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Development of Environmental Durability Test Methods for Composite Bonded Joints

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Heather McCartin, and David Ricsi

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FAA Sponsored Project Information

- Principal Investigators:

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  Dr. Larry DeVries

Graduate Student Researchers:

  Heather McCartin

  David Ricsi

- FAA Technical Monitor:

  Curt Davies

- Collaborators:

  Boeing: Kay Blohowiak, Will Grace, Charles Park

  Air Force Research Laboratory: Jim Mazza

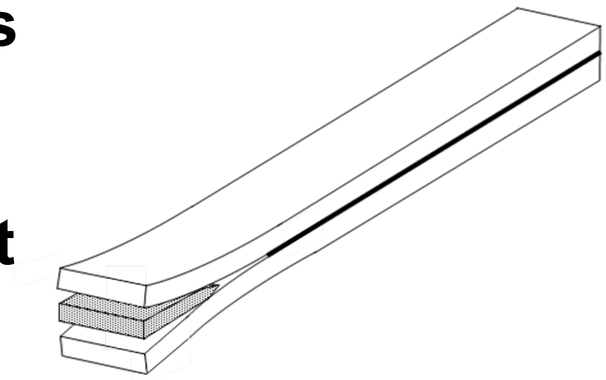
Outline

- 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)"

- 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
- Able to asses quality of bond quickly by causing rapid hydration of oxide layers



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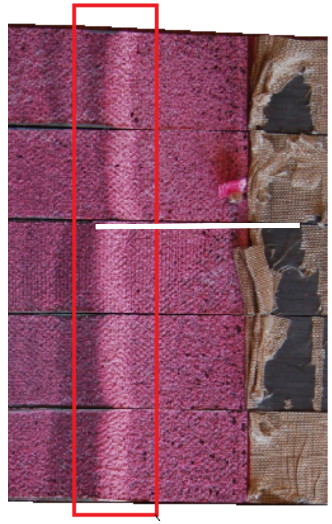
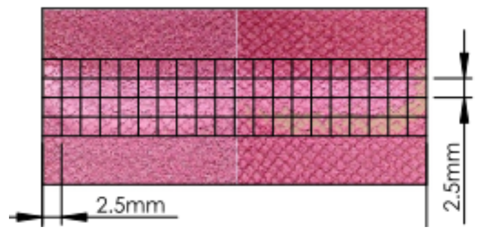
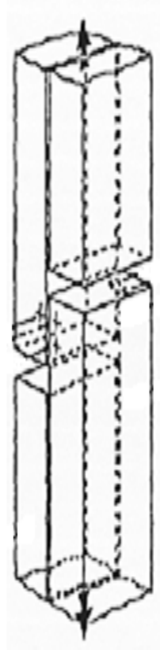
Progress and Status:
Improving ASTM D3762 Metal Wedge Test

- Completed study, proposed improvements
- Communicated results with ASTM Committee D14 (Adhesives) at annual meetings
- Completed revision of ASTM D3762 standard
  - Added detail, corrected errors
  - Added focus on failure mode during environmental crack growth (Cohesion, Mixed Mode, Adhesion)
- Proposed revisions reviewed by Boeing and AFRL collaborators
- Updated revision to be sent out to identified user group
- ASTM balloting of revised standard later in 2016

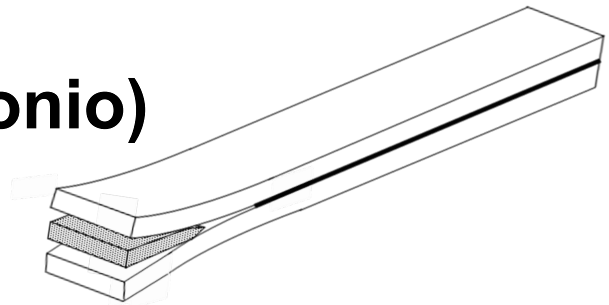




Progress and Status:
Development of D14.80 Composites Task Group



- Meets with ASTM D30 (Composites)
- Balloting remains through D14 (Adhesives)
- Updates/revisions to existing adhesive bonding standards of interest to the Composites community
    - ASTM D5656 Thick-Adherend Lap Shear Test
- Development of new standardized tests
    - Composite Wedge Test
- First meeting: April 2016 (San Antonio)



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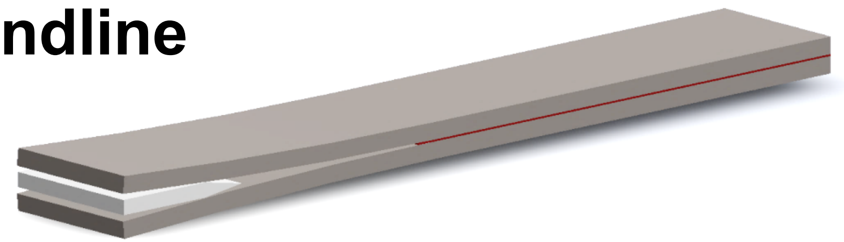
Why Environmental Durability Tests of Composite Bonded Joints?

"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**

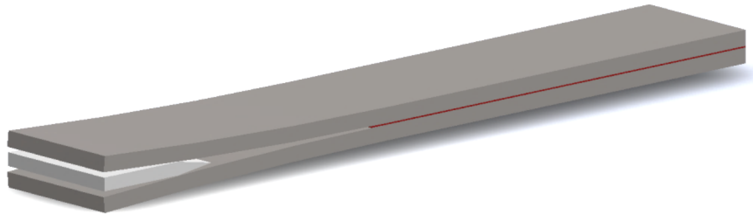


Use of Fracture Toughness, G_c To Assess Environmental Durability

Consider composite adherends as cantilever beams

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

  δ = t/2 (half of wedge thickness)



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

$$T = E_f b h^3 t / 8 a^3$$

Strain energy due to bending: $U = 1/2\, T \delta$

Strain energy release rate: $G_c = dU/da$

$$G_c = 3 E_f t^2 h^3 / 16 a^4$$

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

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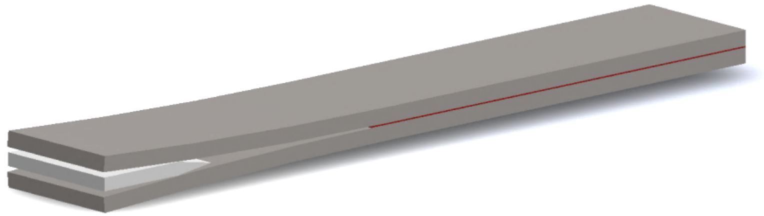

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Strain energy due to bending: $$U = 1/2\, T \delta$$

Strain energy release rate: $$G_c = dU/da$$

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

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
- Different 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

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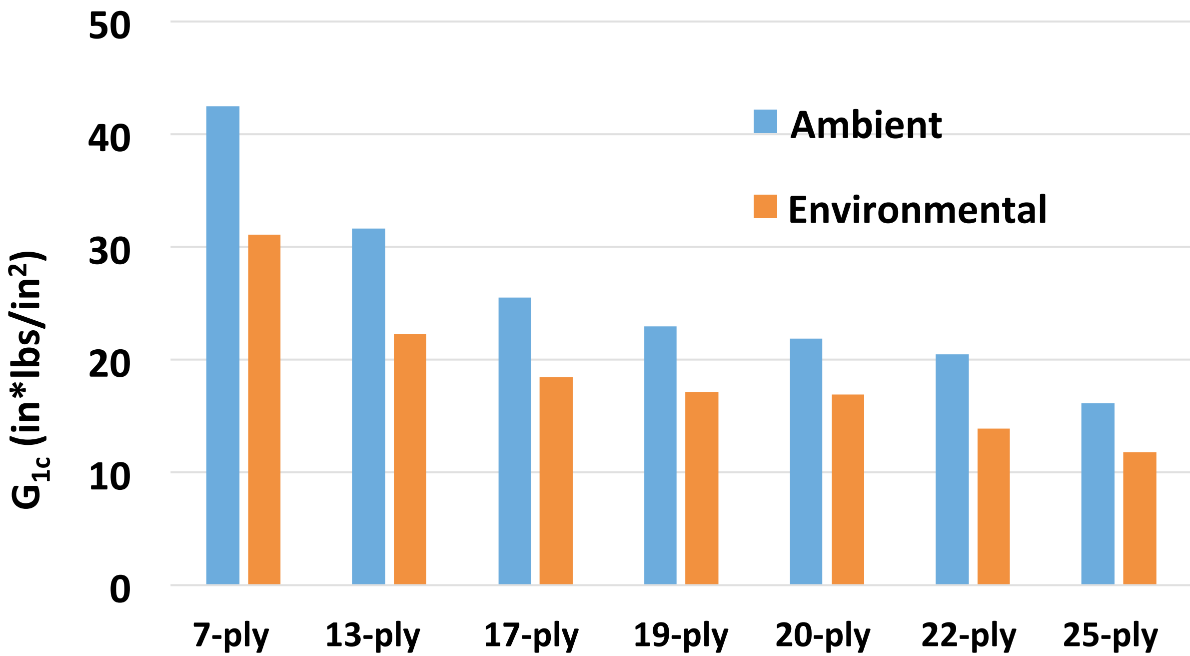
Effects of Composite Adherend Thickness: Fracture Toughness Values



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

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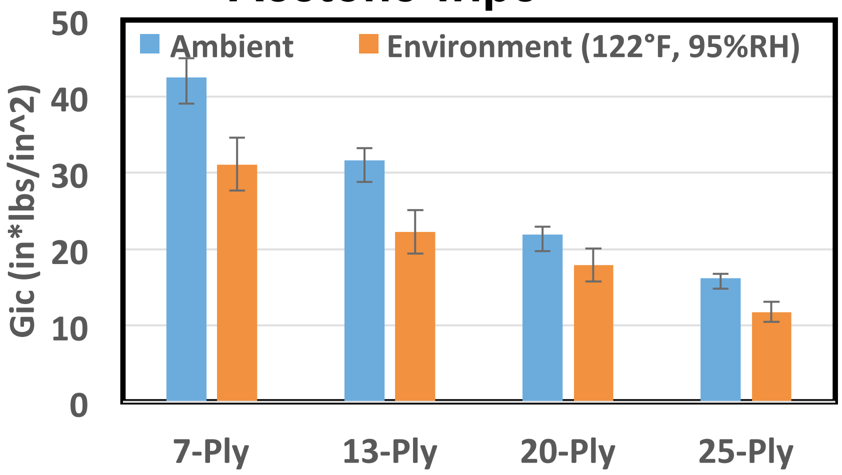
Composite Wedge Test Development:
Assessment of Surface Preparation Effects

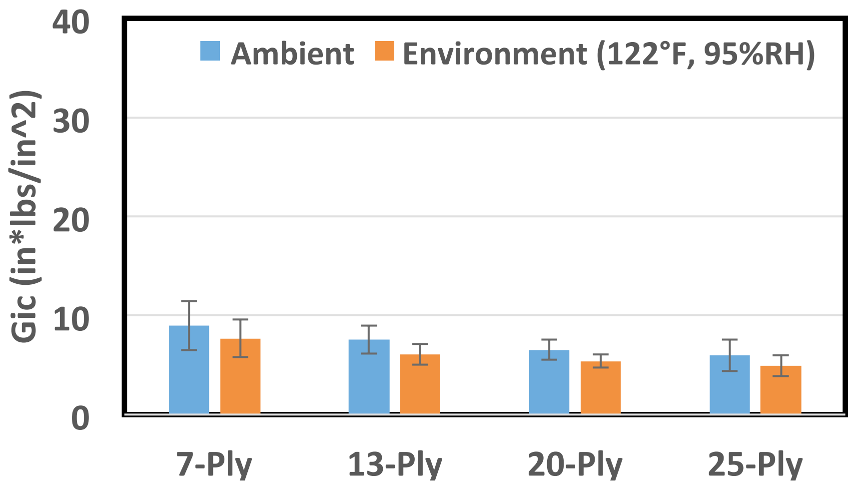
Baseline (“Ideal” Bond)

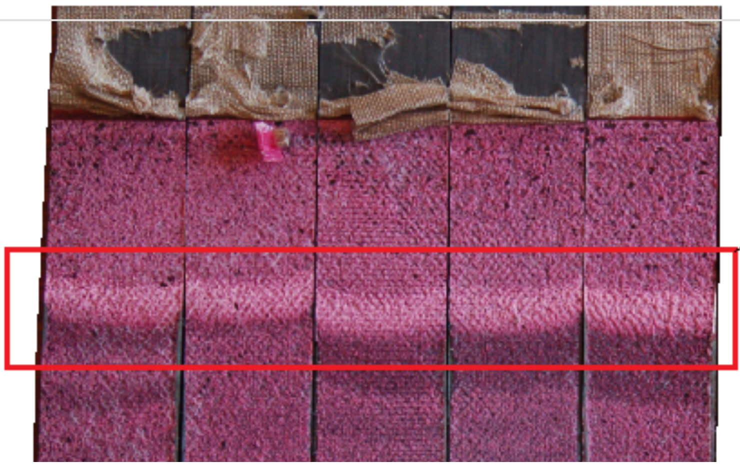
- Use of PTFE peel ply
- Grit blasting
- Acetone wipe



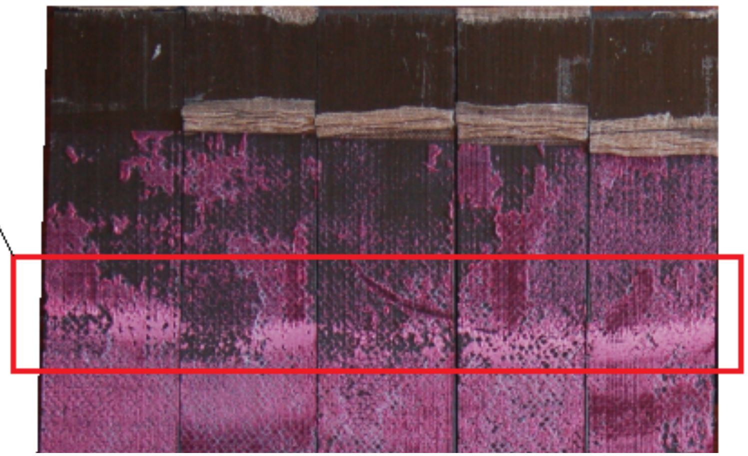
“Non-Ideal” Bond

- Use of Nylon peel ply
- Acetone wipe



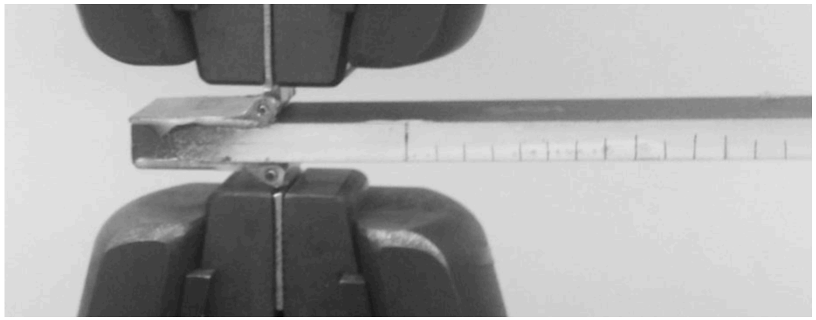


Tested Area



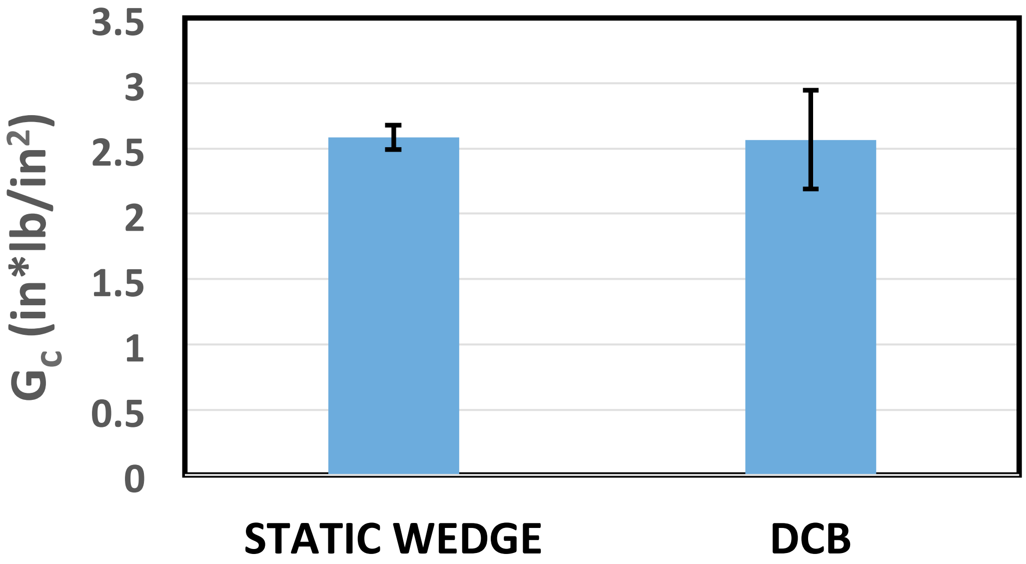
Composite Wedge Test Development:
Comparison With DCB Test (No Adhesive)

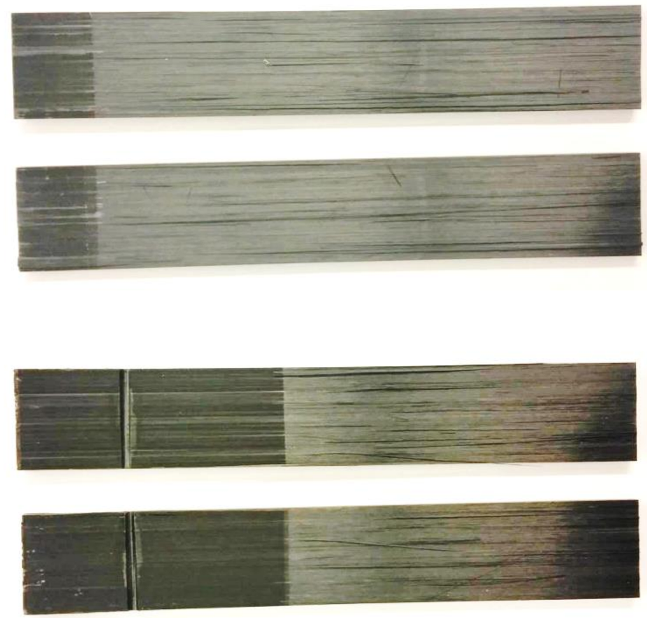
- IM7/8552 unidirectional laminates, 20 ply specimens
- Room temperature/ambient testing
- Comparison of G_c values
  - Wedge test: Gc calculated based on crack length
  - DCB: Gc calculated following ASTM D552



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

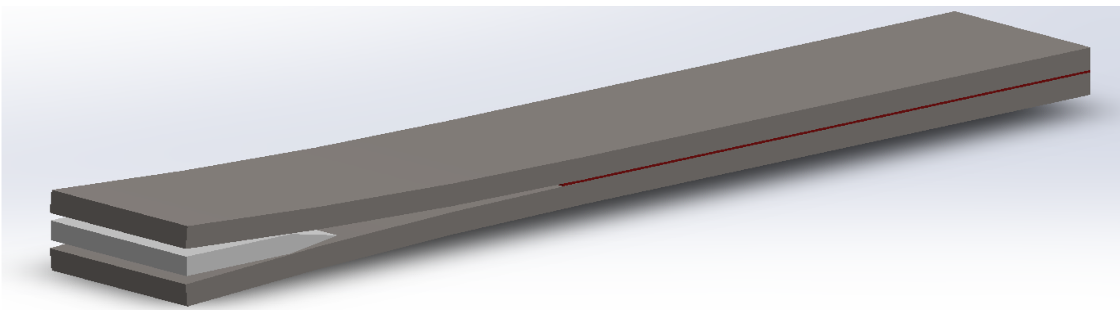
- **Good agreement with measured Gc values**
  - DCB: Gc calculated following ASTM D552
  - Wedge test: Gc calculated based on crack length
- **Similar appearance on fracture surfaces**





Composite Wedge Test Development: Current Focus

- Further 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 composite laminates for adherends
  - Quasi-isotropic, cross-ply
- Further comparisons with other proposed test methods



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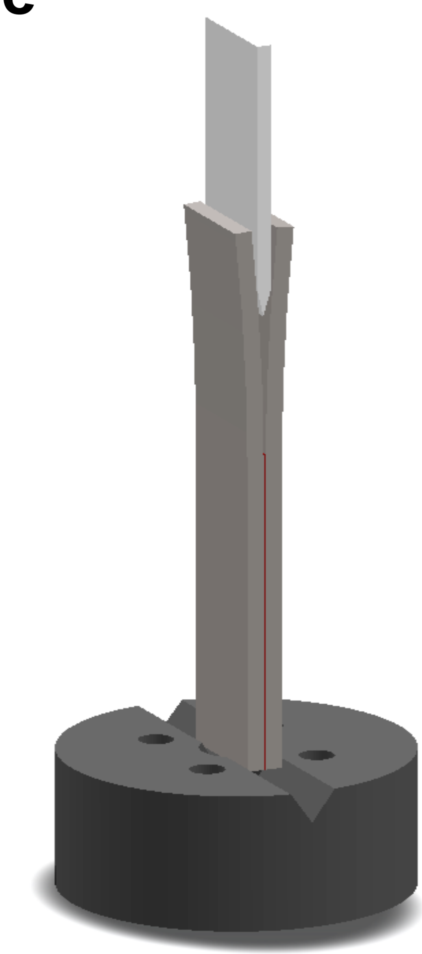
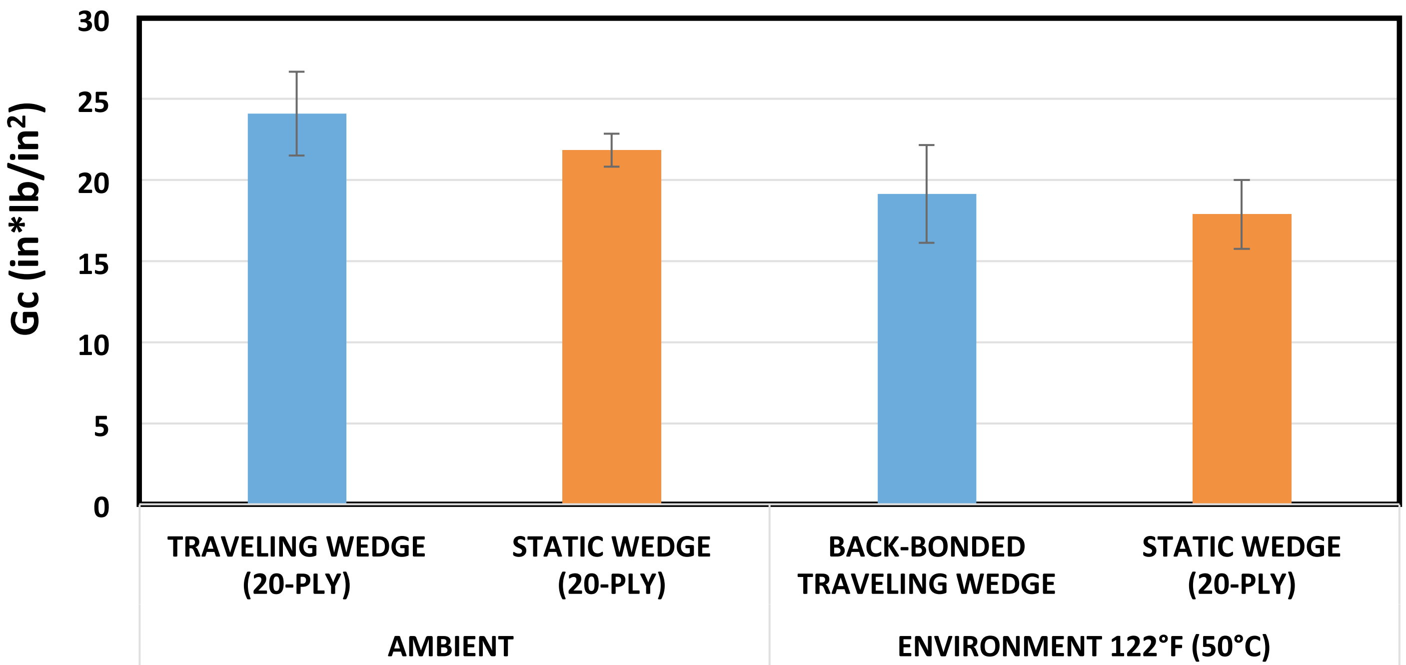
Traveling Wedge Test for Environmental Durability Assessment

- Wedge driven continuously through adhesive bondline at desired temperature
- Measurement of driving force
- 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 using crack length measurements
- Limited prior usage/investigation for environmental durability assessment



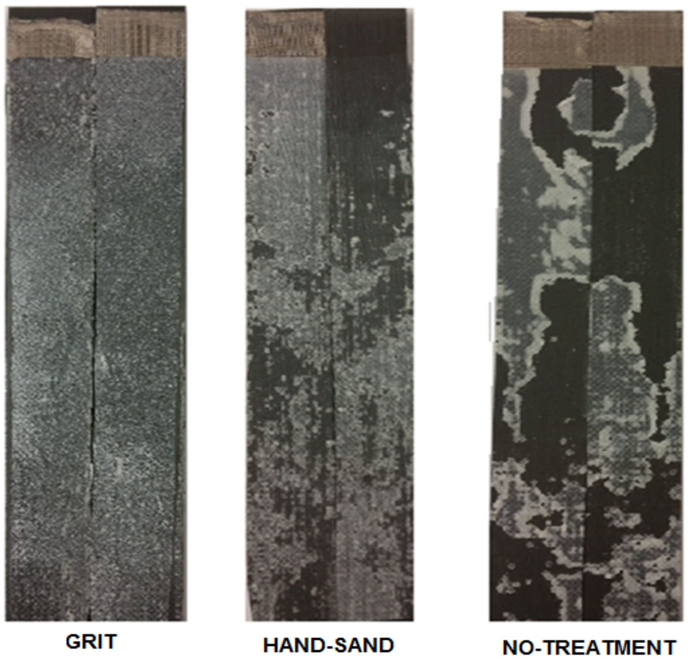
Traveling Wedge Test Development:
Initial Comparison with Static Wedge Test

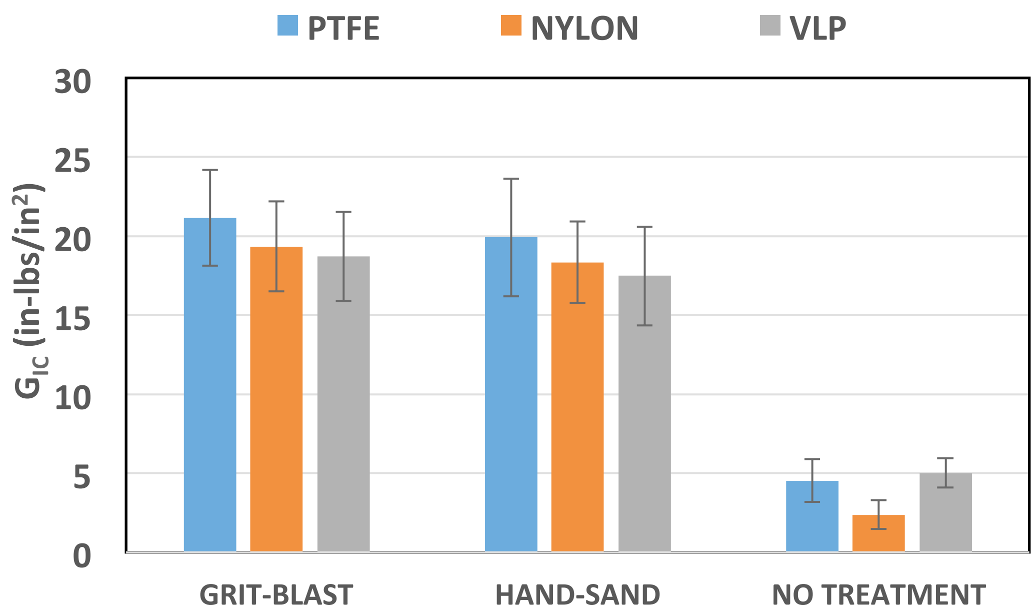
- **20 ply IM7/8552 adherends, AF163-2K film adhesive, “ideal” bonding condition**
- **Ambient & 122°F (50°C)/95% humidity moisture conditioning/ testing environment**
- **G_c values based on crack lengths in general agreement**



Traveling Wedge Test - Thin Adherends:
Effects of Surface Treatment

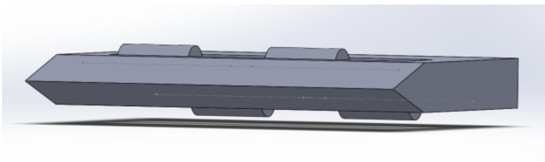
- Moisture conditioning of 3 ply composite adherends
- Low-temperature, quick cure “back-bonding” of composite doublers
- Tested at elevated temperature 122°F (50°C)

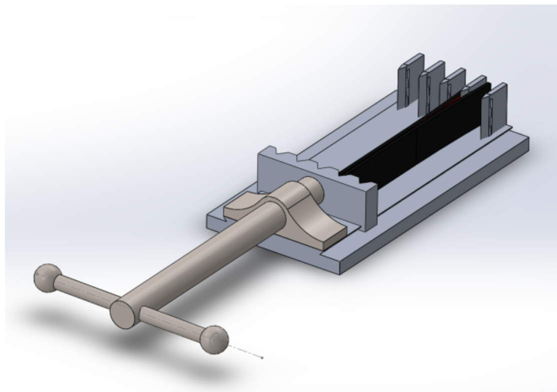




Traveling Wedge Test Assessment: Current Focus

- Development of "hybrid" traveling wedge test
  - Reduce friction/binding through use of rollers
  - Explore use of thin adherends
  - Force measurements during traveling wedge testing to estimate G_c
  - Periodic environmental durability testing via static wedge configuration
- Comparison of G_c estimates with static wedge, and back-bonded DCB





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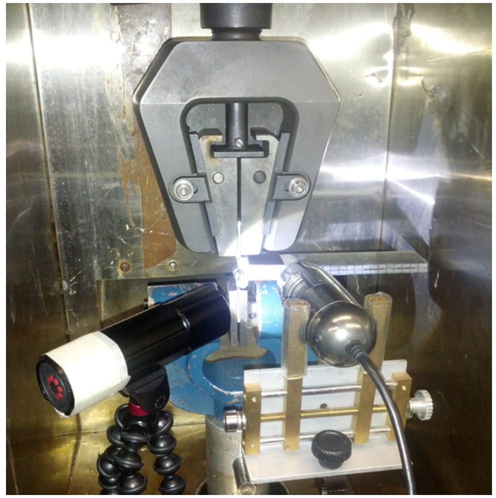
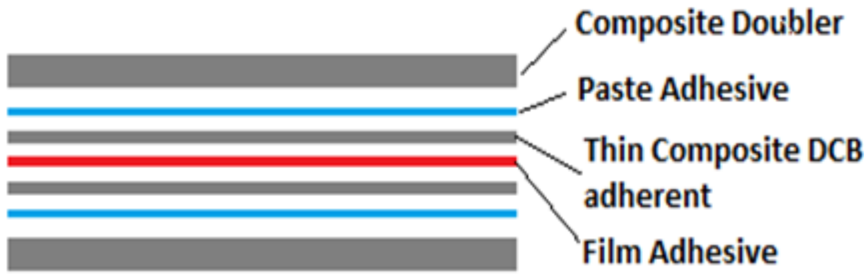
Environmental Durability Testing:
Boeing Back-Bonded DCB Test

- 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
- Useful for G_c comparisons

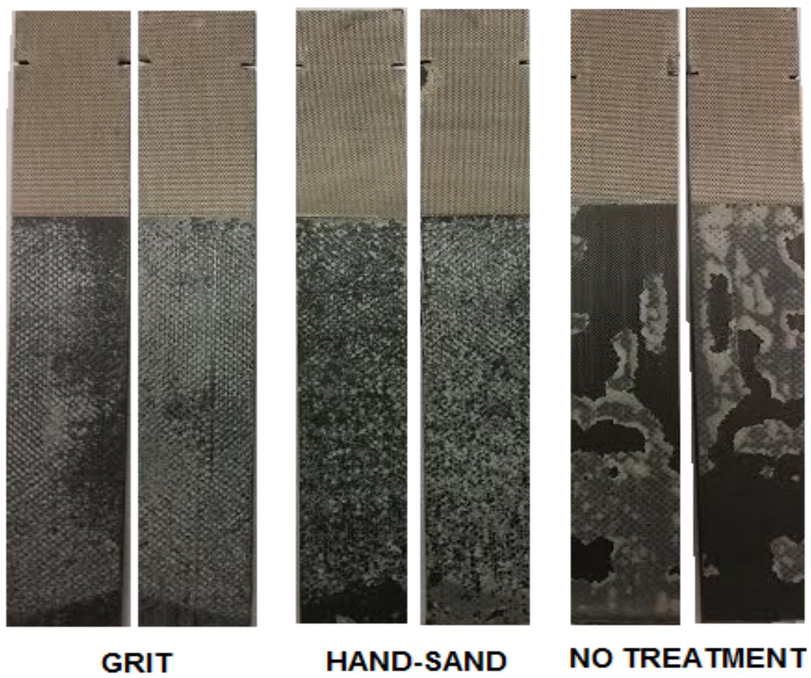


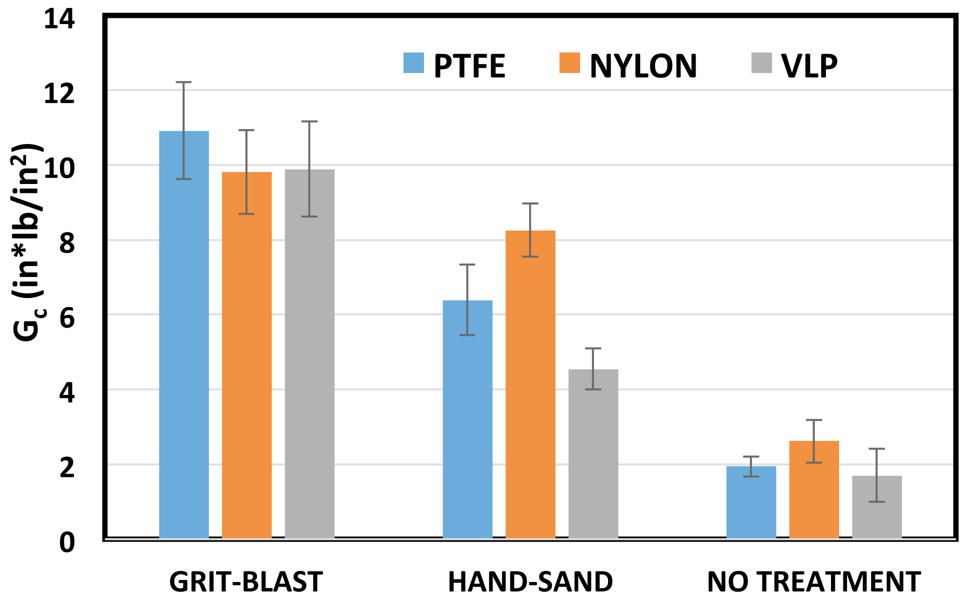


Van Voast, Blohowiak, Osborne and Belcher,
"Rapid Test Methods for Adhesives and Adhesion" (SAMPE 2013)

Back-Bonded DCB Test Results: Surface Treatment Effects

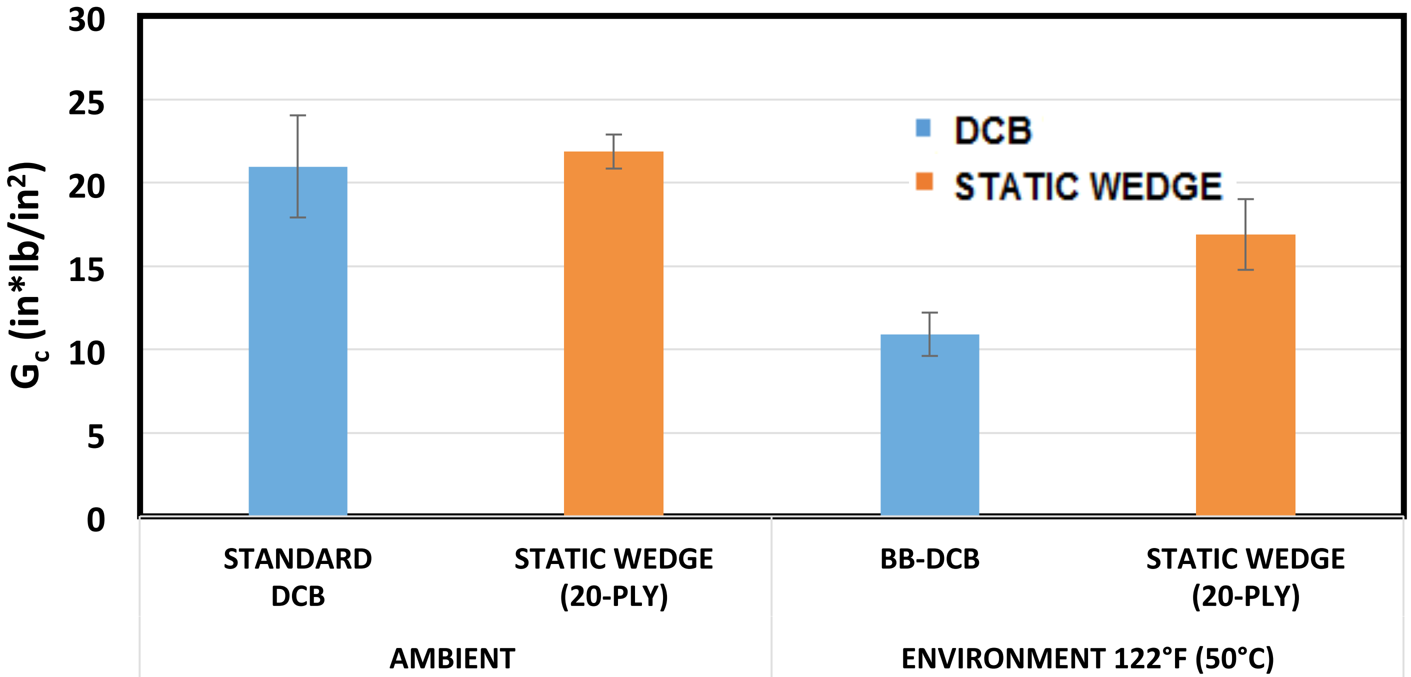
- Three types of peel ply: PTFE, Nylon, and VLP
- Three surface preps: Grit blast, hand sand, no treatment.
- Moisture saturated (3 ply adherends), tested at 122°F (50°C)





Back-Bonded DCB vs. Static Wedge Test: Initial Fracture Toughness Comparisons

- Higher fracture toughness values at ambient conditions
- Good agreement at ambient conditions
- Significant differences at environment using back-bonded DCB specimens
- Further investigation underway



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 "hybrid" traveling wedge test for assessing larger bond areas
- Explore related usages of composite wedge test
  - Thermal cycling
  - Fluid sensitivity

BENEFITS TO AVIATION

- Improved environmental durability test method for metal bonds (metal wedge test, ASTM D3762)

- Composite wedge test for assessing the environmental durability of composite bonds
- Evaluation of other candidate test methods for assessing environmental durability of adhesively bonded aircraft structures

- Dissemination of research results through FAA technical reports and conference/journal publications

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