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Test Method Development for Environmental Durability of Composite Bonded Joints

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Advanced Materials in Transport Aircraft Structures

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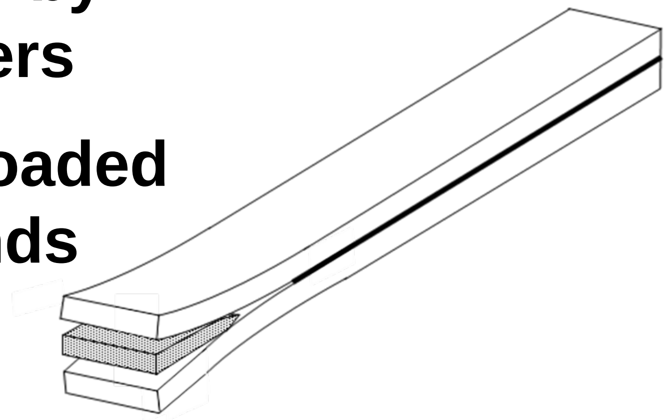
Outline

- Update on earlier work: Environmental durability testing of bonded metallic joints
- Current focus: Environmental durability test methods for composite bonded joints
  - Static wedge test
  - Traveling wedge test
  - Back-bonded Double Cantilever Beam (DCB) test
- Plans for upcoming research

Our Earlier Research Focus:
Improving ASTM D3762 Metal Wedge Test

ASTM D 3762: "Standard Test Method for Adhesive-Bonded Surface Durability of Aluminum (Wedge Test)"



- Able to asses quality of bond quickly by causing rapid hydration of oxide layers
- Bonded aluminum cantilever beam loaded by forcing a wedge between adherends
- Wedge is retained in specimen
- Assembly placed into test environment
- Crack growth due to environmental exposure measured following prescribed time period

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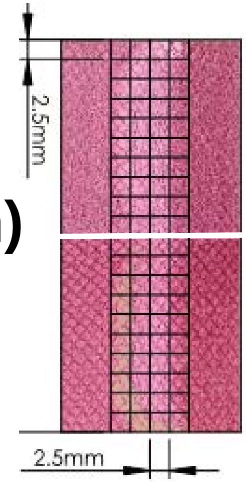
Progress and Status:
Improving ASTM D3762 Metal Wedge Test

- **Completed study, proposed improvements**
- **Communicated results with ASTM Committee D14 (Adhesives) at annual meeting (April 2015, Anaheim)**
- **Initiated ASTM work item to modify standard**
- **Completed revision of ASTM D3762 standard**
- **Revised standard under review by collaborators**
- **Initial balloting of revised ASTM D3762 in 2016**
- **Arranged for revisions of ASTM D14 standards of interest to aerospace community via ASTM D30 partnership**
  - **Formation of D14.80.xx Task Groups**
  - **Task Group meets concurrent with D30**
  - **Balloting through D14.80 subcommittee and D14 main**



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- **Current focus: Environmental durability test methods for composite bonded joints**
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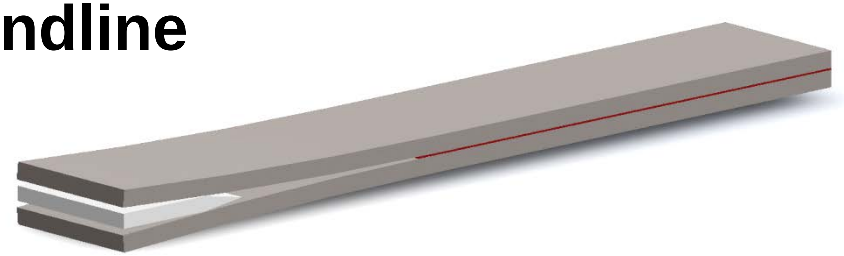
Why Environmental Durability Tests of Composite Bonded Joints?

"There is currently no known mechanism similar to metal-bond hydration for composites"

- **Ensure longer-term environmental durability of composite bonds**
- **Investigate effects of environmental exposure on performance of bonded composite joints**
  - **Failure mode: cohesion versus adhesion failure**
  - **Estimate fracture toughness reduction**
- **Evaluate effectiveness of surface preparation**

Development of a Composite Wedge Test: Additional Complexities

- **Variable flexural stiffness of composite adherends**
- **Environmental crack growth dependent on adherend flexural stiffness**
  - **Flexural stiffness must be within an acceptable range**
    or…
  - **Must tailor wedge thickness for composite adherends**
    or…
  - **Must use another quantity to assess durability**
- **Restrictions in fiber orientation adjacent to bonded interface**
- **Failure in the composite laminate prior to failure in the adhesive or at the bondline**

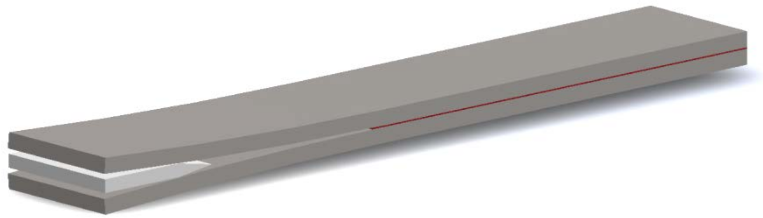


Use of Fracture Toughness, G_c To Assess Environmental Durability

Consider composite adherends as cantilever beams

- Measured values of crack length, a
- Known value of beam deflection, δ

  $\delta = t/2$ (half of wedge thickness)



Tip deflection of a cantilever beam: $\delta = \frac{t}{2} = \frac{P\, l^3}{3\, E_f\, I} = \frac{T\, a^3}{3\, E_f\, I}$

$$T = \frac{E_f\, b\, h^3\, t}{8\, a^3}$$

Strain energy due to bending: $U = \frac{1}{2} T\, \delta$

Strain energy release rate: $G_c = \frac{dU}{da}$

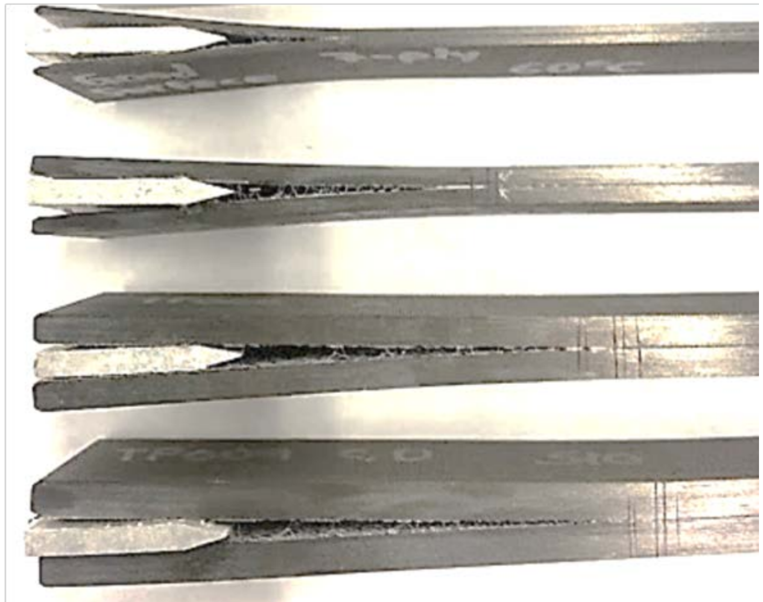
$$G_c = \frac{3\, E_f\, t^2\, h^3}{16\, a^4} \left[\frac{1}{(1+0.64\, \frac{h}{a})^4} \right]$$

Correction factor for crack tip rotation

a = crack length
t = wedge thickness
h = adherend thickness
b = specimen width
T = load to deflect tip of beam
E_f = flexural modulus
G_c = fracture toughness

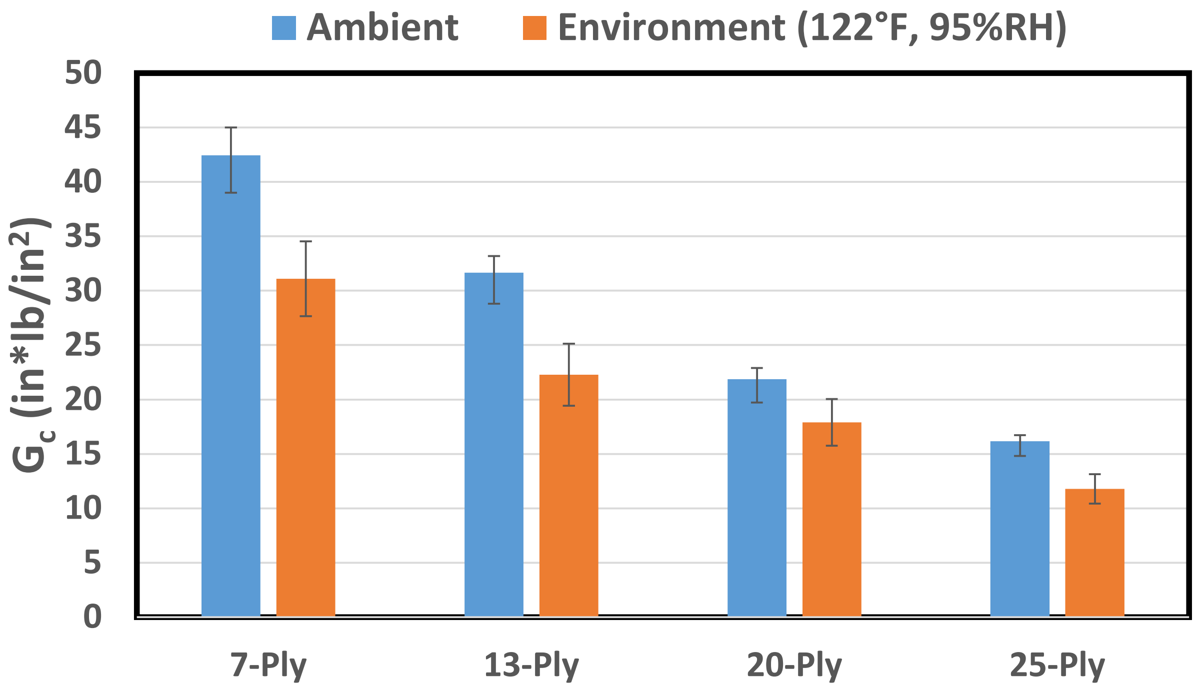
Experimental Investigation:
Composite Wedge Test Development

- **Unidirectional IM7/8552 carbon/epoxy adherends**
- **AF163-2K film adhesive**
- **"Ideal Bond": Grit-blast & acetone wipe bond surfaces**
- **Four adherend thicknesses to produce different E_f**
  - **7 ply (~0.05 in.):**
    Minimize crack length
  - **13 ply (~0.09 in.):**
    Match EI of aluminum
  - **20 ply (~0.14 in.):**
    Match thickness of aluminum
  - **25 ply (~0.18 in.):**
    Maximize crack growth



- **122°F (50°C) and 95% humidity environment**

Effects of Composite Adherend Thickness: Fracture Toughness Values



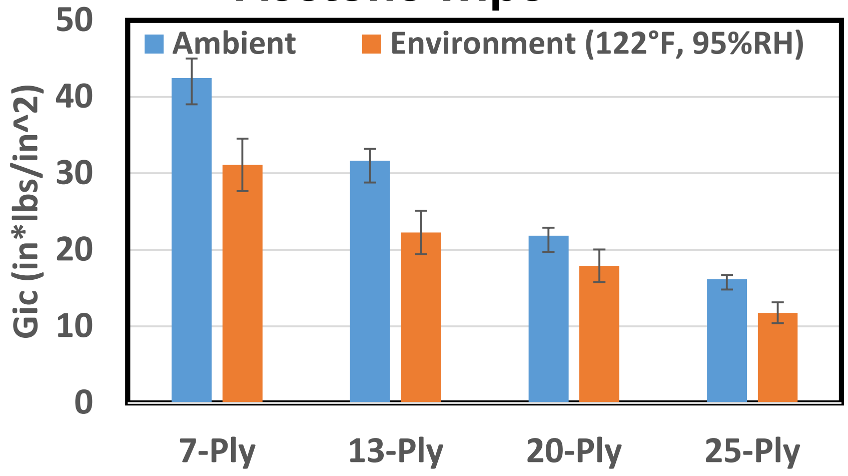
- **20 ply (0.14”) adherend thickness preferred**
  - **E*I value ~3.6 times that of 1/8” aluminum**
  - **Greater environmental crack growth**

- **Further sensitivity study on adherend thickness underway**

Composite Wedge Test Development:
Initial Assessment of Bond Durability

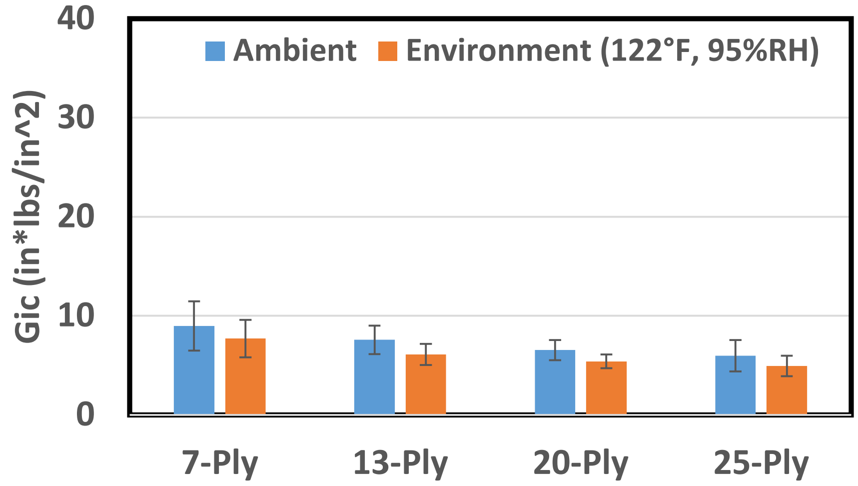
Baseline ("Ideal" Bond)

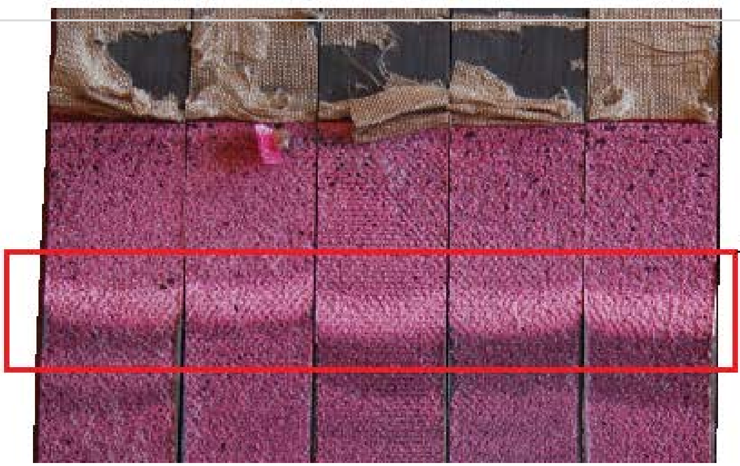
- Use of PTFE peel ply
- Grit blasting
- Acetone wipe



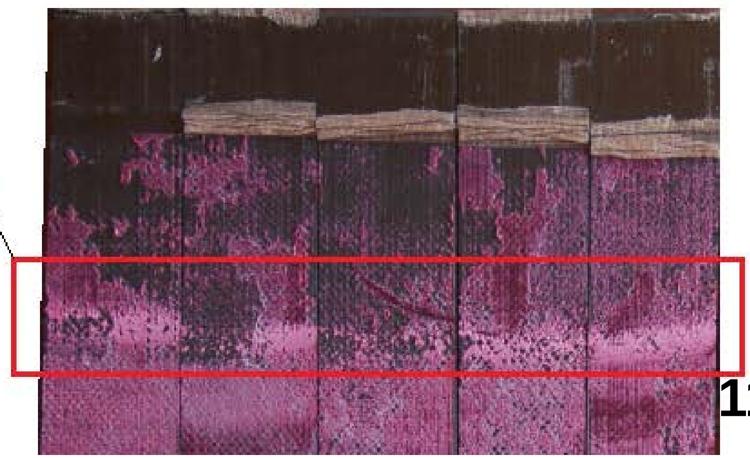
"Non-Ideal" Bond

- Use of Nylon peel ply
- Acetone wipe



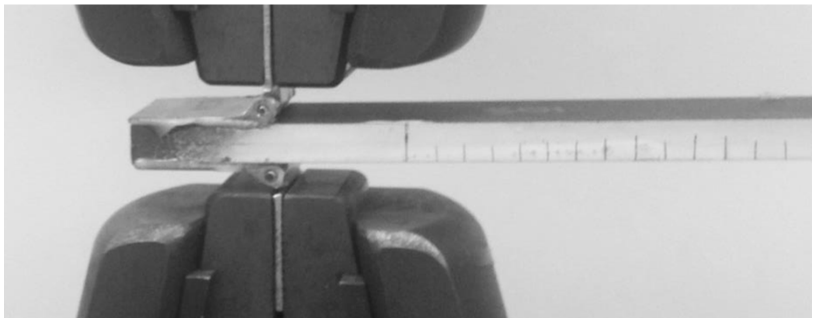


Tested Area



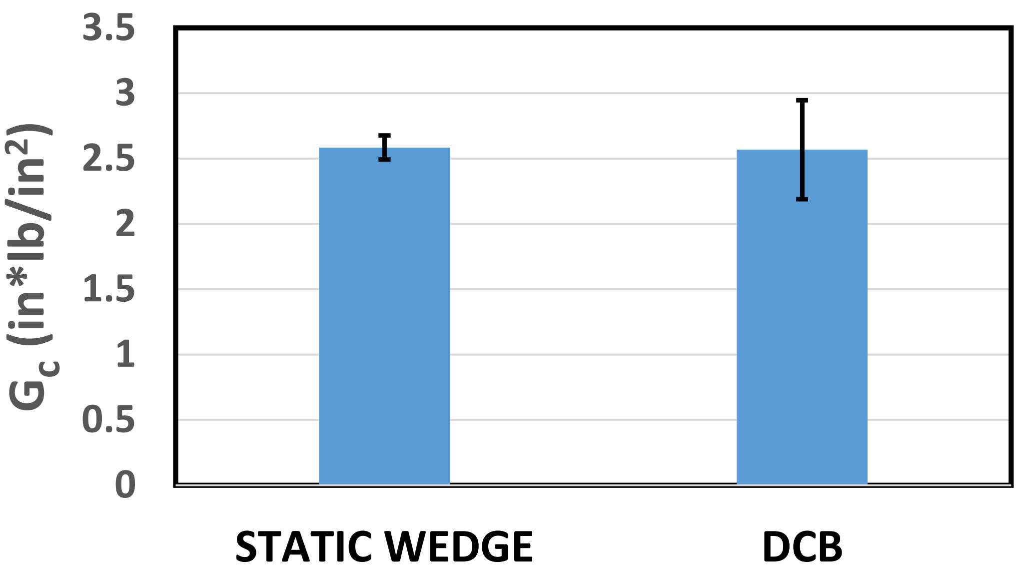
Composite Wedge Test Development:
Comparison With DCB Test (No Adhesive)

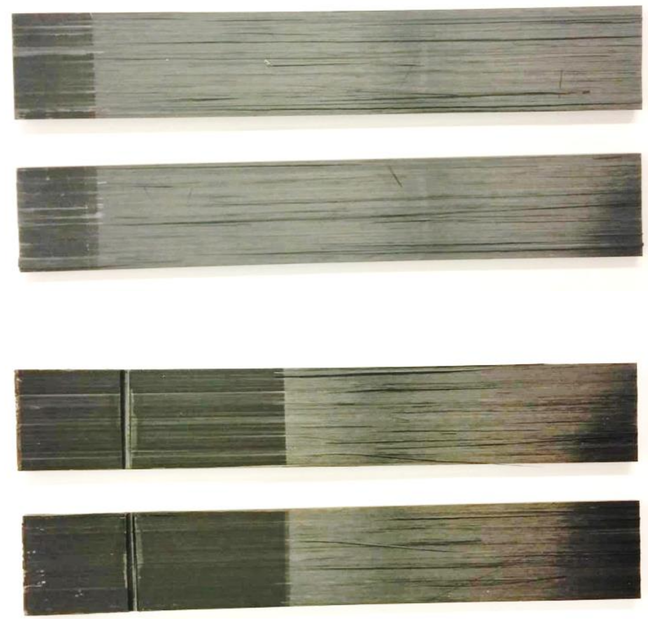
- **IM7/8552 unidirectional laminates, 20 ply specimens**
- **Room temperature/ambient testing**
- **Comparison of G_c values**
  - **Wedge test: Gc calculated based on crack length**
  - **DCB: Gc calculated following ASTM D552**



Comparison With DCB Test (No Adhesive): Test Results for IM7/8552

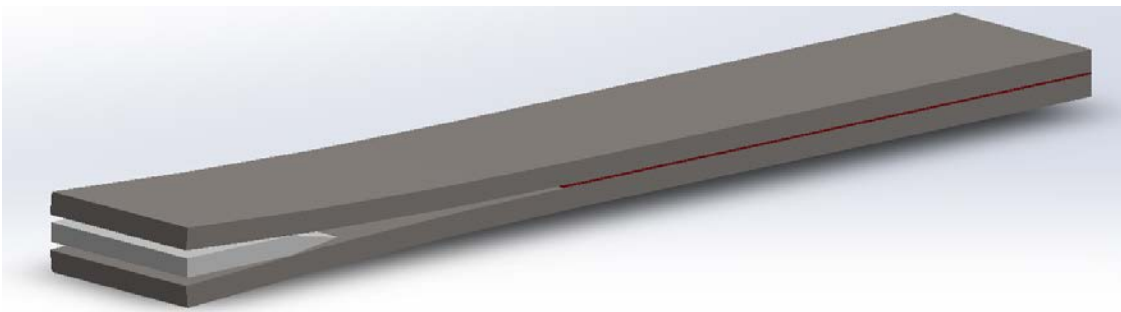
- **Good agreement with measured Gc values**
  - **DCB: Gc calculated following ASTM D552**
  - **Wedge test: Gc calculated based on crack length**
- **Similar appearance on fracture surfaces**





Composite Wedge Test Development:
Current Focus

- Investigate sensitivity of apparent G_c to variations in flexural modulus
  - Moderate thickness variations of IM7/8552 adherends
  - Use of other composite materials for adherends
- Investigate other adhesives
  - 3M AF-555M Film Adhesives
- Comparisons with other proposed test methods



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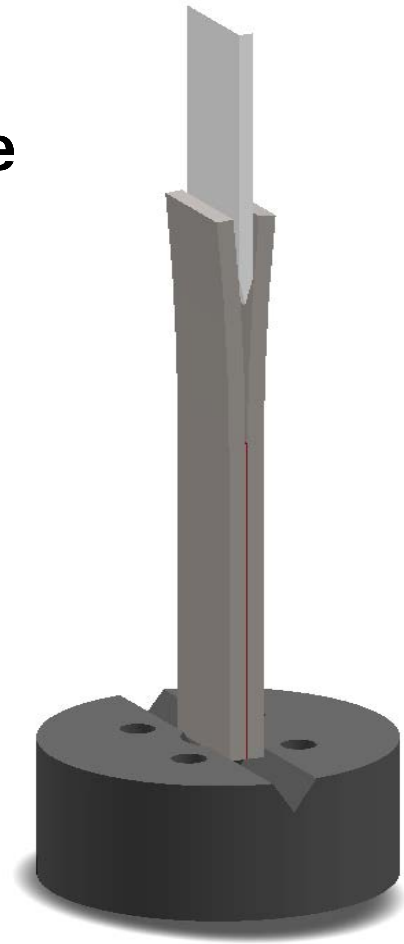
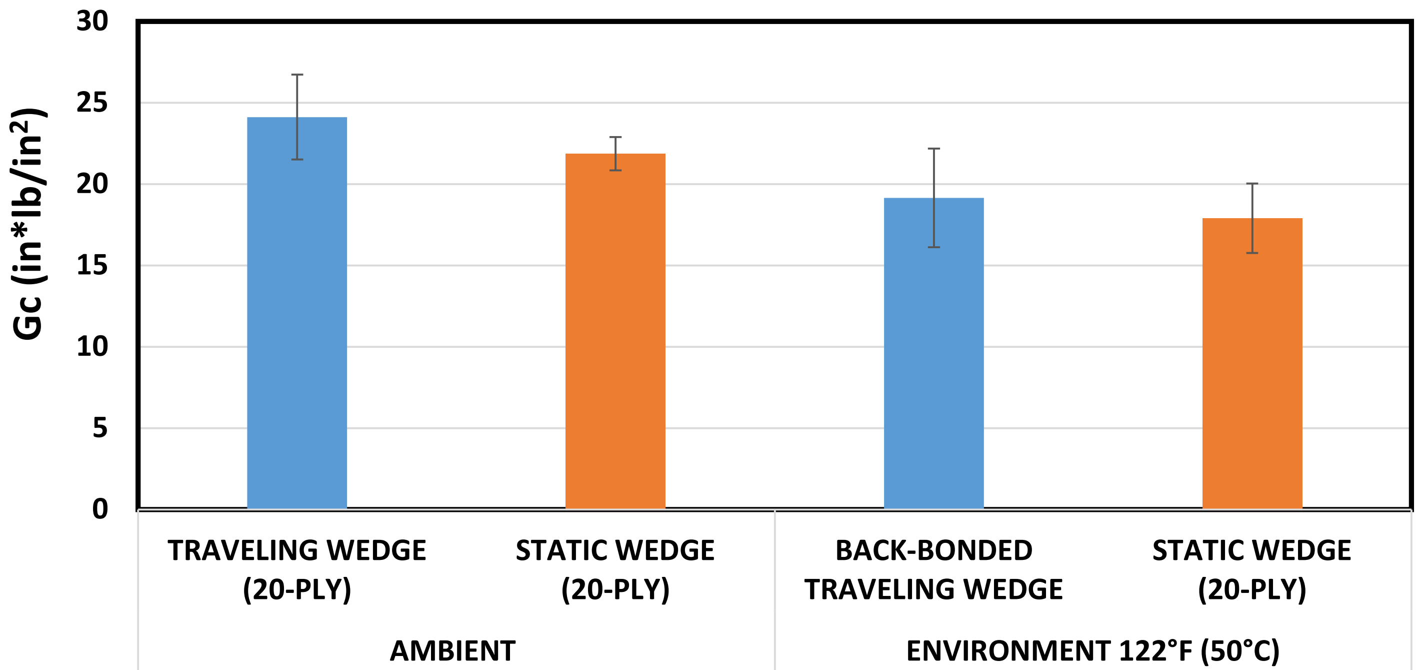
Traveling Wedge Test for Environmental Durability Assessment

- Longer version of static wedge specimen, potential to assess relatively large bond area
- Wedge driven continuously through adhesive bondline at desired temperature
- Requires moisture saturation of bonded composite specimen prior to testing
  - Use of thin adherends
  - “Back-bonding following conditioning
- Can provide an estimate of G_c with crack length measurements (as for conventional wedge test)
- Limited prior usage/investigation for environmental durability assessment



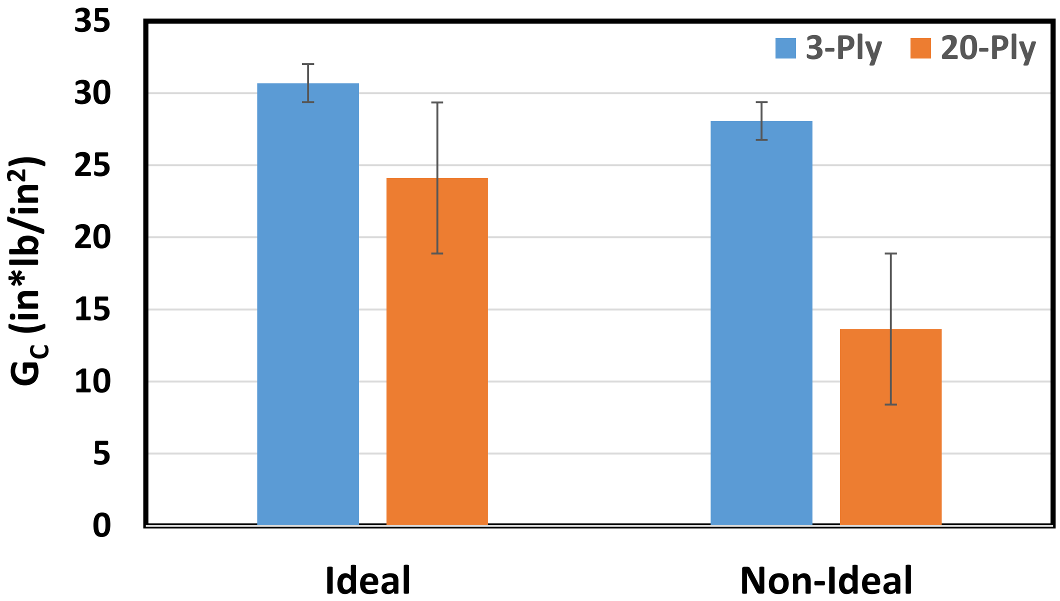
Traveling Wedge Test Development:
Initial Comparison with Static Wedge Test

- **20 ply IM7/8552 adherends, AF163-2K film adhesive, “ideal” bonding condition**
- **Ambient & 122°F (50°C)/95% humidity moisture conditioning/testing environment**
- **General agreement in G_c values based on crack lengths**



Traveling Wedge Test Development: Effect of Adherend Thickness

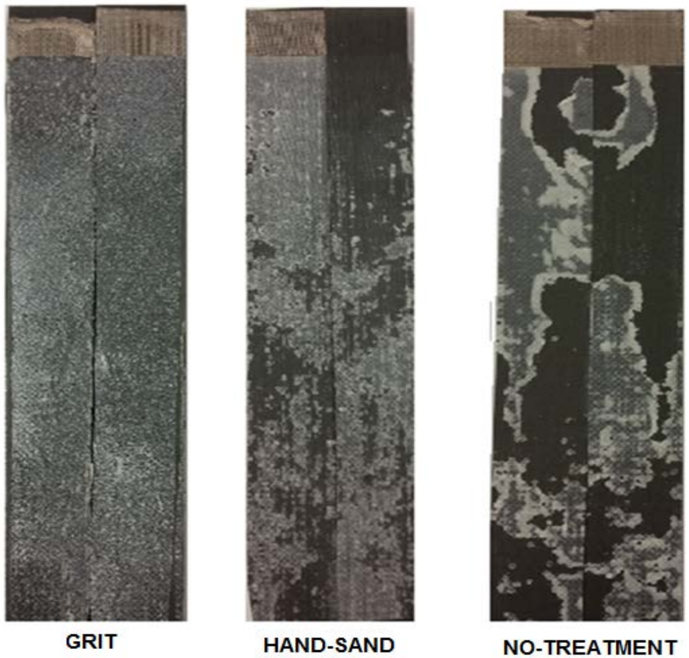
- **“Ideal” and “Non-ideal” bond conditions**
- **Tested at room temperature/ambient conditions**

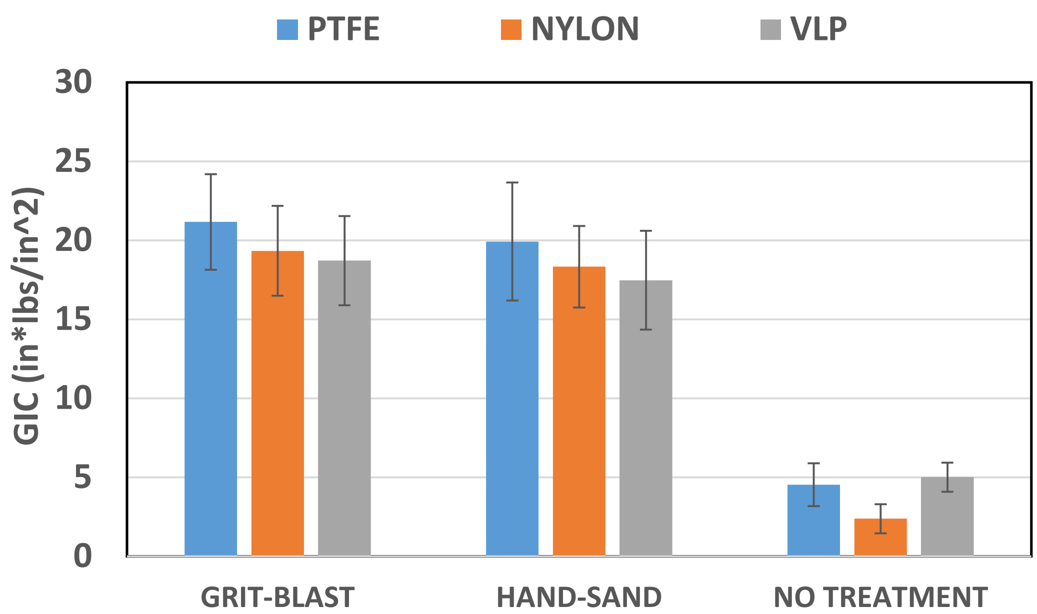


Significant differences in G_c values based on different adherend thicknesses

Traveling Wedge Test Results: Back-Bonded Thin Adherends

- **Bonding of thin adherends (3 ply)**
- **Moisture saturated followed by low-temperature, quick cure bond of composite doublers**





Tested at elevated temperatures 122°F (50°C)

Traveling Wedge Test Assessment: Current Status

- **Further evaluation of adherend thickness effects**
  - **Interest is use of thin adherends for moisture conditioning**
- **Development of modified traveling wedge fixturing**
  - **Reduce friction/binding**
  - **Permit use of thin adherends**
- **Comparison of G_c estimates with static wedge, and back-bonded DCB tests**

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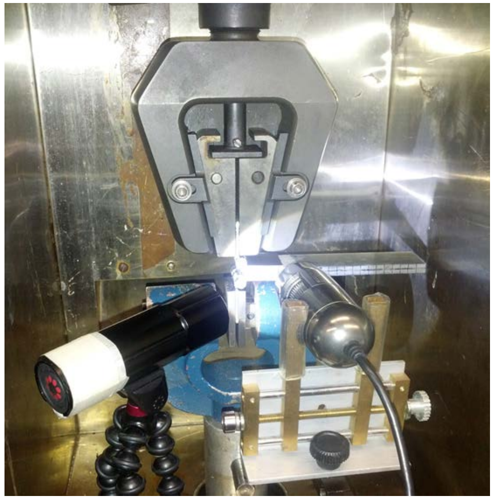
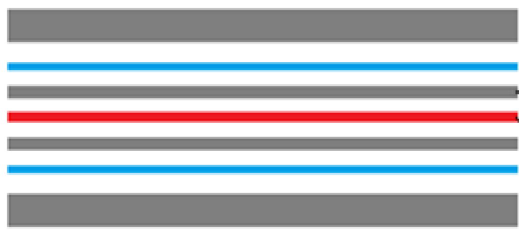
Environmental Durability Testing:
Boeing Back-Bonded DCB Test

- **Bond thin adherends with desired surface preparation and adhesive**
- **Moisture saturate thin bonded composite specimen**
- **Bond doubler panels to thin specimens to produce full DCB specimen thickness**
- **Test at elevated temperature conditions**

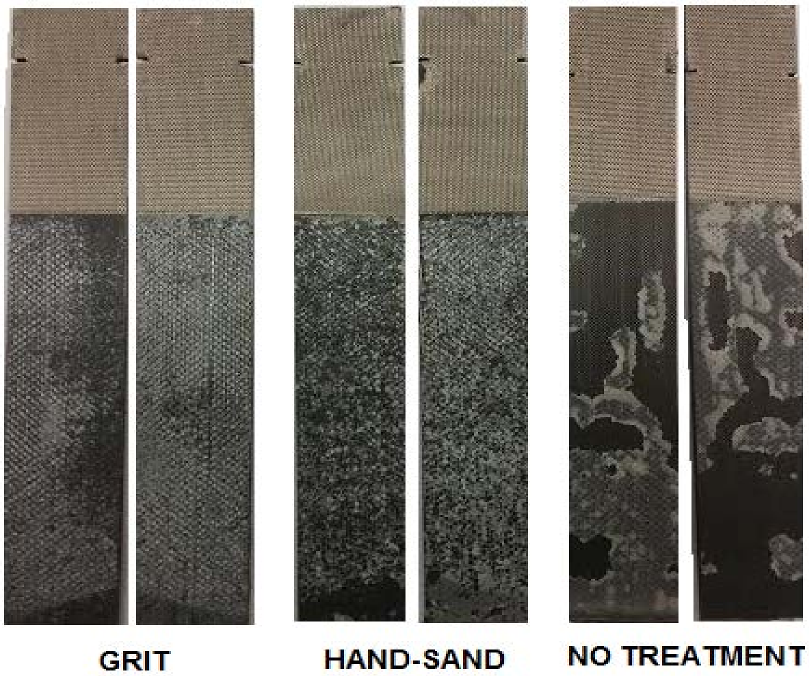


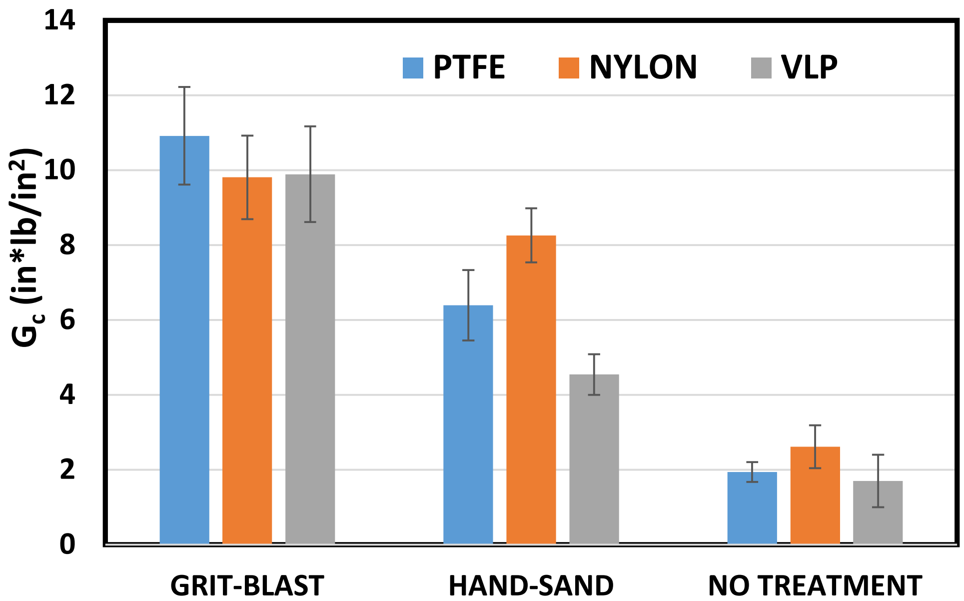


Van Voast, Blohowiak, Osborne and Belcher,
“Rapid Test Methods for Adhesives and Adhesion” (SAMPE 2013)

Back-Bonded DCB Test Results: Fracture Toughness Values

- Three types of peel ply: PTFE, Nylon, and VLP
- Three surface preps: Grit blast, hand sand, no treatment.
- Moisture saturated (3 ply adherends), tested at 122°F (50°C)





Environmental Durability Testing of Composites: Plans for Upcoming Research

- Continue development of composite wedge test
  - Variations in flexural modulus
  - Investigate other composite adherends & adhesives
  - Comparisons with other proposed test methods

- Further development of traveling wedge test fixturing for use with thin adherends

- Explore related usages of composite wedge test
  - Thermal cycling
  - Fluid sensitivity