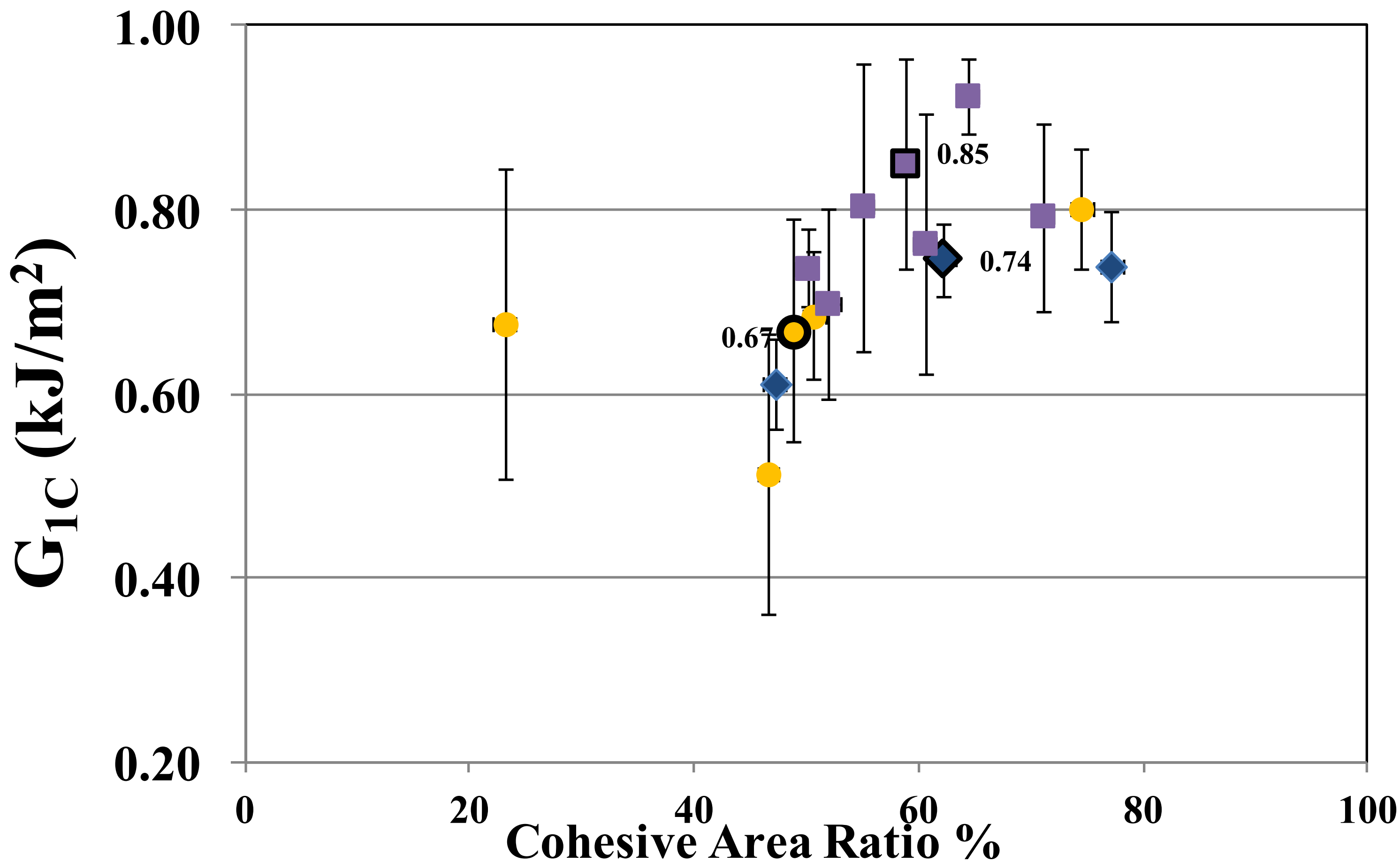
G_{1C} - 0.33 kJ/m^2
COH % - 39.30

Similar Stamp Size

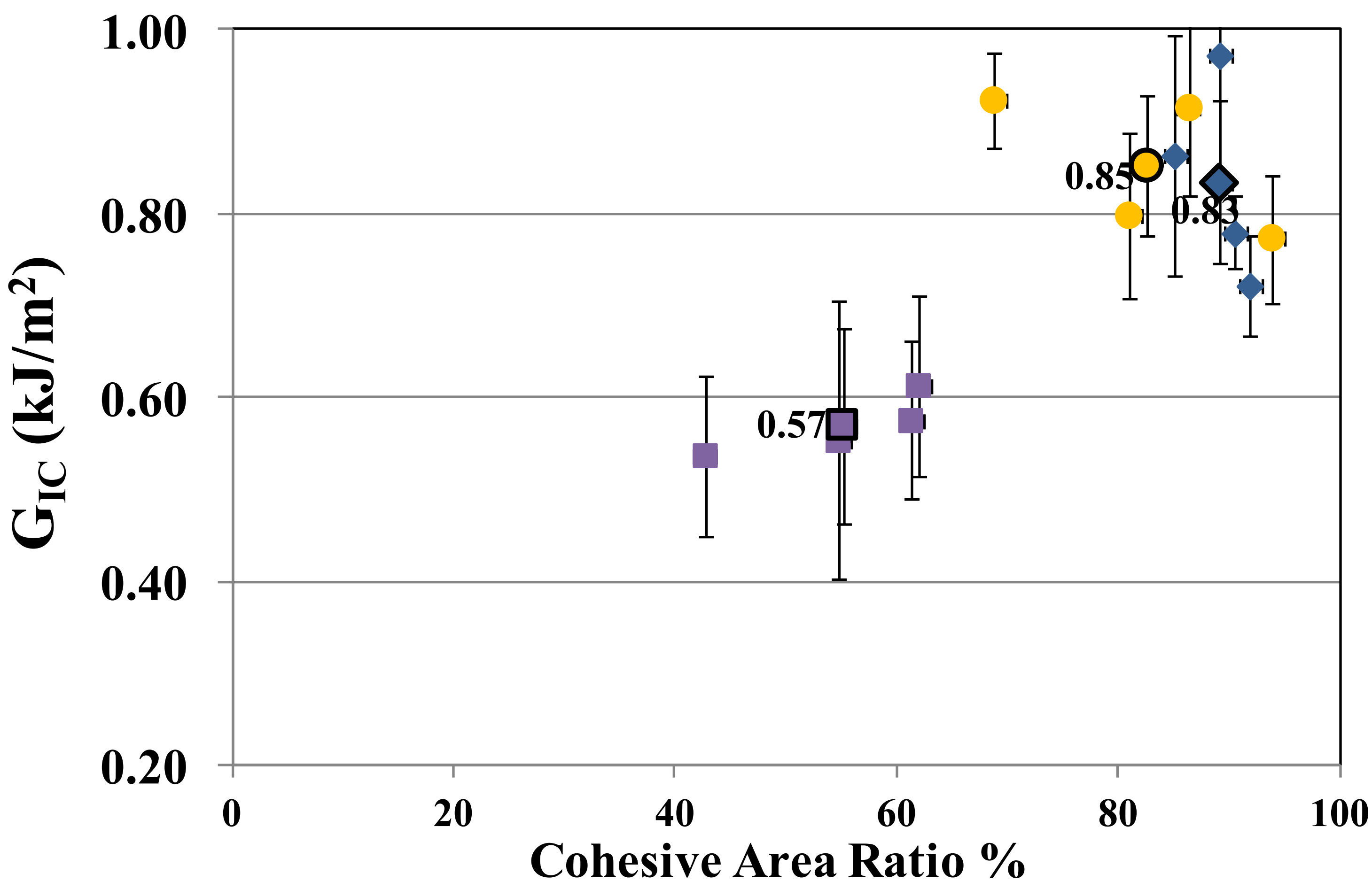
Varying Cohesive Area

Significant Change in Bond Quality

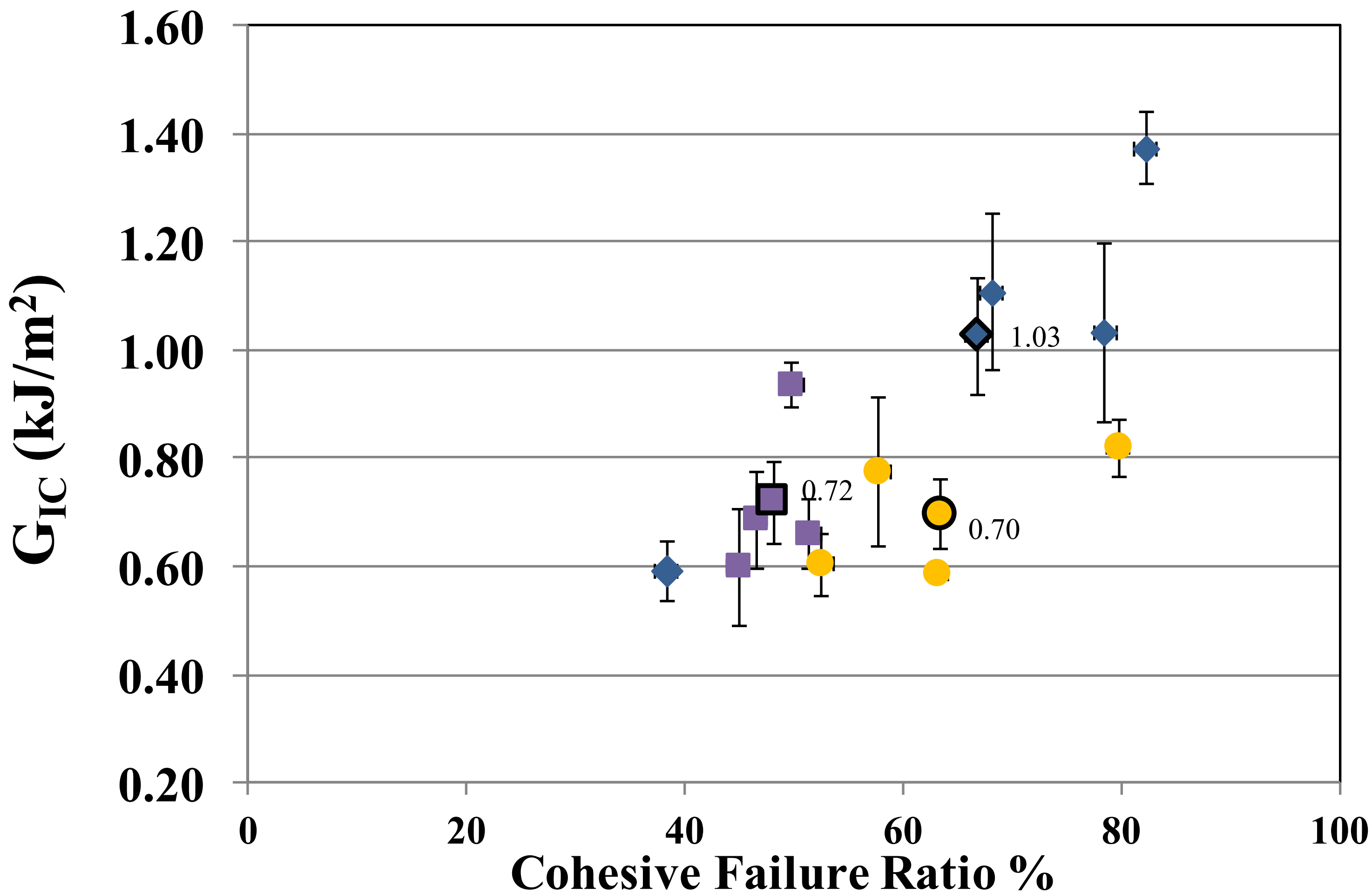
Environmental Conditioning



Fatigue in Ambient Air



Combined Fatigue & Env. Exposure



In-situ Micro-scale Evaluation End Notch Fracture (ENF)

Description

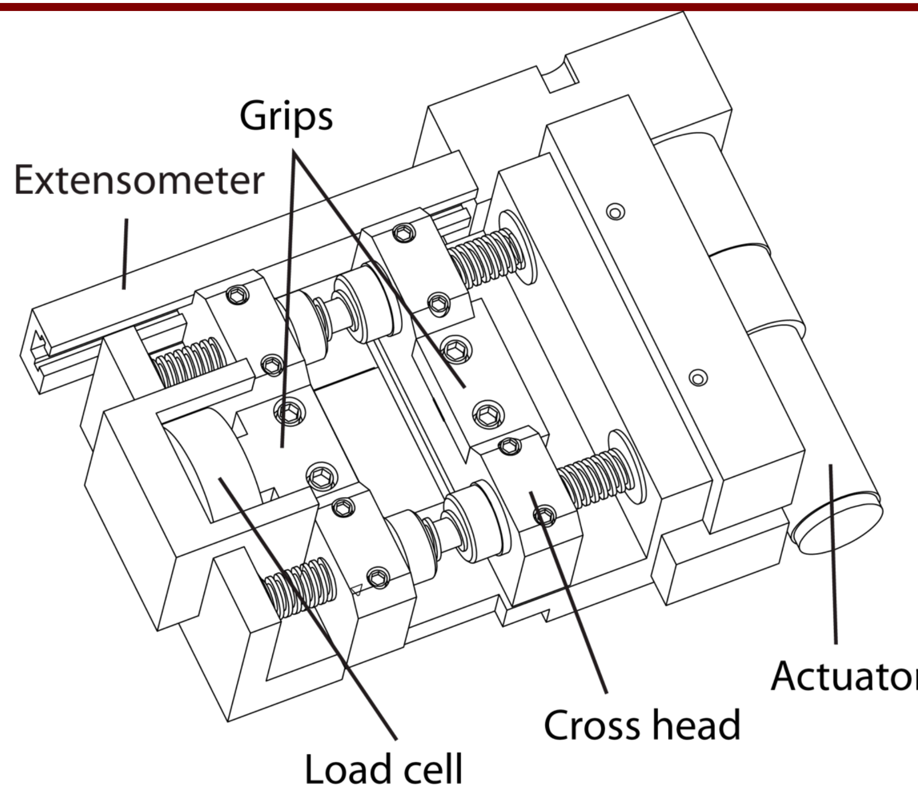
In situ load frame for simultaneous loading and imaging of samples within the FIB chamber.

Capabilities

High resolution strain measurement
Programmable loading programs
Very low strain rate are achievable

Testing modes

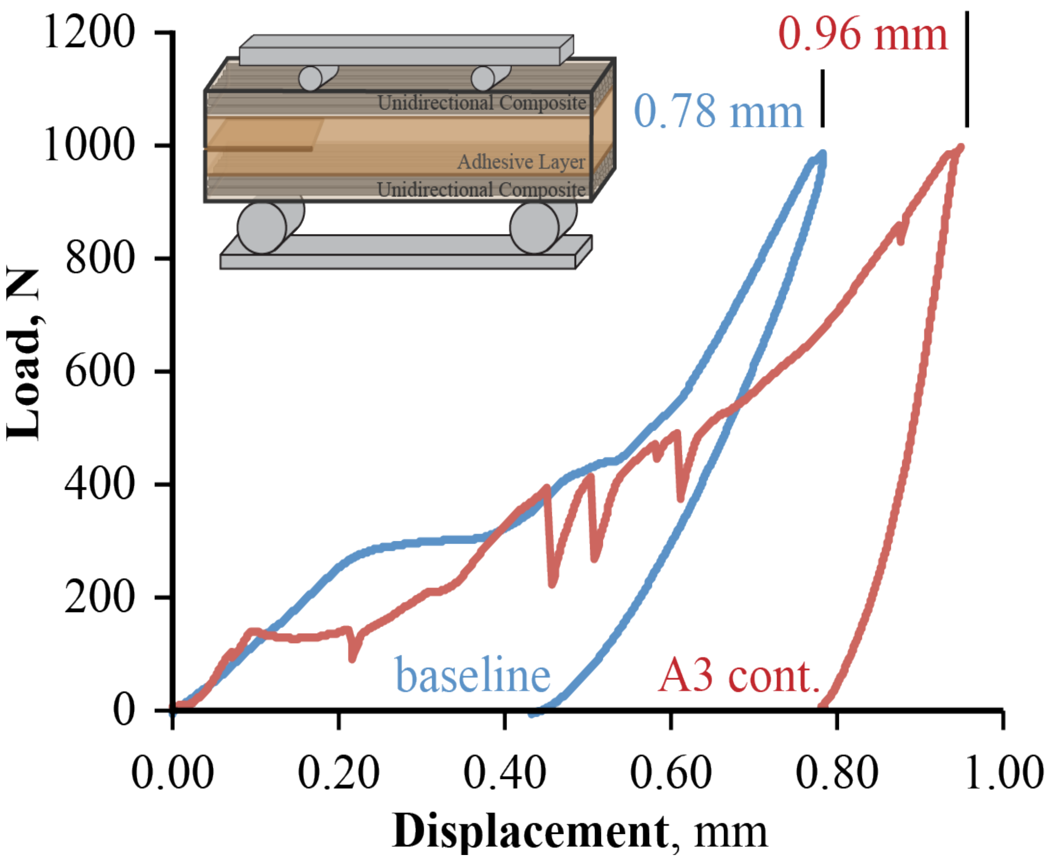
- Tension
- Compression
- Fatigue
- 3 point bending
- 4 point bending
- Fracture
- Compact tension

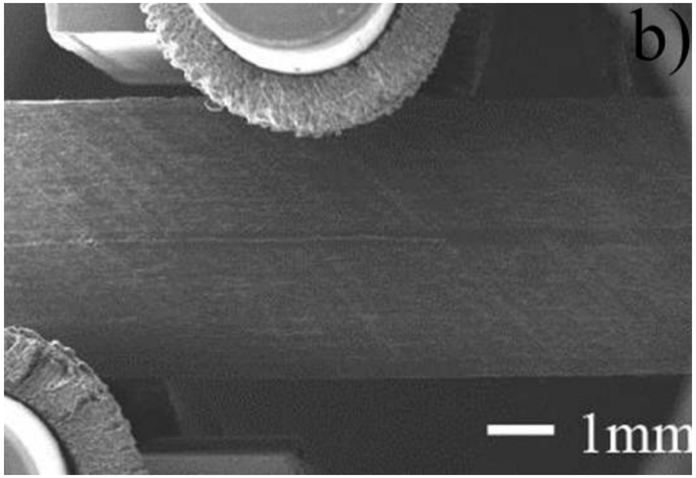


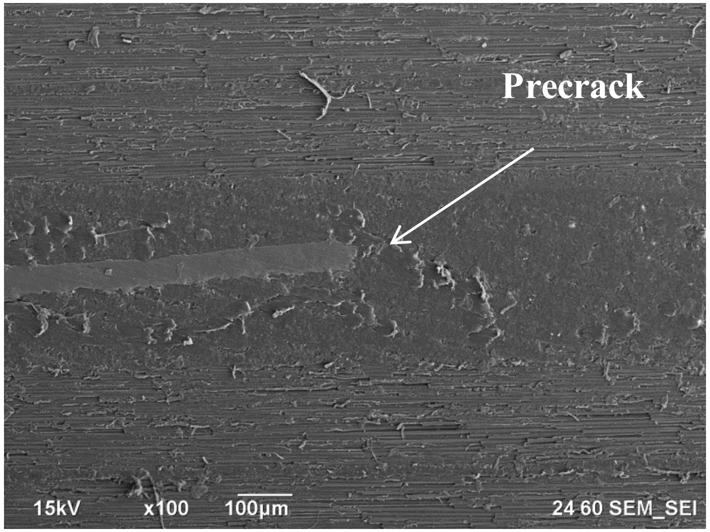
Specifications

Load Capacity	4500N	Max. Strain Travel	30 mm
Load Cell Accuracy	0.2%	Linear Scale Accuracy	20 nm resolution

In-situ Micro-scale Evaluation End Notch Fracture (ENF)

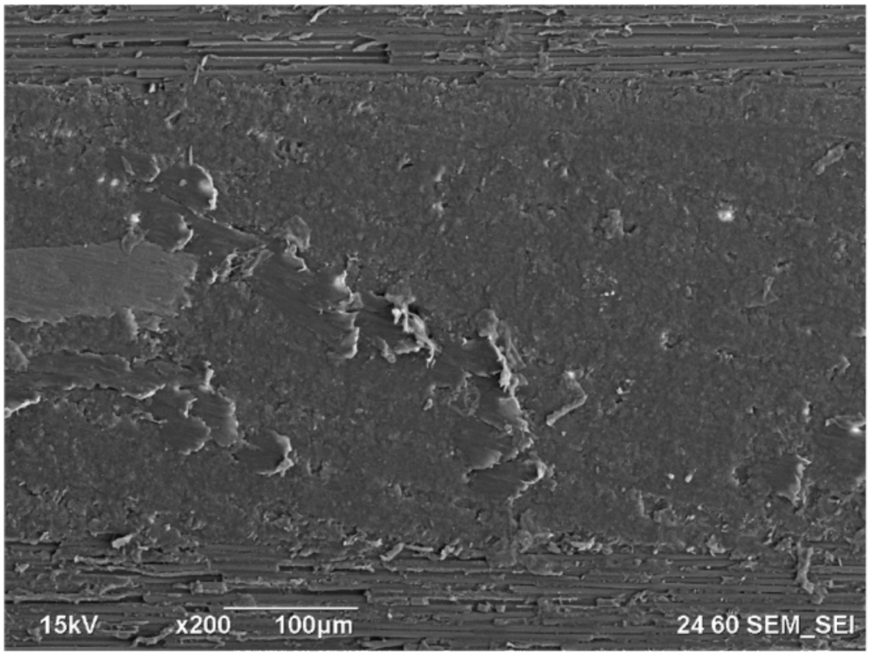




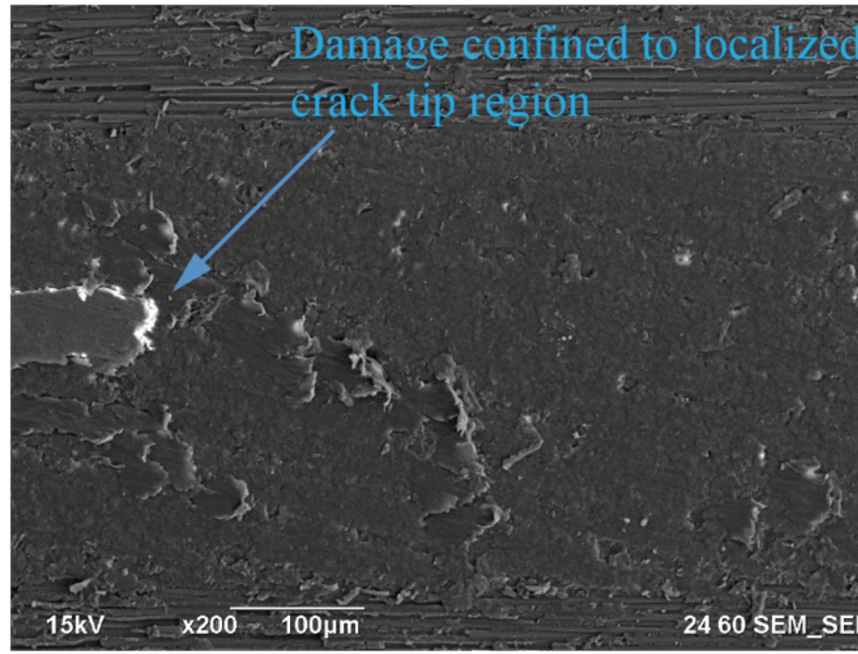


In-situ Micro-scale Evaluation End Notch Fracture (ENF)

Baseline

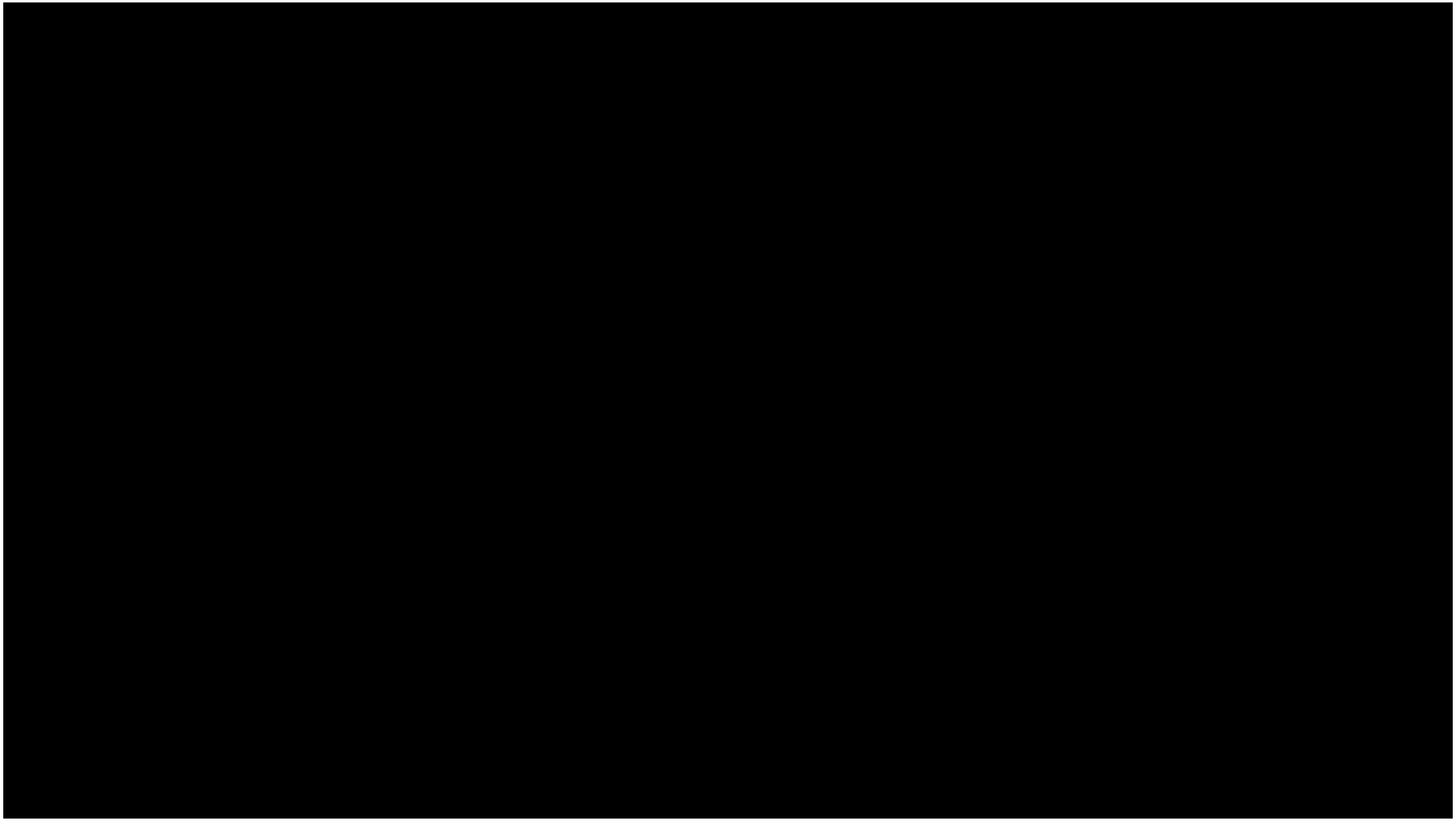


Prior to Loading

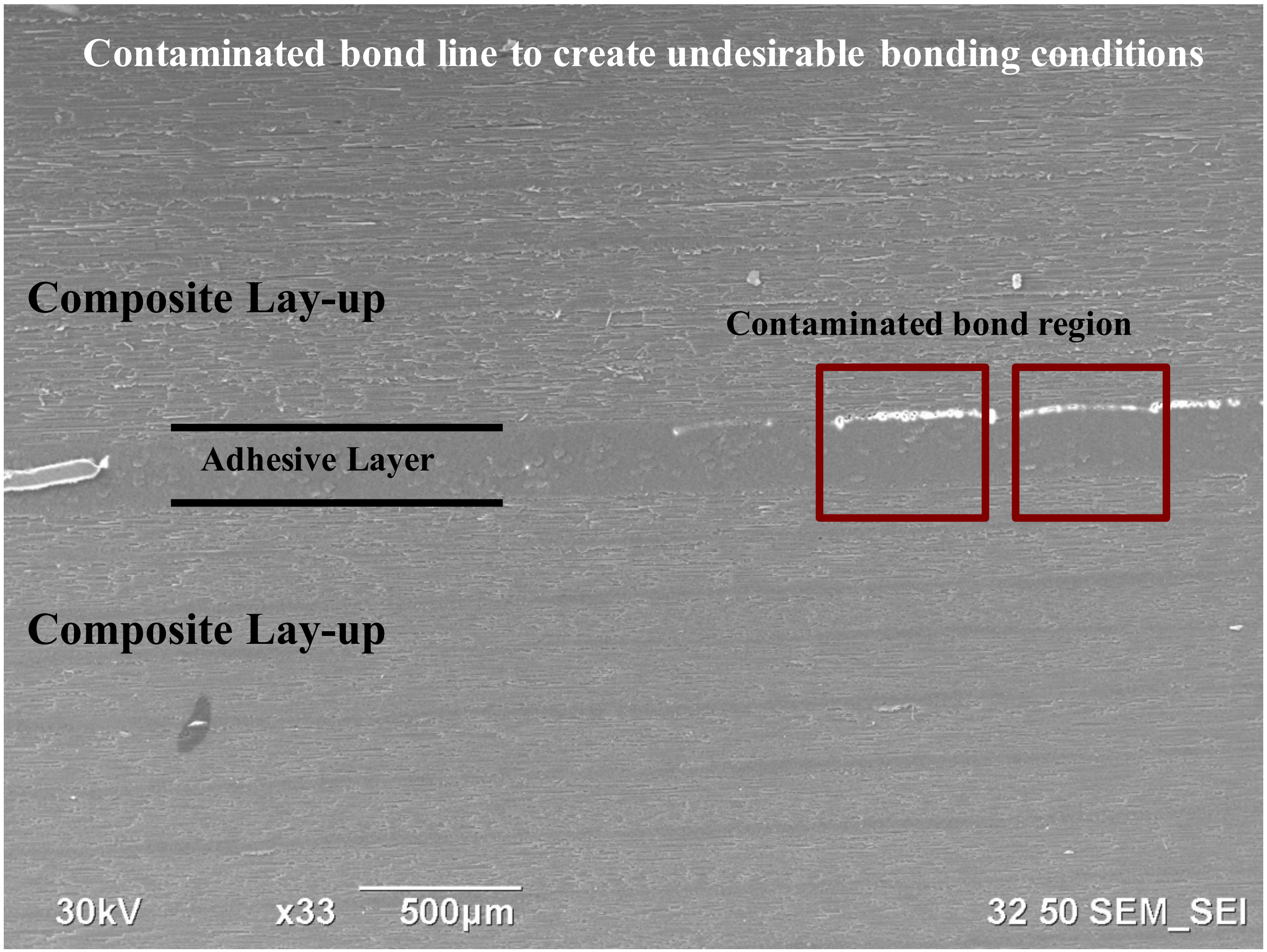


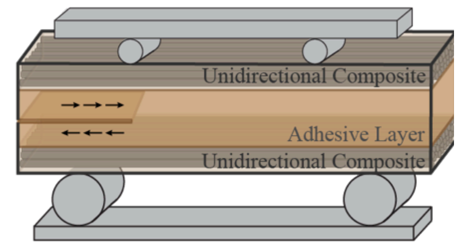
At Peak Load (1000N)

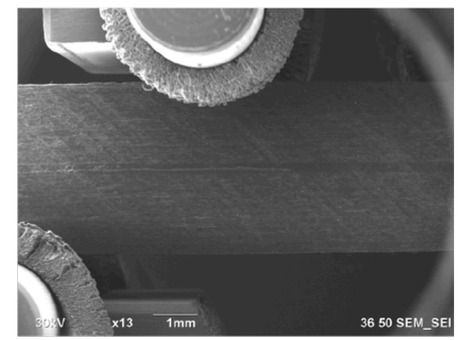
In-situ Micro-scale Evaluation End Notch Fracture (ENF)



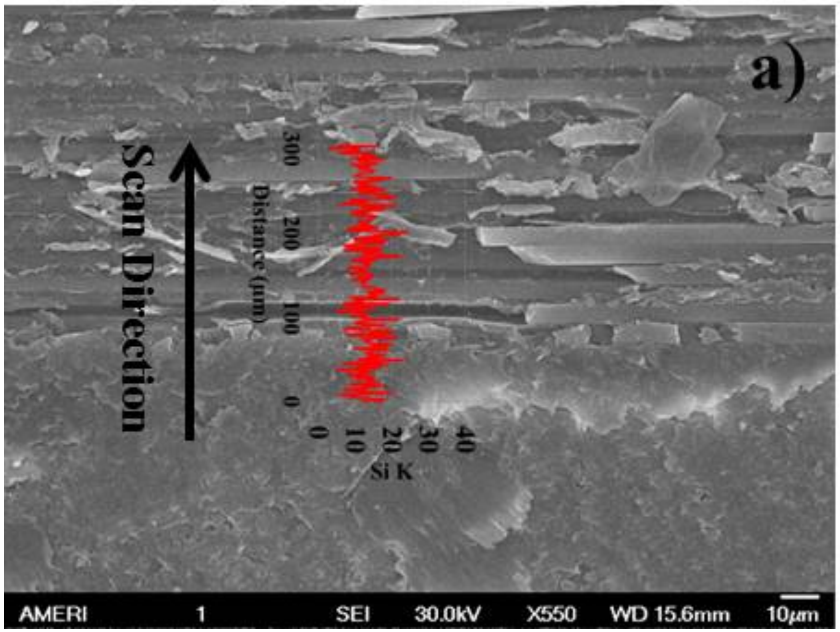
In-situ Micro-scale Evaluation End Notch Fracture (ENF)



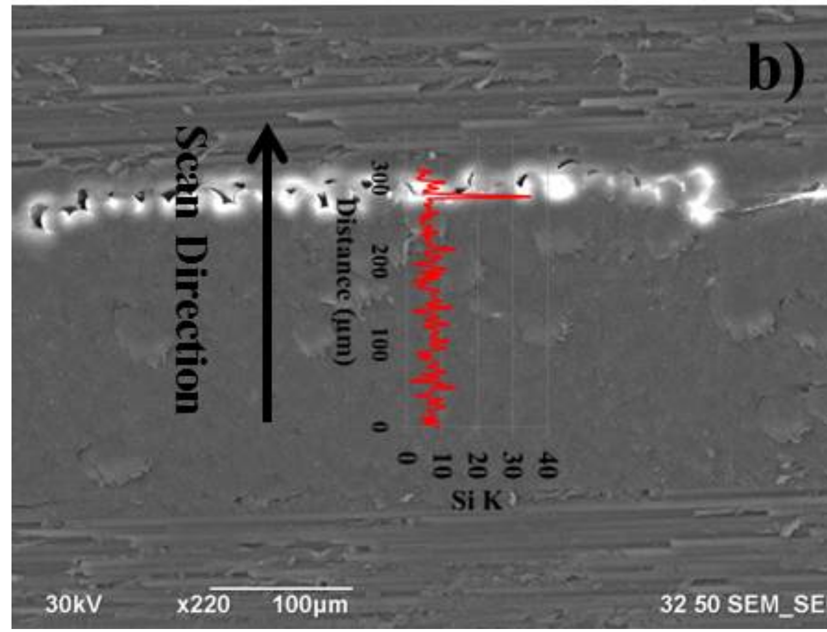




Verification and Validation

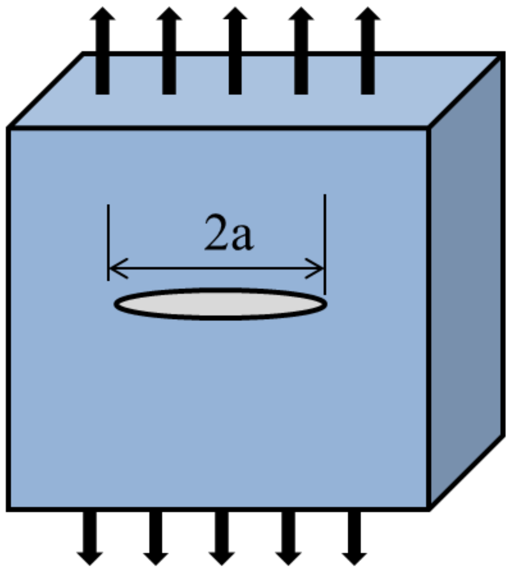


Non-Contaminated



Contaminated

Linear Elastic Fracture Mechanics to Model Effects of Contamination



Penny Shaped Crack embedded in a solid

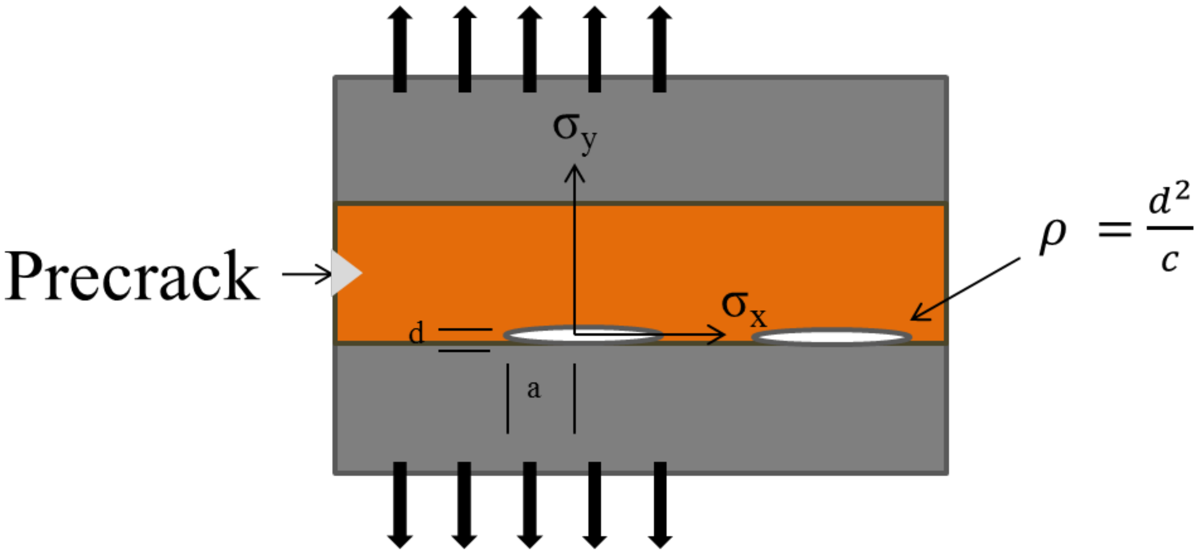
↓

Solid subjected to remotely applied stress

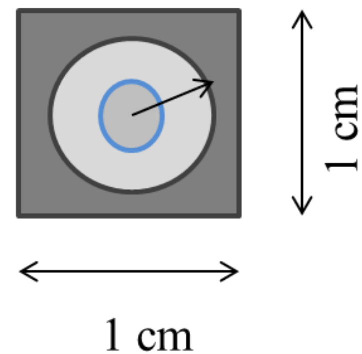
2a is the diameter of the penny shaped crack

Stress Intensity Factor at the crack plane, $K_C = \sigma_y\sqrt{\pi a}$

σ_y - Remotely applied stress



RVE Unit Cell

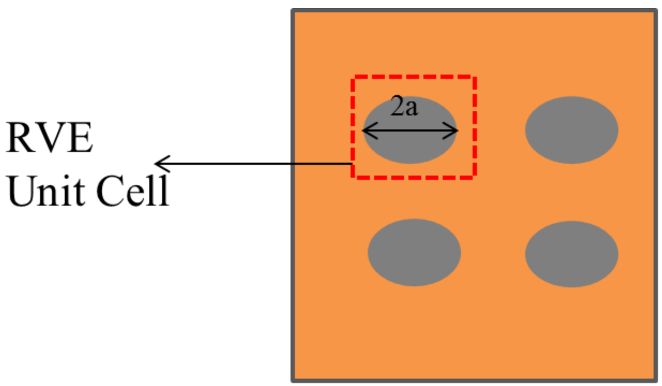


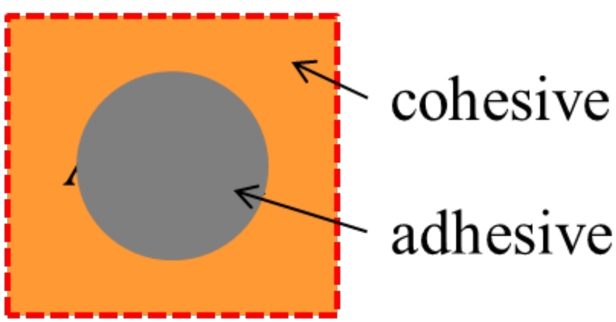
Penny shaped cracks = Contaminated sites.

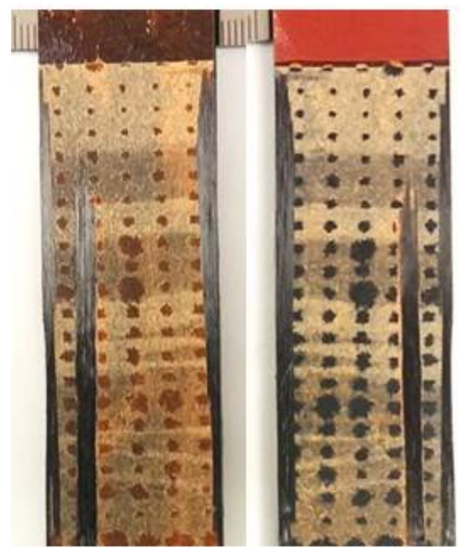
Modifications to the theory:

a) RVE Unit Cell considerations
b) Crack size as varied in a RVE Unit Cell

Approach







A1L-06

G_{1C} - 0.78 kJ/m^2
COH % - 68.38

A3-05

G_{1C} - 0.78 kJ/m^2
COH % - 71.07

A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

Stress Intensity factor K_c for RVE Unit Cell

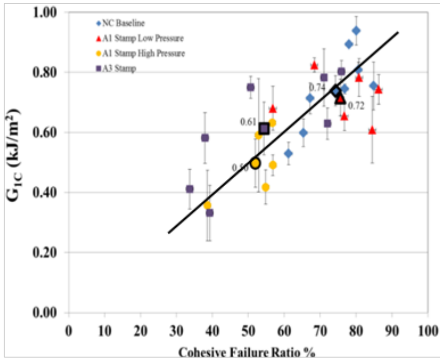
Relationship between Stress Intensity Factor, K_C and Fracture Toughness, G_C

$$K_C = \sqrt{E\,G_C}$$

$$G_C = \frac{{K_C}^2}{E}$$

$$G_C = \frac{(A_{cohesive} * \sigma_s\sqrt{\pi a})^2}{E}$$

Input Parameters



Typical Structural Adhesives possess

Young’s modulus between 3 GPa

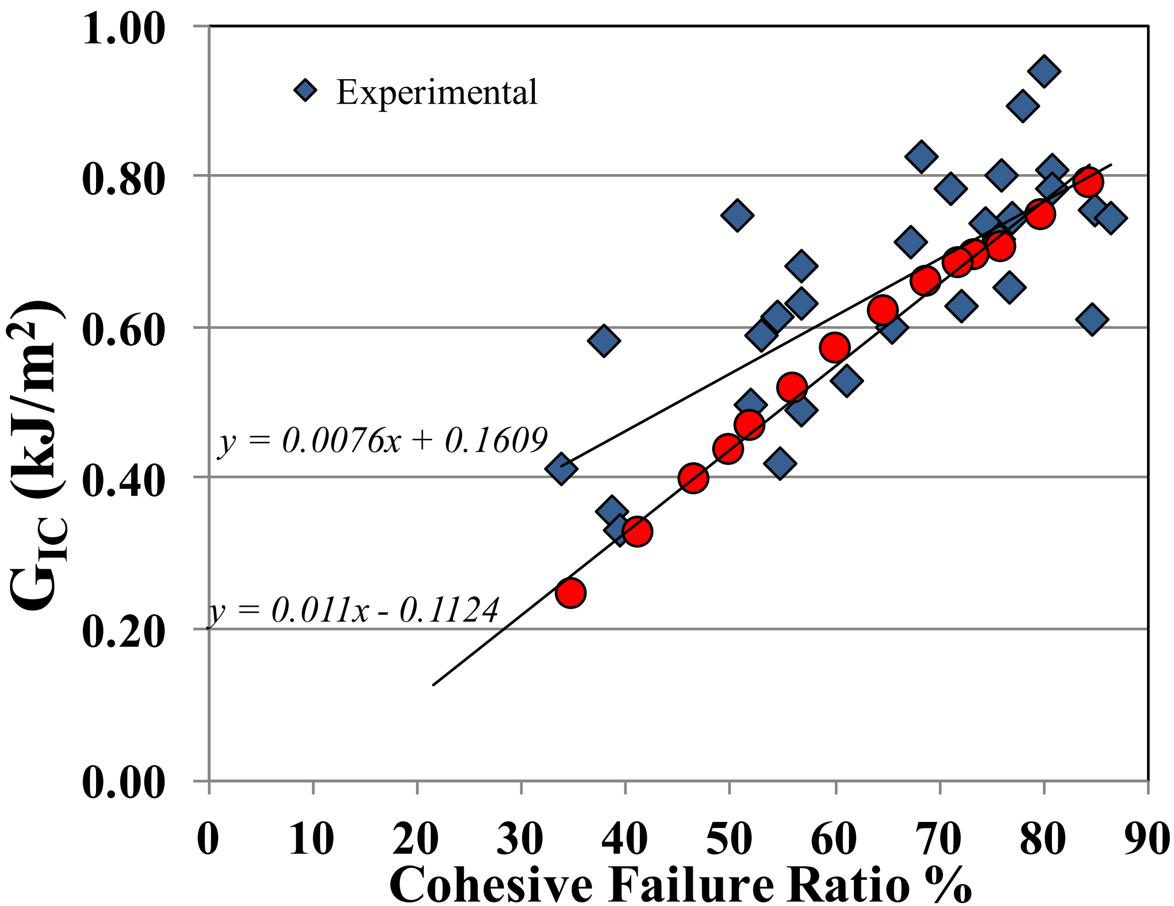
Tensile Strength between 4-6 Mpa

Varying Crack Flaw Size

Output Parameter

The relationship between critical energy release rate and cohesive area

Experimental vs Predicted



Tensile Strength – 4.6 MPa & Young Modulus, E= 3 GPa

Conclusions/Summary

- Durability assessment was conducted by conditioning of specimens using a 3-point bending fixture for mechanical fatiguing in air and in environmental chamber.
- Adhesion/Cohesion failure mode patterns were observed with the Freekote contamination.
- G_{IC} properties correlate well with cohesive area ratio
- Line Profile analysis and area analysis of the failure surface are used to quantify the areas of contamination.
- Micro-scale fracture testing revealed location of initial damage and damage propagation in contaminated specimen.
- LEFM was used to model the behavior of contaminated regions

A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

Composite Bond Integrity/Long-Term Durability of Composite Bonds

Future Work:

- In situ analysis of fatigued and environmentally exposed samples to examine fracture properties and damage initiation.
- Investigate additional contamination procedures to change surface chemistry and determine fracture properties of additional cases.
- Change contaminate application locations and dimensionality to investigate additional morphologies.

Benefit to Aviation:

- Better understanding of durability assessment for adhesively bonded composite joints.
- Assisting in the development of bonding quality assurance procedures.

Composite Bond Integrity/Long-Term Durability of Composite Bonds

Questions?