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Test Method Development for Environmental Durability of Composite Bonded Joints

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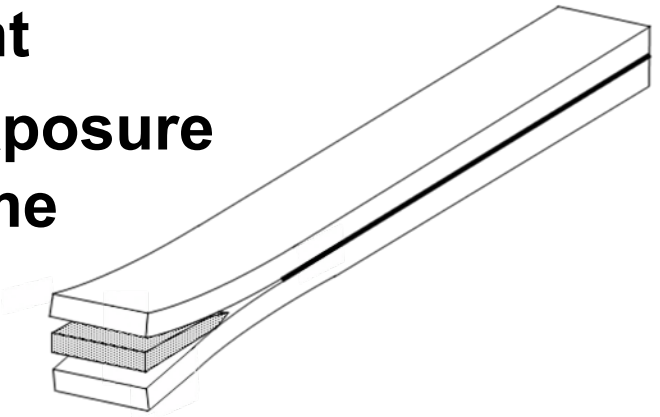
Outline

- **Introduction: Environmental durability testing of bonded joints**
- **Candidate environmental durability test methods for composite bonded joints:**
  - **Static wedge test**
  - **Traveling wedge test**
  - **Back-Bonded Double Cantilever Beam (DCB) test**
- **Current Status and Upcoming Work**

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 assess 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 is measured following a prescribed time period



Why Environmental Durability Tests of Composite Bonded Joints?

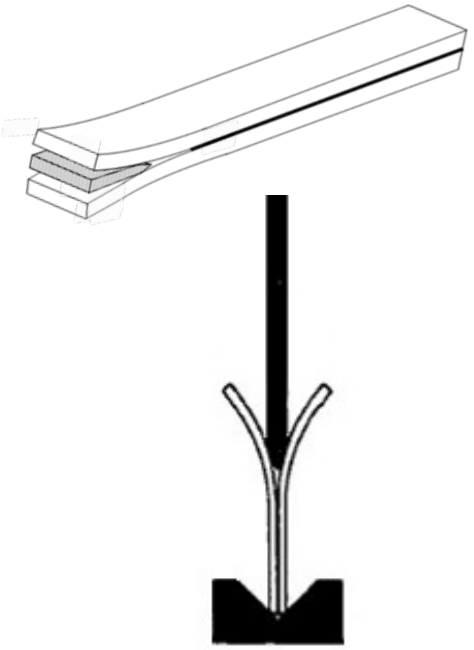
"There is currently no known mechanism similar to metal-bond hydration for composites"

- **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**

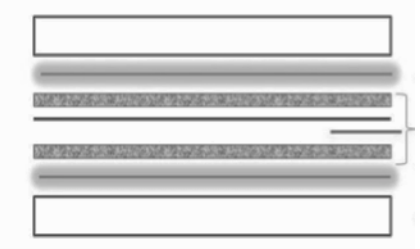
Environmental Durability Testing of Composite Bonded Joints

Candidate Test Methods:

- **Static Wedge Crack Test**



- **Traveling Wedge Test**
- **Boeing Back-Bonded DCB**

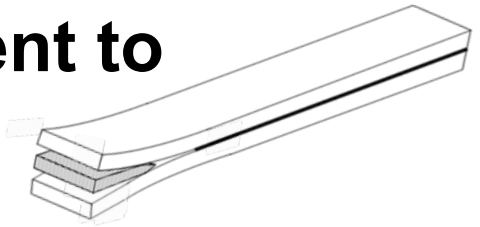


Blohowiak et al., "SAMPE 2013 Rapid Test Methods for Adhesion" (2013)

Van Voast et al., SAMPE 2013

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



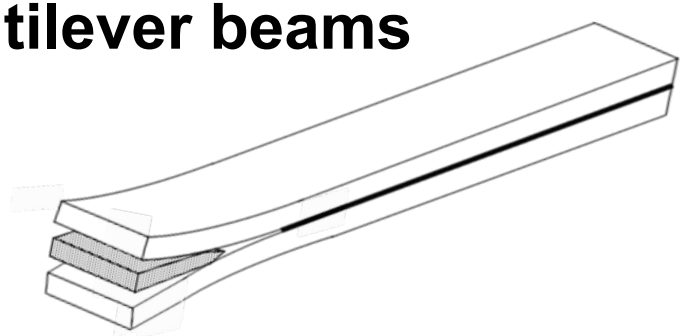
- Failure in the composite laminate prior to failure in the adhesive or at the bondline

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: $$G_c = dU/da$$

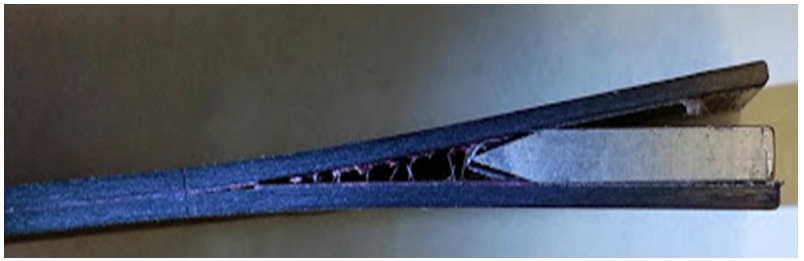
$$G_c = 3 E_f t^2 h^3 / 16 a^4$$

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

Experimental Investigation:

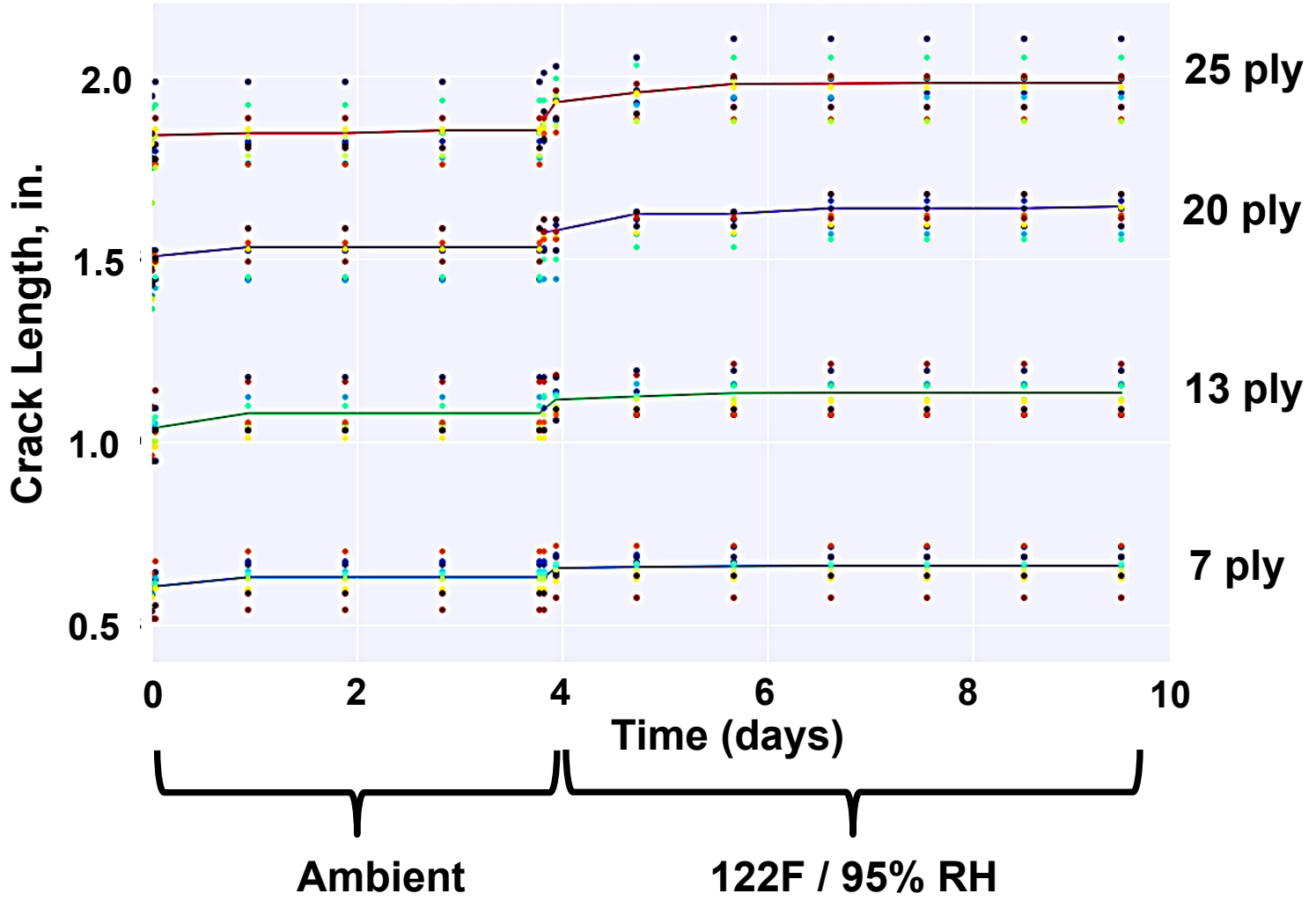
Composite Wedge Test Development

- 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.): Thin adherends, minimize crack length
  - 13 ply (~0.09 in.): Match EI of aluminum adherends
  - 20 ply (~0.14 in.): Match thickness of aluminum, (1/8 in.)
  - 25 ply (~0.18 in.): Thick adherends, maximize crack growth
- 122°F (50°C) and 95% humidity environment



Effects of Composite Adherend Thickness: Crack Length – "Ideal" Bond

What is the desired thickness/bending stiffness of the bonded composite adherends?



Effects of Composite Adherend Thickness: Crack Length – "Ideal" Bond

Specimens following environmental exposure

7 ply

13 ply

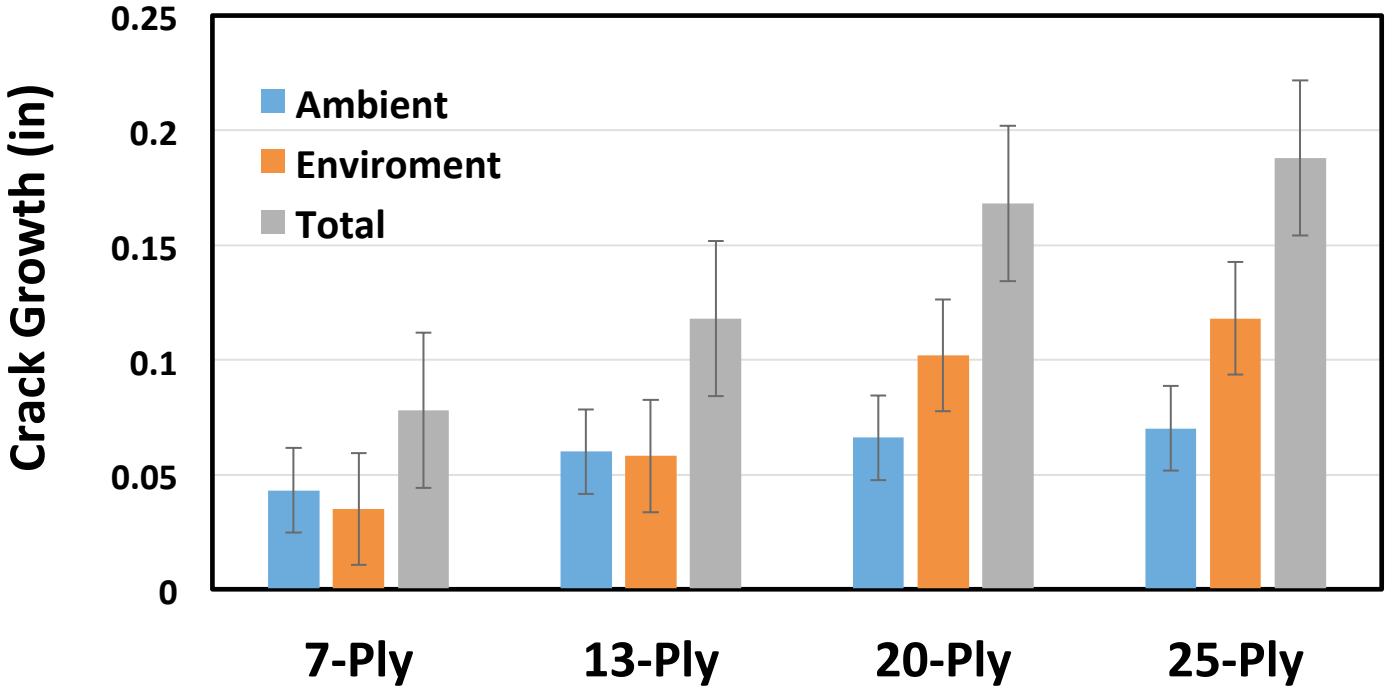
20 ply

25 ply

Aluminum

Effects of Composite Adherend Thickness: Crack Growth – "Ideal" Bond

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

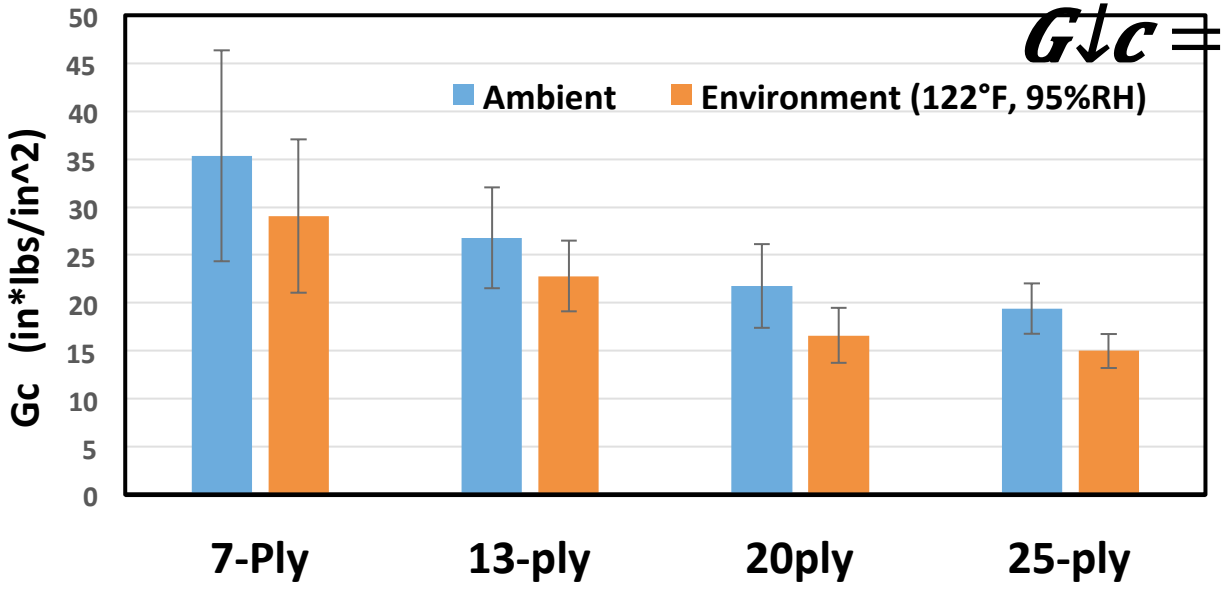


Increasing adherend thickness (and flexural stiffness)…

- **Increases crack length**
- **Increases crack growth**

Effects of Composite Adherend Thickness: Fracture Toughness G_c – "Ideal Bond"

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

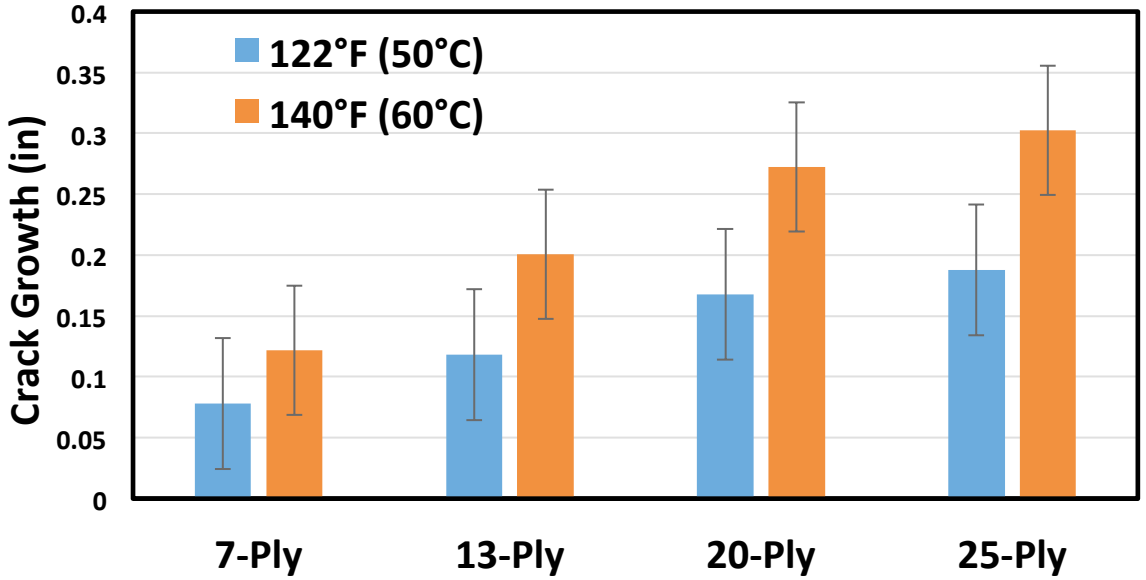


$$G_{Ic} = 3\,Ef\,t^2\,h^3 / 16$$

- Differences observed in G_c values for various adherend thicknesses
  - Methods of G_c calculation under investigation

Composite Wedge Test Development:
Selection of Environmental Conditions

122°F (50°C) versus 140°F (60°C), "Ideal" Bond



- **Significant increase in crack growth with increasing temperature… for "ideal" bond condition**
- ***How should user determine suitable environmental conditions for composite wedge testing?***

Composite Wedge Test Development:
Assessment of Bond Durability – "Non Ideal" Bonds

- **Compare two surface preparations:**

Baseline ("Ideal" Bond)

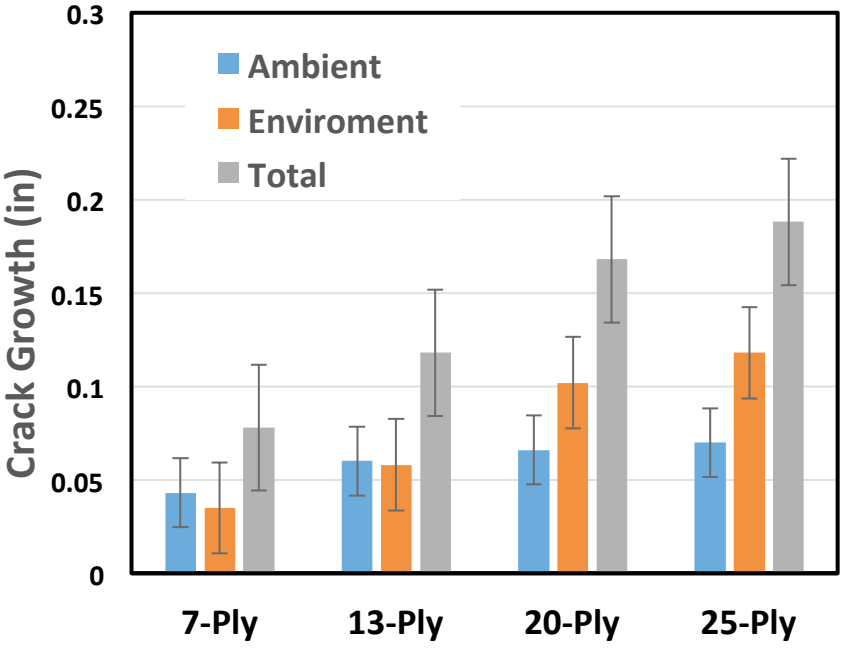
- Use of PTFE peel ply
- Acetone wipe after peel ply removal
- Grit blasting followed by air cleaning
- Acetone wipe
- Drying for at least 4 hours

"Non-Ideal" Bond

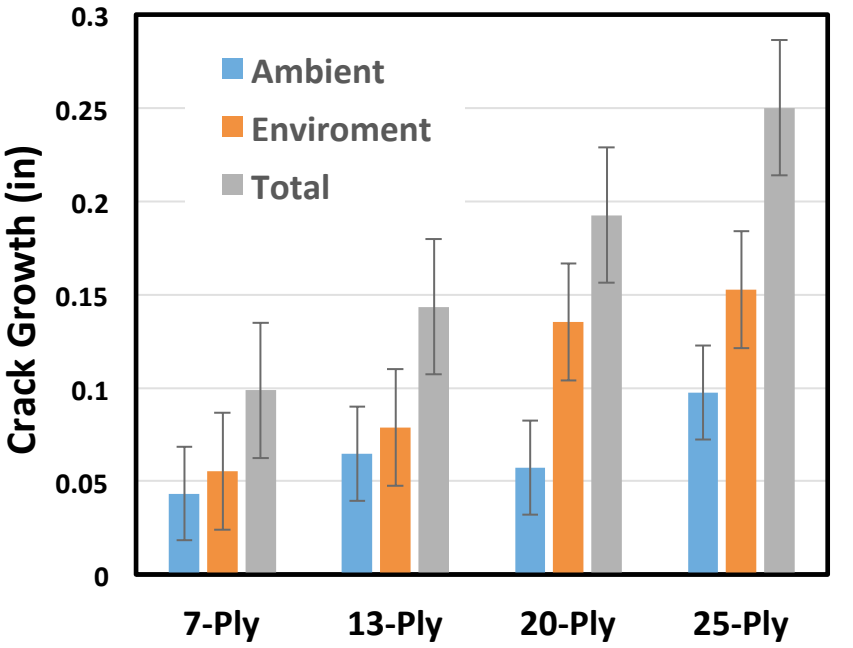
- Use of Nylon peel ply
- Acetone wipe after peel ply removal
- Drying for at least 4 hours

- **AF163-2K film adhesive**
- **122°F (50°C) and 95% humidity environment**
- **Four adherend thicknesses: 7, 13, 20, 25 plies**

Assessment of Bond Durability: Crack Growth



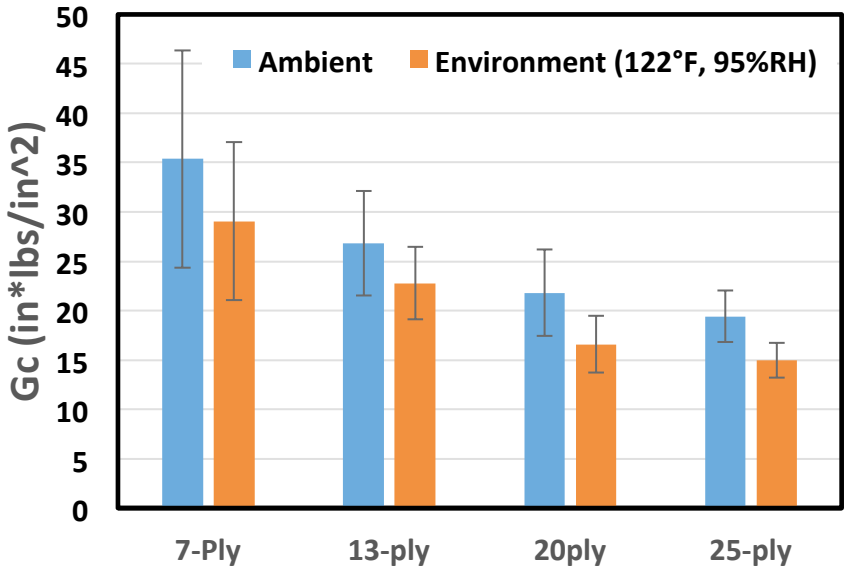
Ideal Bond



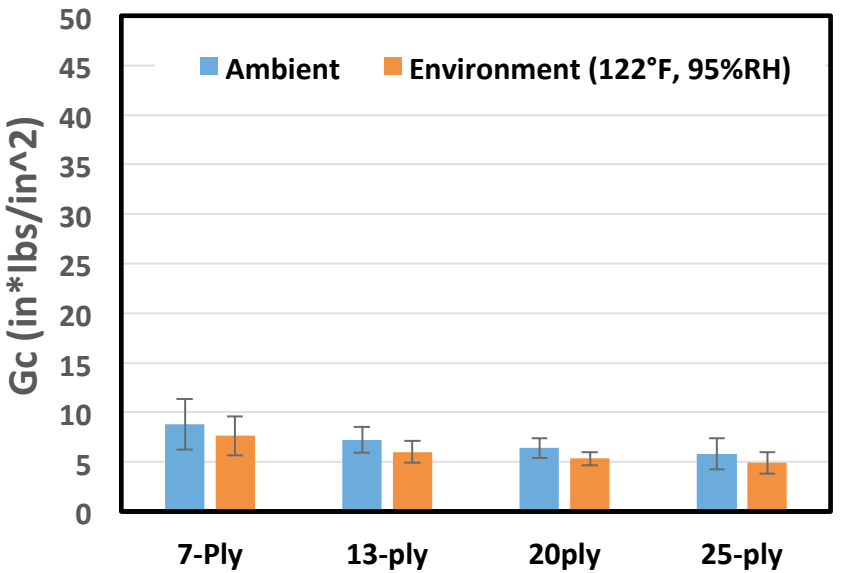
Non-Ideal Bond

Assessment of Bond Durability: Fracture Toughness G_c Values

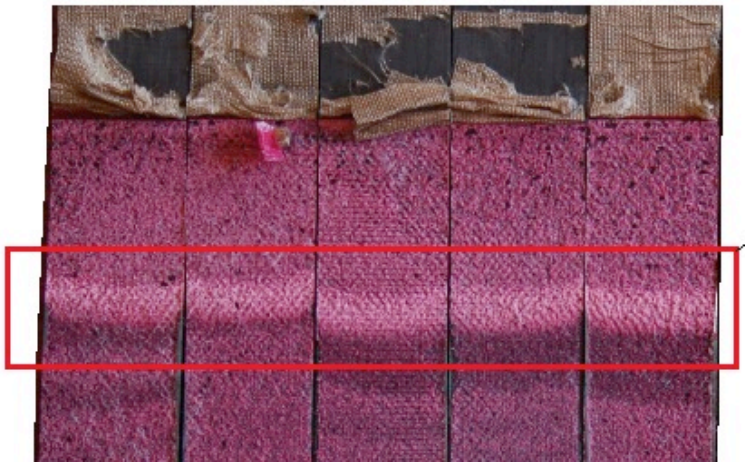
122°F (50°C) and 95% humidity environment

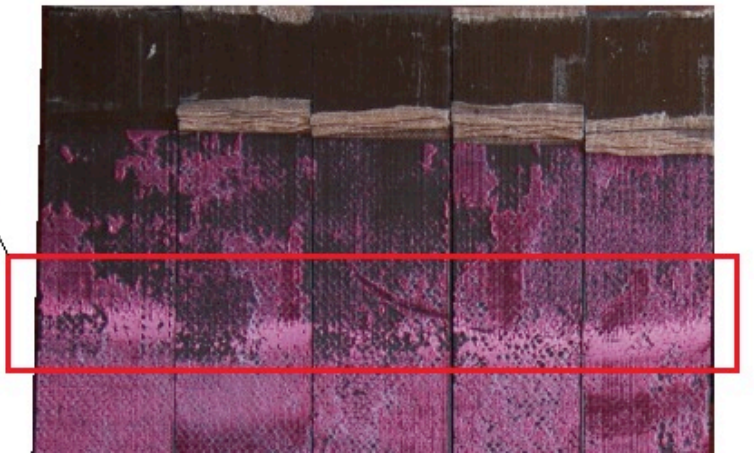


Ideal Bond



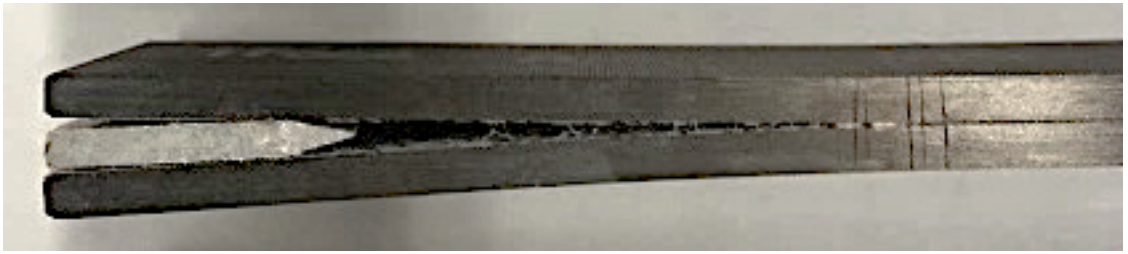
Non-Ideal Bond





Composite Wedge Test Development:
Summary of Findings To Date

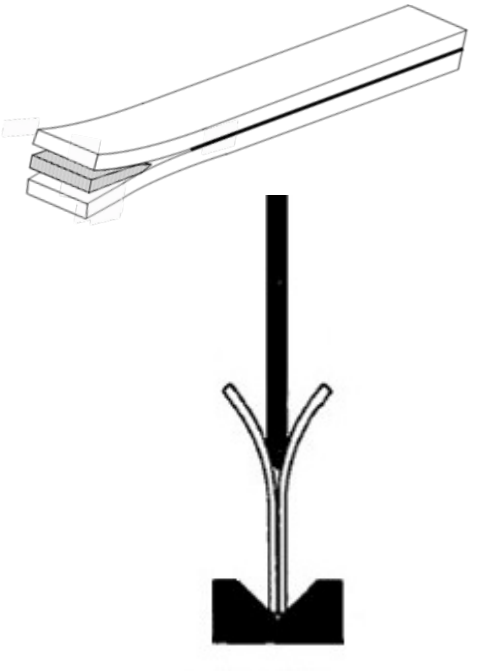
- 20 ply adherend thickness appears favorable
  - E*I value ~3.6 times that of 1/8 in. thick aluminum
  - Greater environmental crack growth
- Differences observed in apparent G_c values for various adherend thicknesses
  - Methods of G_c calculation under investigation
- 122°F (50°C) and 95% humidity environmental conditions appear reasonable for current materials



Environmental Durability Testing of Composite Bonded Joints

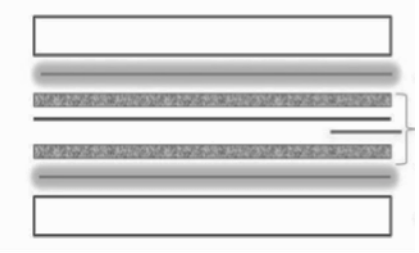
Candidate Test Methods:

- **Static Wedge Crack Test**



- **Traveling Wedge Test**

- **Boeing Back-Bonded DCB**



Blohowiak et al., "SAMPE 2013 Rapid Test Methods for Adhesion" (2013)

Van Voast et al., SAMPE 2013

Traveling Wedge Test for Environmental Durability Assessment

- Longer version of static wedge specimen
- Moisture saturation of bonded composite specimen prior to testing
- Wedge driven continuously through adhesive bondline at elevated temperature using testing machine
- Assessment of relatively large bond area
- Can provide an estimate of G_c with crack length measurements
- Limited prior usage/investigation for environmental durability assessment

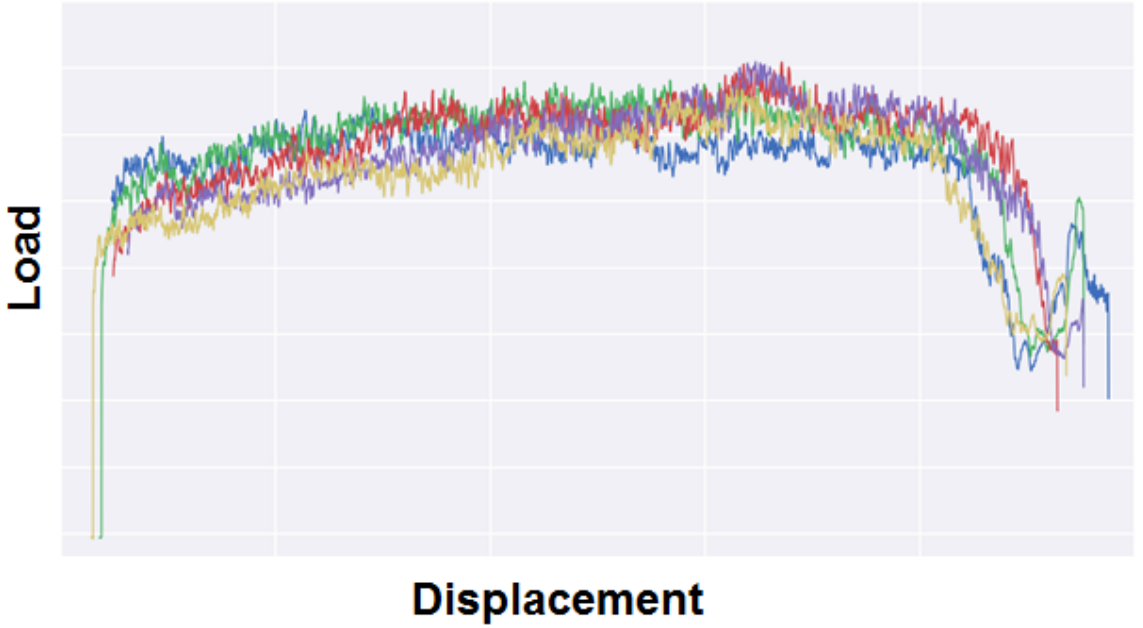
Traveling Wedge Test: Initial Assessment

- Unidirectional IM7/8552 carbon/epoxy adherends
  - Thin adherends: (3 ply, 0.024 in.)
    - Preferred for shorter moisture saturation time
    - Of concern due to short crack length
  - Thick adherends: (20 ply, 0.144 in.)
    - More representative of static wedge and DCB specimens
    - Back-bonded to reduce moisture saturation time
- AF163-2K film adhesive
- Two surface preparations investigated
  - "Ideal": Grit-blast & acetone wipe
  - "Non Ideal": Nylon peel ply & acetone wipe

Traveling Wedge Test Results:
Thick Adherends at RT/Ambient Conditions

“Ideal” bond (grit blasted/solvent wipe)

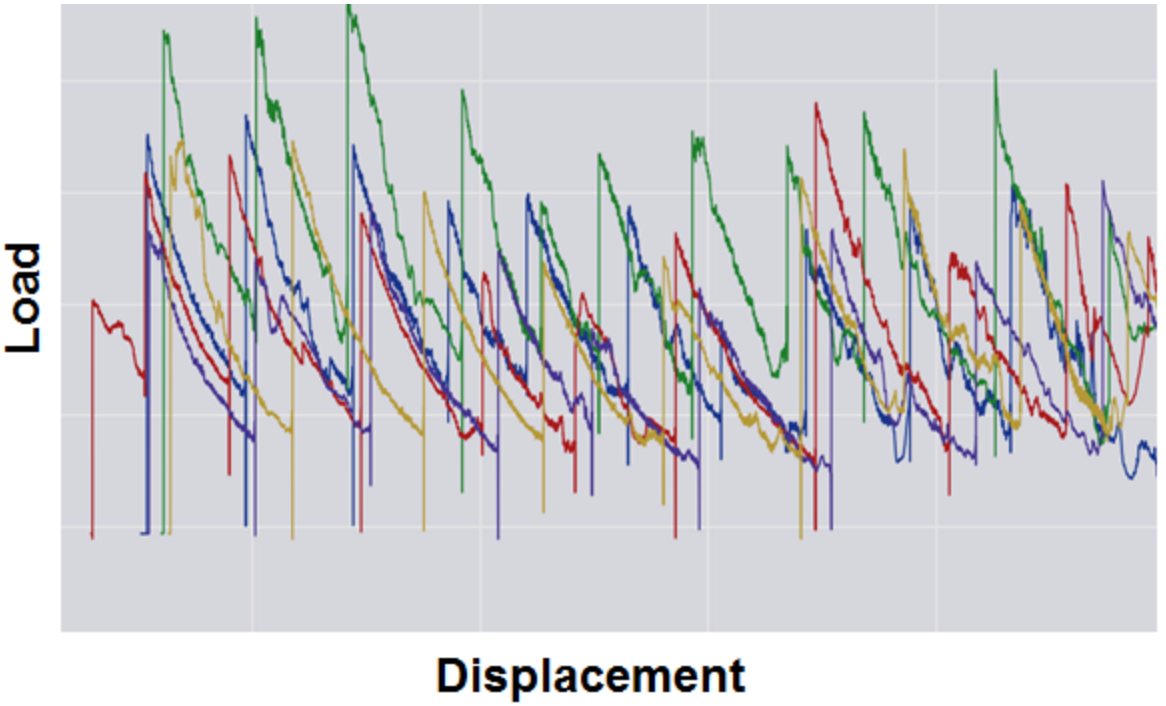
- Cohesion failure
- Stable crack growth
- Repeatable results



Traveling Wedge Test Results:
Thick Adherends at RT/Ambient (Con'd)

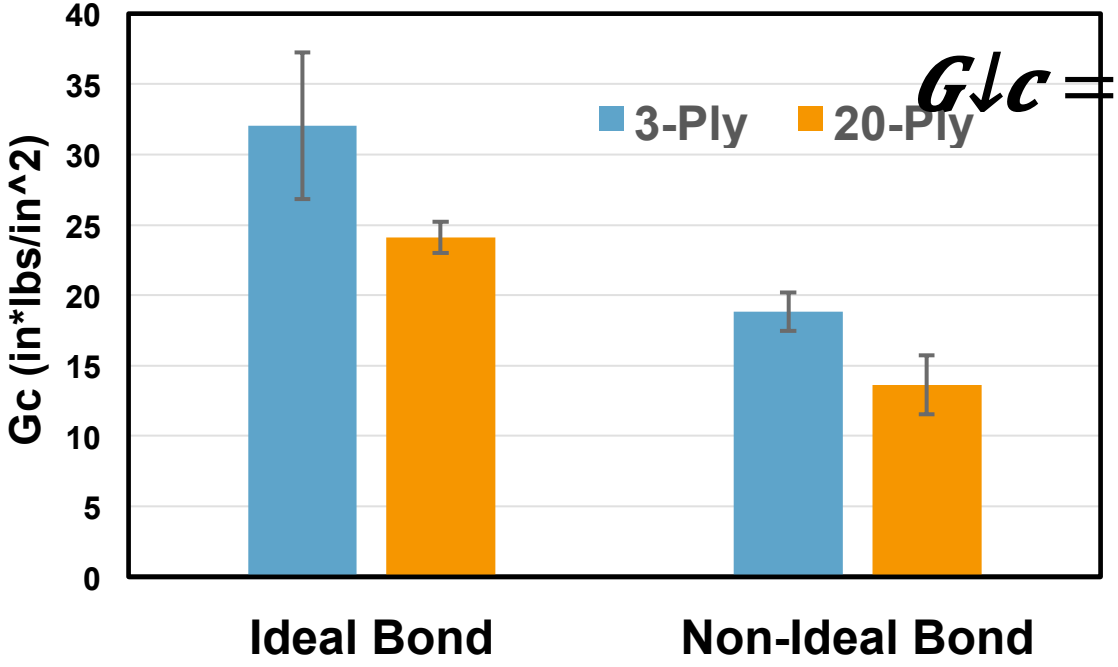
"Non-Ideal" bond (Nylon peel ply/solvent wipe)

- Adhesion failure
- "Stick-slip crack growth behavior
- Large load drops during crack growth



Example Traveling Wedge Test Results: Fracture Toughness G_c Values

Tested at room temperature/ambient conditions



$$G_c = 3 E f t^2 h^3 / 1$$

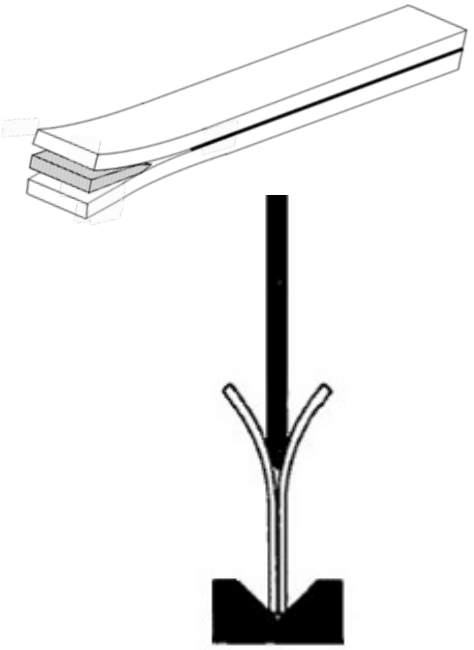
- Differences observed in G_c values for different adherend thicknesses

  (Methods of G_c calculation under investigation)

Environmental Durability Testing of Composite Bonded Joints

Candidate Test Methods:

- **Static Wedge Crack Test**



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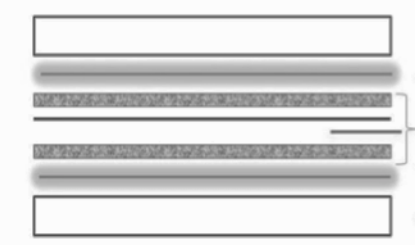
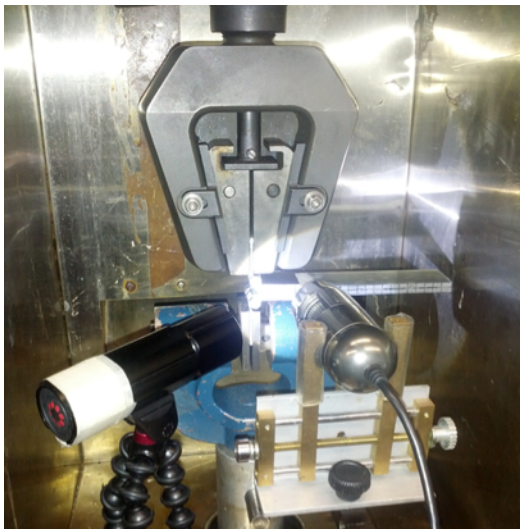


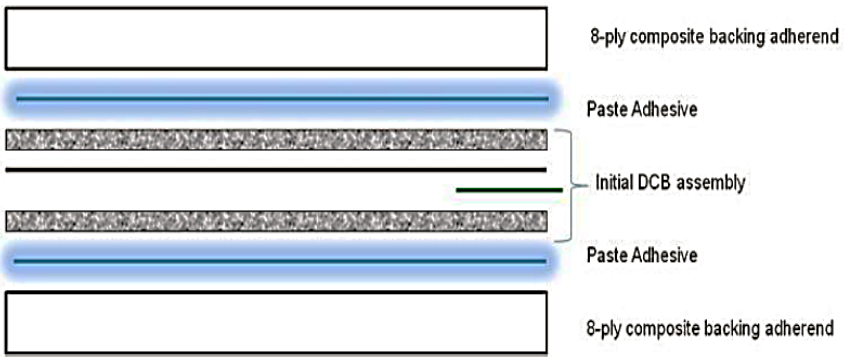
Blohowiak et al., "SAMPE 2013 Rapid Test Methods for Adhesion" (2013)

Van Voast et al., SAMPE 2013

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

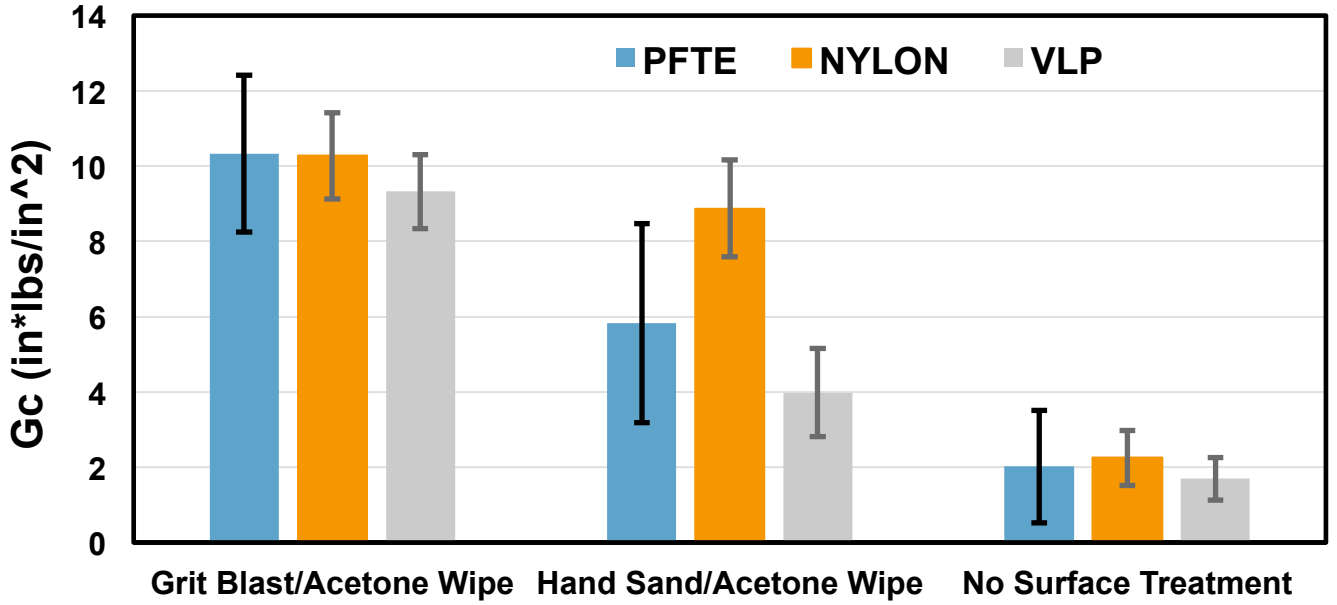




Van Voast, Blohowiak, Osborne and Belcher,
"Rapid Test Methods for Adhesives and Adhesion" (SAMPE 2013)

Back-Bonded DCB Test Results: Fracture Toughness G_c Values

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



Environmental Durability Testing of Composites:
Summary and Future Work

In summary…

- Composite Wedge Crack Test appears promising
  - Simple test to assess environmental durability
  - Small bond area is evaluated
- Applicability of traveling wedge test uncertain
  - Relatively large bond area may be evaluated
- Boeing Back-Bonded DCB test may serve as a baseline
  - Accurate, well accepted measure of Gc

Looking ahead…

- Focus on G_c comparisons between test methods
- Investigate hybrid wedge/DCB test
- Evaluate other adhesives and surface prep conditions

Thank you for your attention!

Questions?