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Development and Evaluation of Environmental Durability Test Methods For Composite Bonded Joints

Dan Adams, Larry DeVries,
David Ricsi
University of Utah

2015 Technical Review

THE UNIVERSITY OF UTAH

FAA Sponsored Project Information

- Principal Investigators:

  Dr. Dan Adams

  Dr. Larry DeVries

Graduate Student Researchers:

  David Ricsi

  Nicholas Brown

- FAA Technical Monitor:

  Curt Davies

- Collaborators:

  Boeing: Kay Blohowiak, Will Grace, Charles Park

  Air Force Research Laboratory: Jim Mazza

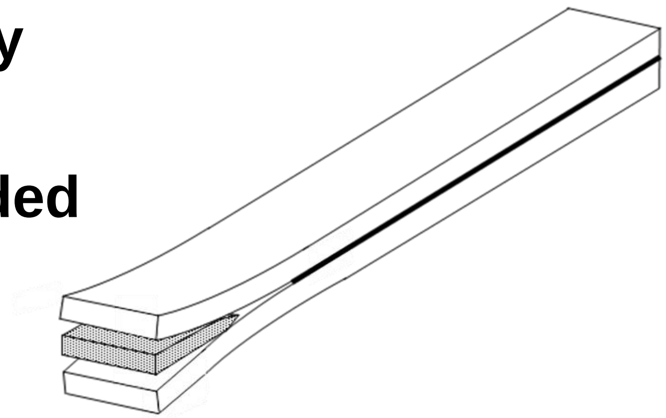
Outline

- **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 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



Revised ASTM standard to be presented to ASTM D14 Committee at Spring meeting

Why Environmental Durability Tests of Composite Bonded Joints?

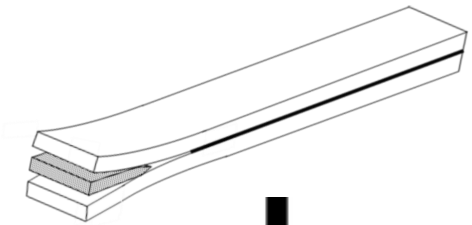
"There is currently no known mechanism similar to metal-bond hydration for composites"

- **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

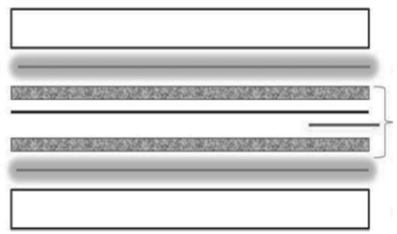
Candidate Test Methods:

- **Static Wedge Crack Test**



- **Traveling Wedge Test**

- **Boeing Back-Bonded DCB**

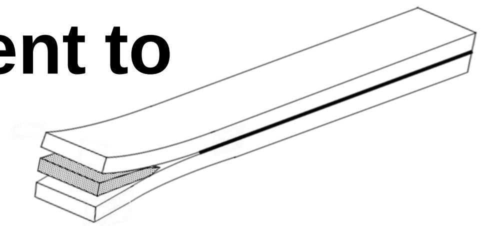


Blohowiak et al., "SAMPE 2013 Rapid Test Methods for Adhesion" (2013)

Van Voast et al., SAMPE 2013

Development of a Composite Wedge Test: Additional Complexities

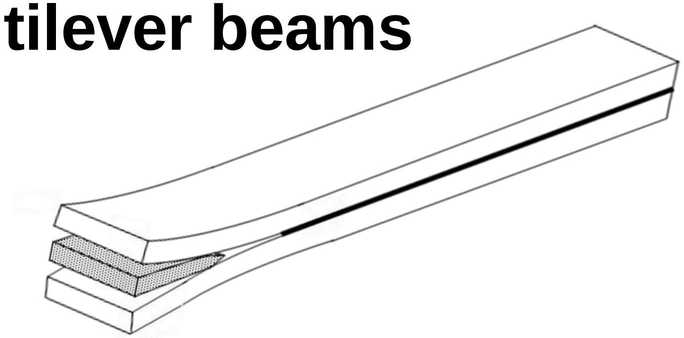
- **Variable flexural stiffness of composite adherends**
  - **Environmental crack growth dependent on adherend flexural stiffness**
    - **Flexural stiffness must be within an acceptable range or…**
    - **Must tailor wedge thickness for composite adherends or…**
    - **Must use another quantity 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: $$\delta = \frac{t}{2} = \frac{P\,l^3}{3\,E_f\,I} = \frac{T\,a^3}{3\,E_f\,I}$$

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

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

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

$$G_c = \frac{3\,E_f\,t^2\,h^3}{16\,a^4}$$

a = crack length

t = wedge thickness

h = adherend thickness

b = specimen width

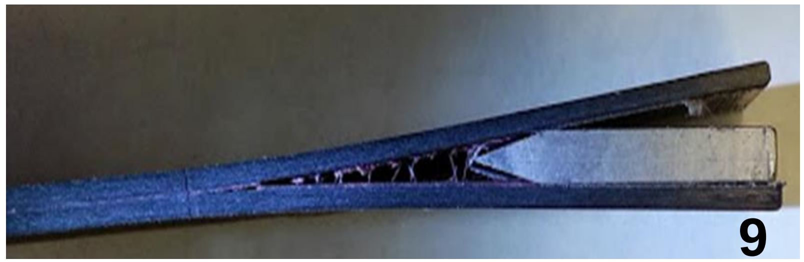
T = load to deflect tip of beam

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
- 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

Specimens following environmental exposure

7 ply

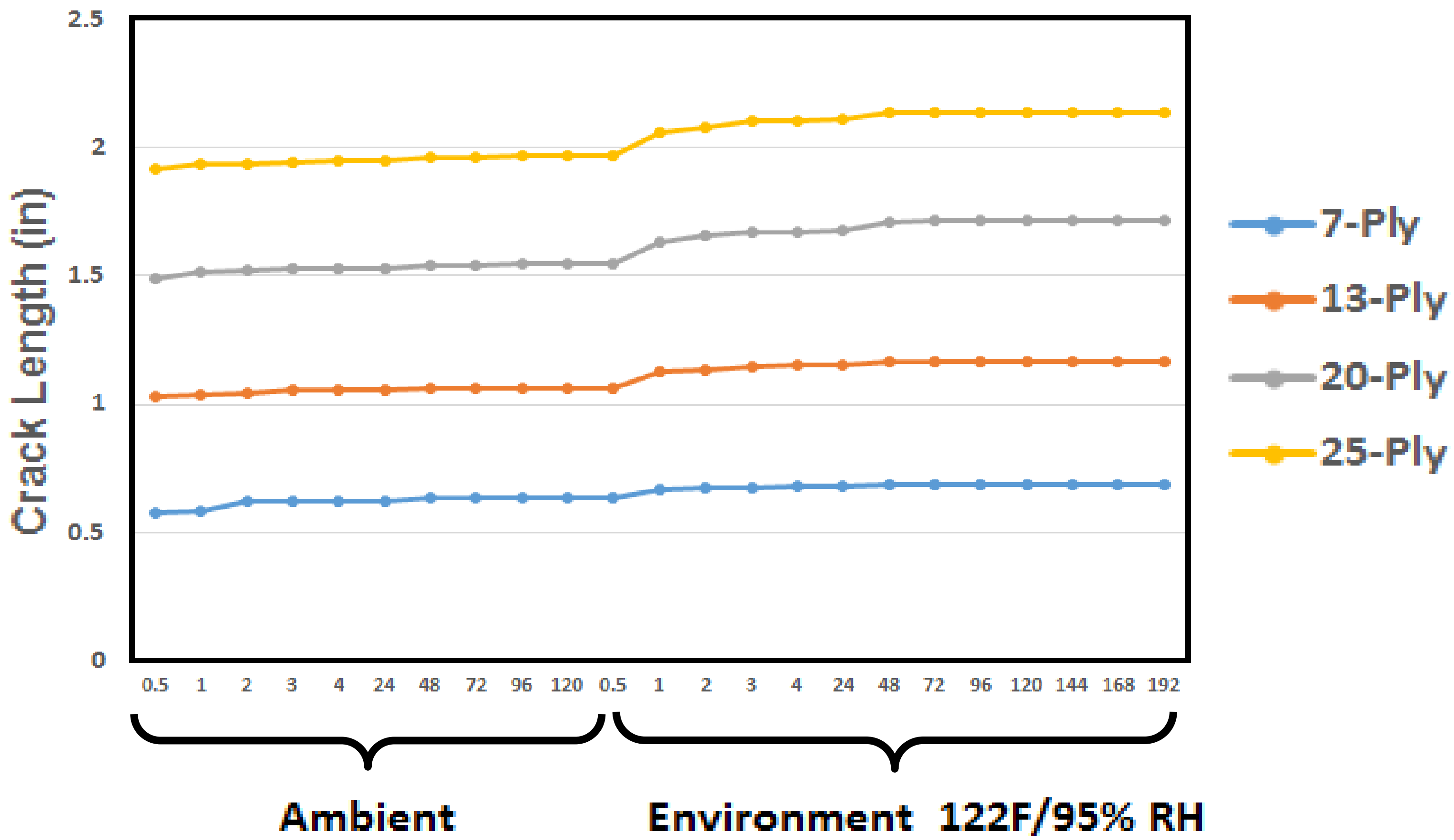
13 ply

20 ply

25 ply

Aluminum

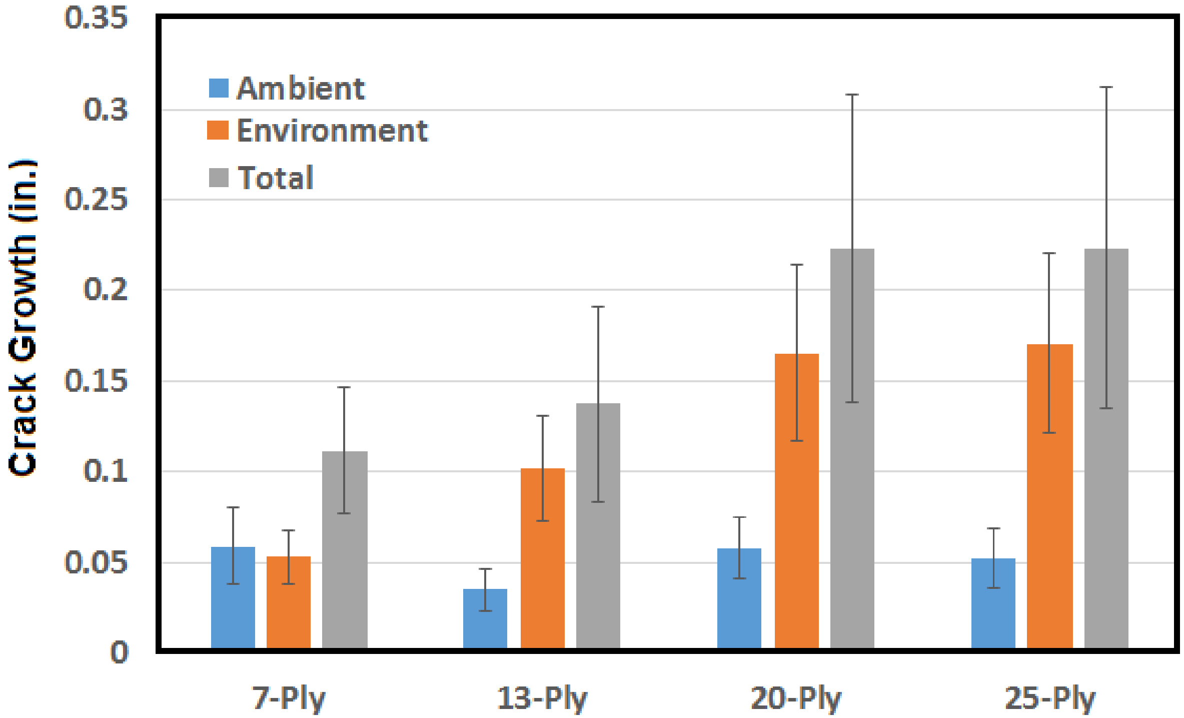
Effects of Composite Adherend Thickness: Total Crack Length During Testing



Increasing adherend thickness produces longer crack lengths

Effects of Composite Adherend Thickness: Crack Growth

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

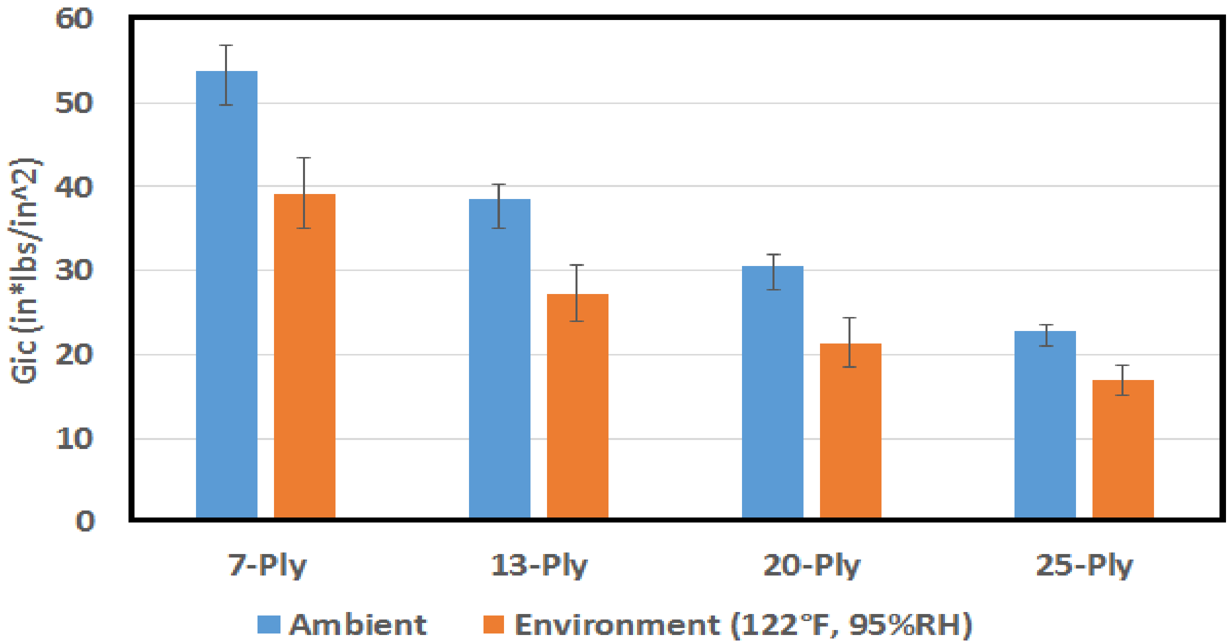


Increasing adherend thickness (and flexural stiffness)…

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

Effects of Composite Adherend Thickness: Fracture Toughness - G_c Values

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

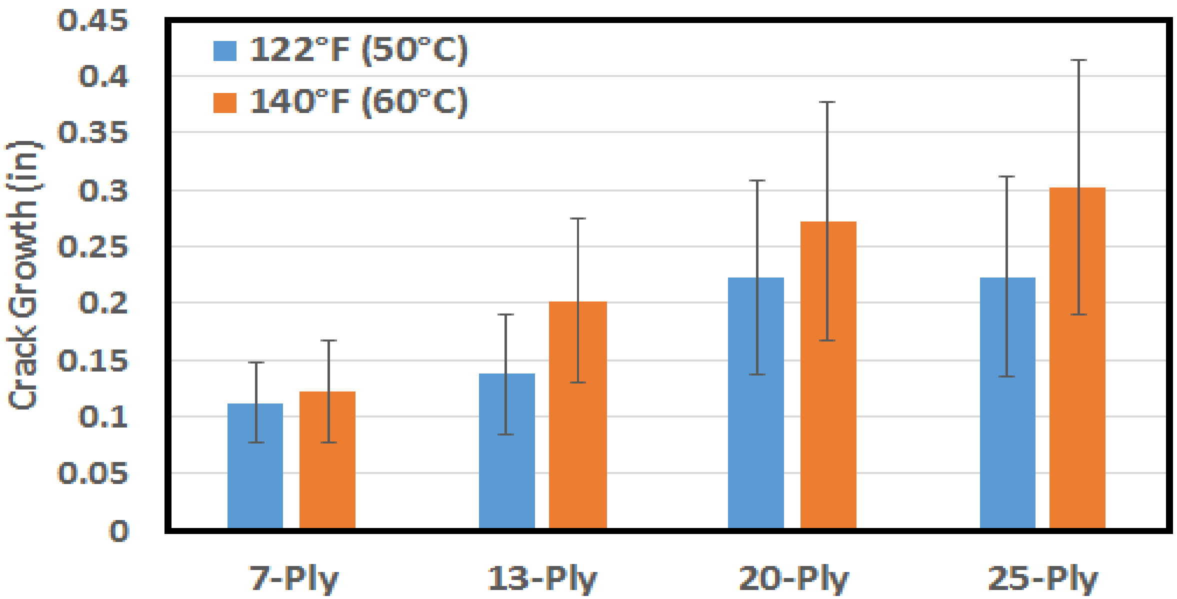


$$G_c = \frac{3\,Ef\;t^2\,h^3}{16\,a^4}$$

- **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)



- **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:
Initial Assessment of Surface Prep Effects

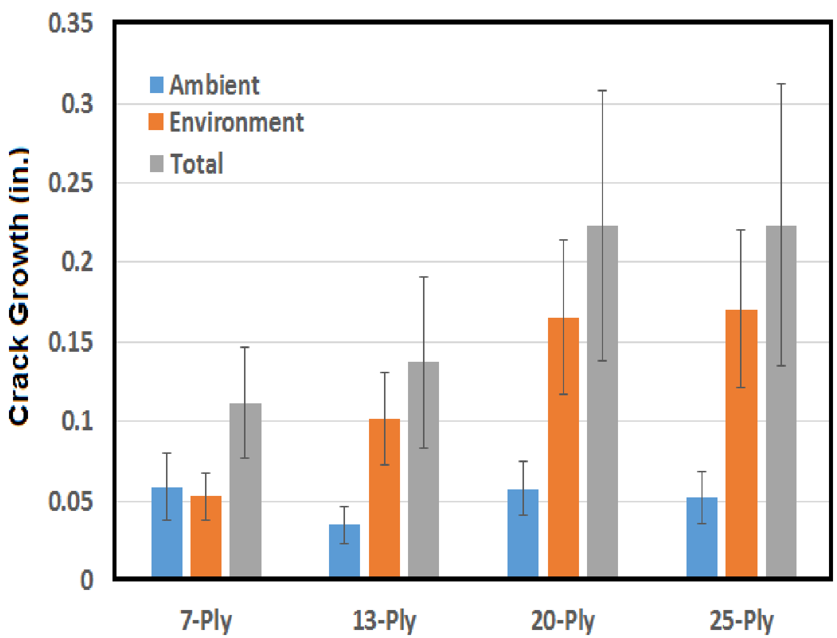
- **Compare two surface preparations:**

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

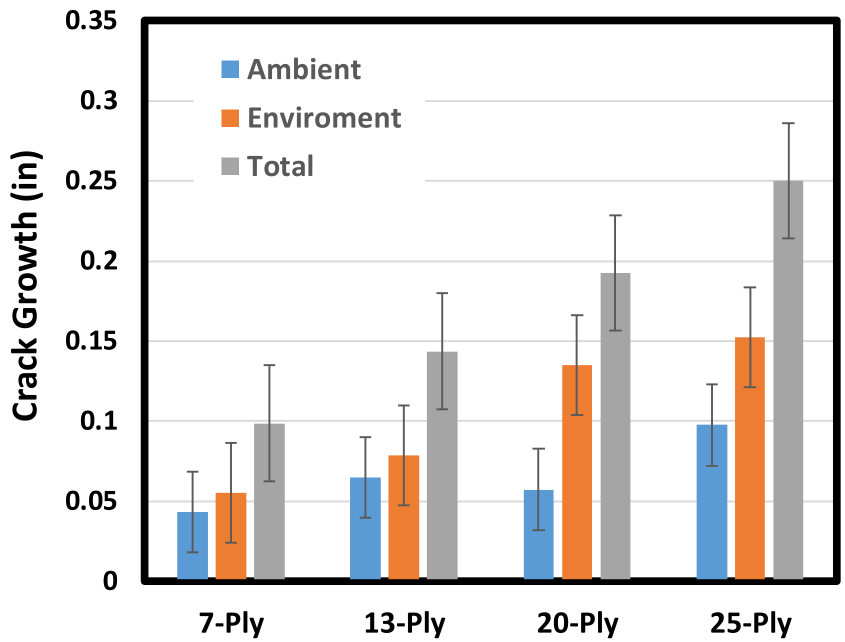
"Non-Ideal" Bond
- Use of Nylon peel ply
- Acetone wipe after peel ply removal
- Drying for at least 4 hours

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

Assessment of Surface Prep Effects: Crack Growth



Ideal Bond



Non-Ideal Bond

Increase in environmental crack growth due to differences in surface preparation

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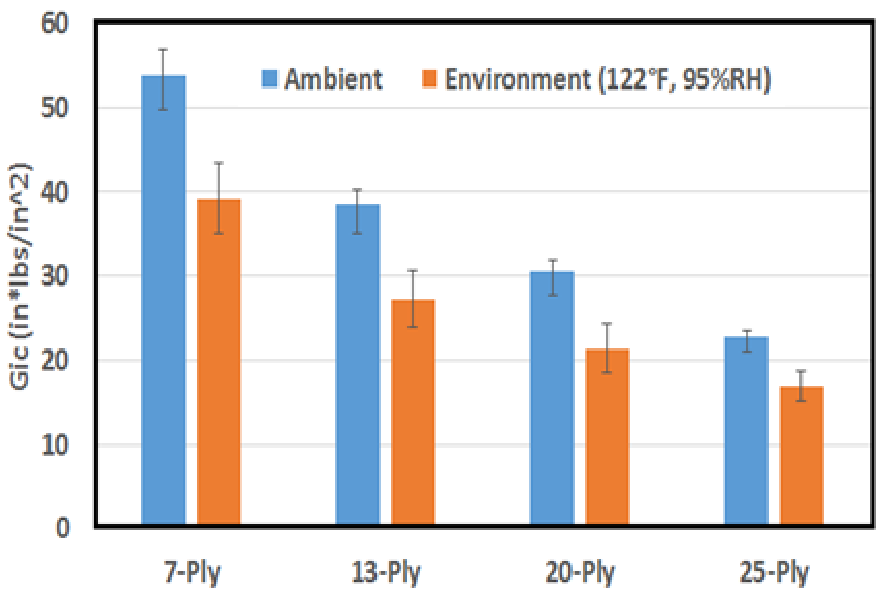
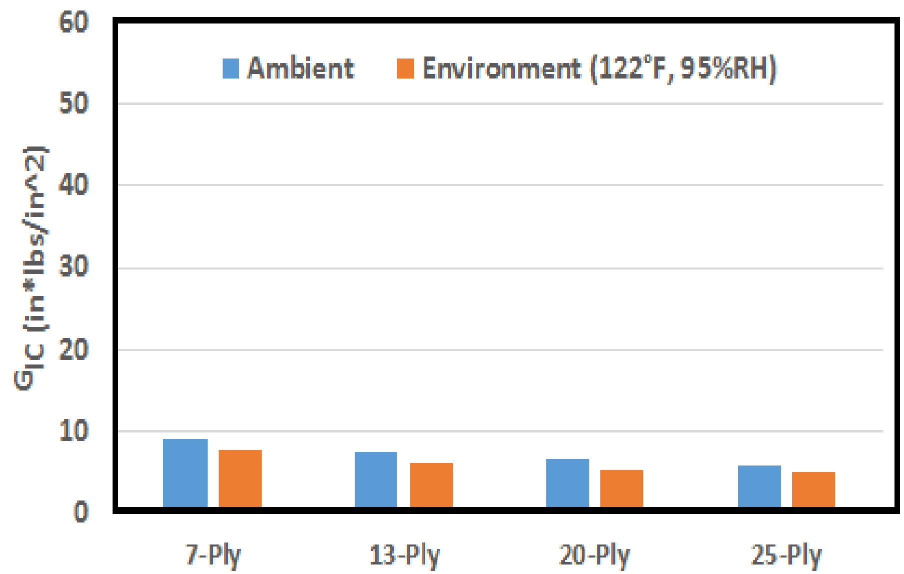
Assessment of Surface Prep Effects: Fracture Toughness - G_c Values

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



Ideal Bond



Non-Ideal Bond

Significant decrease in fracture toughness due to moderate increase in crack growth

$$G_c = \frac{3\,Ef\;t^2\,h^3}{16\,a^4}$$

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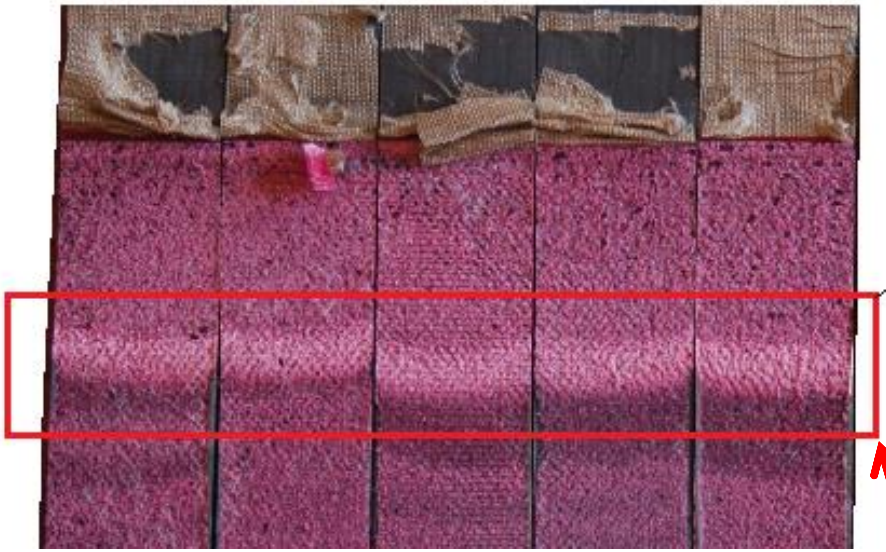
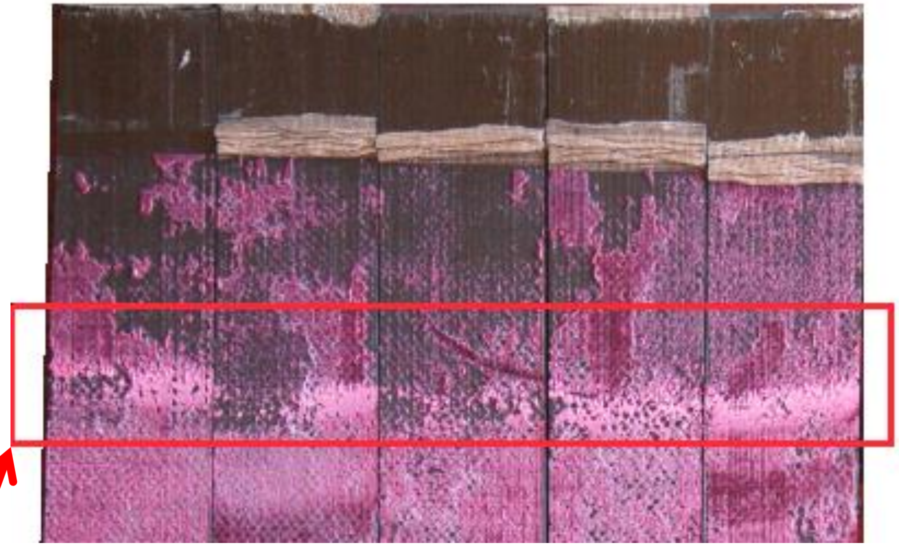
Assessment of Surface Prep Effects: Failure Modes

Ideal Bond



Non-Ideal Bond



Tested region

Change in failure mode (cohesion to adhesion) associated with decrease in fracture toughness

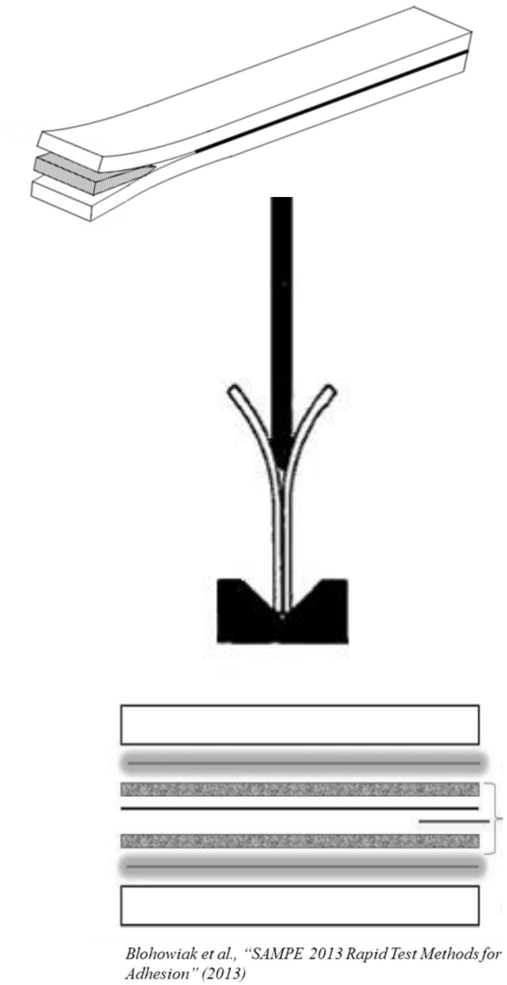
Environmental Durability Testing of Composite Bonded Joints

Candidate Test Methods:

- **Static Wedge Crack Test**

➡ **Traveling Wedge Test**

- **Boeing Back-Bonded DCB**



Van Voast et al., SAMPE 2013

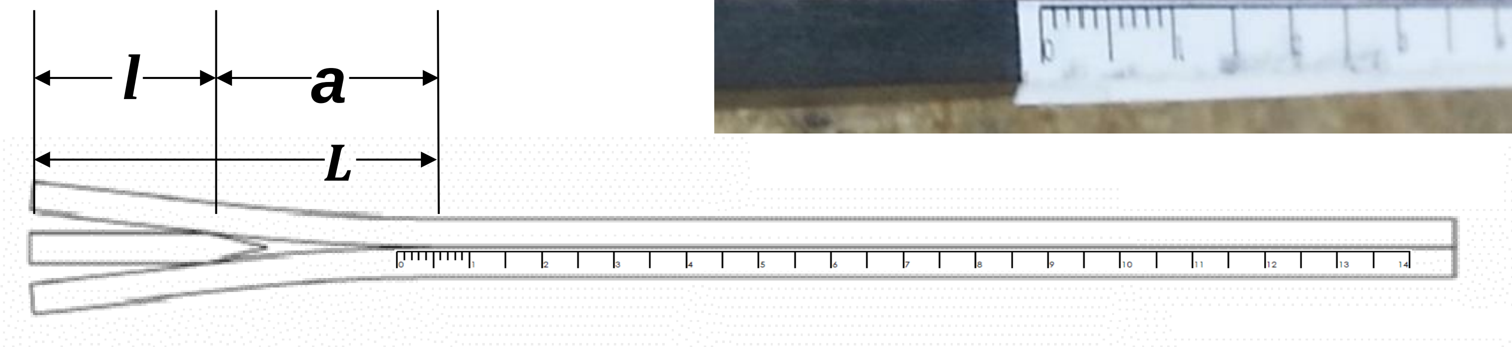
Traveling Wedge Test for Environmental Durability Assessment

- **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 investigation for environmental durability assessment**

Traveling Wedge Test: Initial Assessment

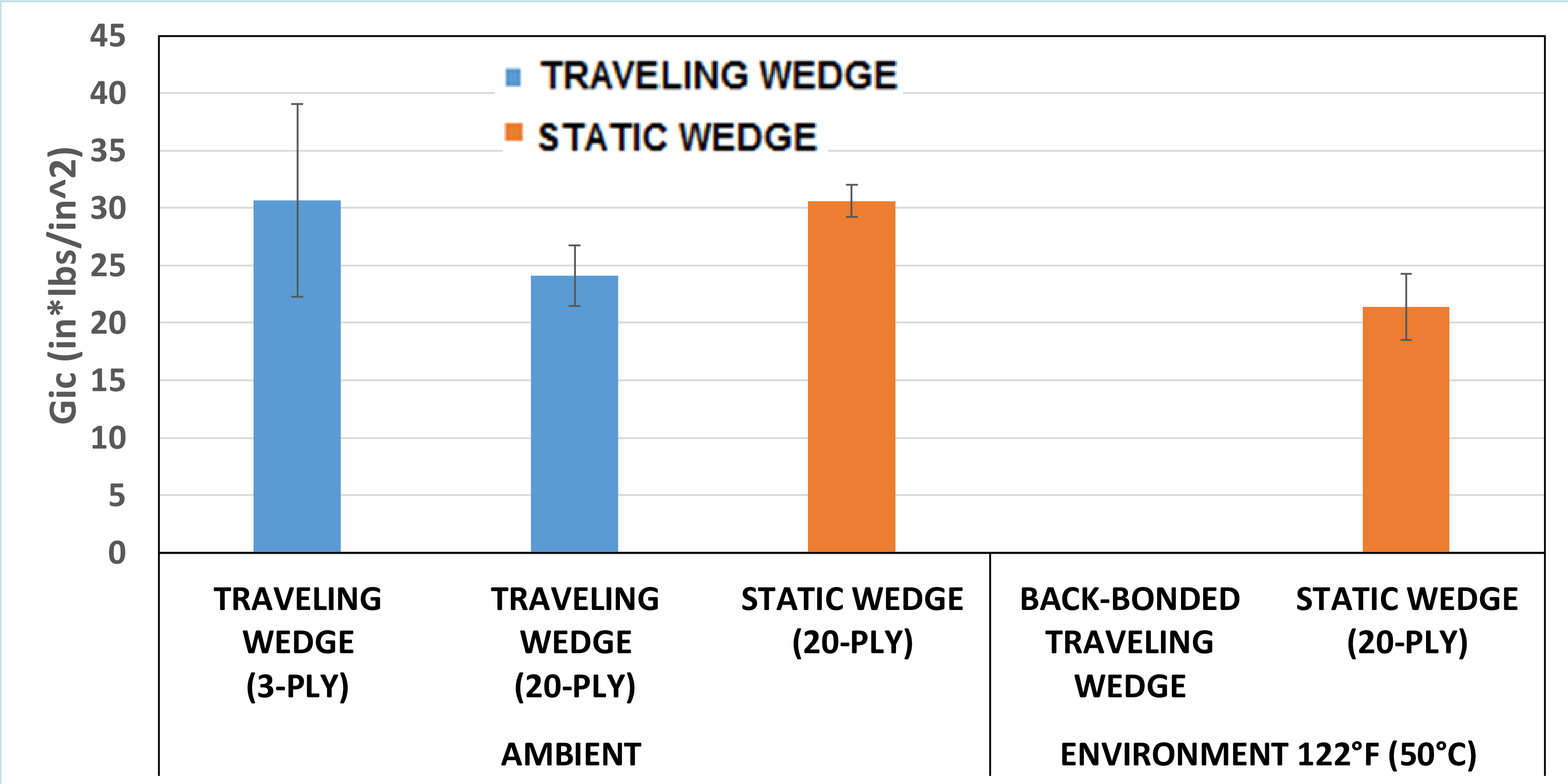
- Unidirectional IM7/8552 carbon/epoxy adherends
  - Thin adherends: (3 ply, 0.024 in.)
  - Back-bonded thick adherends: (20 ply, 0.144 in.)
    - 3 ply adherends for reduced moisture saturation time
    - Back-bonded for specimen thickness representative of static wedge and DCB specimens
- AF163-2K film adhesive
- “Ideal” and “Non Ideal” surface preparations

$$G_c = \frac{3\, E_f\, t^2\, h^3}{16\, \mathrm{a}^4}$$



Fracture Toughness Comparison: Traveling Wedge Vs. Static Wedge

- General agreement in fracture toughness values at ambient conditions
- Hot/wet traveling wedge testing underway

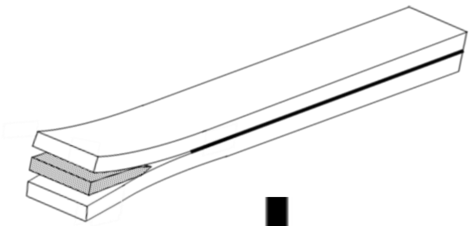


Traveling Wedge Test Assessment: Current and Upcoming Work

- **Further evaluation of adherend thickness effects**
- **Comparison of G_c estimates with static wedge, and back-bonded DCB tests**
- **Modify the wedge apparatus**
  - **Reduce friction/binding**
  - **Permit use of thin adherends**

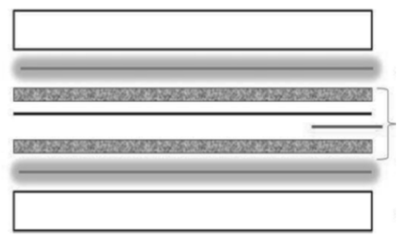
Candidate Test Methods:

- Static Wedge Crack Test



- Traveling Wedge Test

➡ **Boeing Back-Bonded DCB**

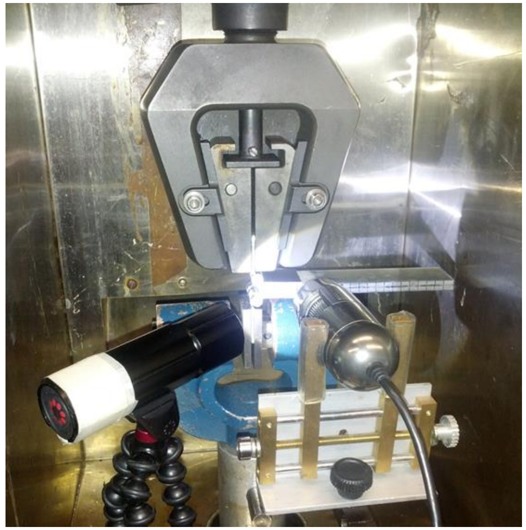


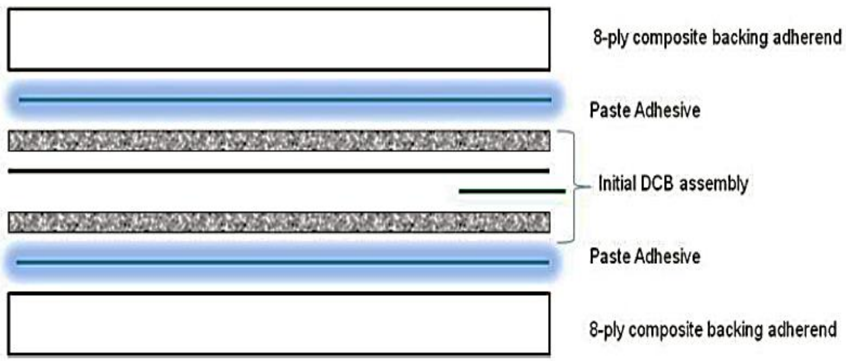
Blohowiak et al., "SAMPE 2013 Rapid Test Methods for Adhesion" (2013)

Van Voast et al., SAMPE 2013

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

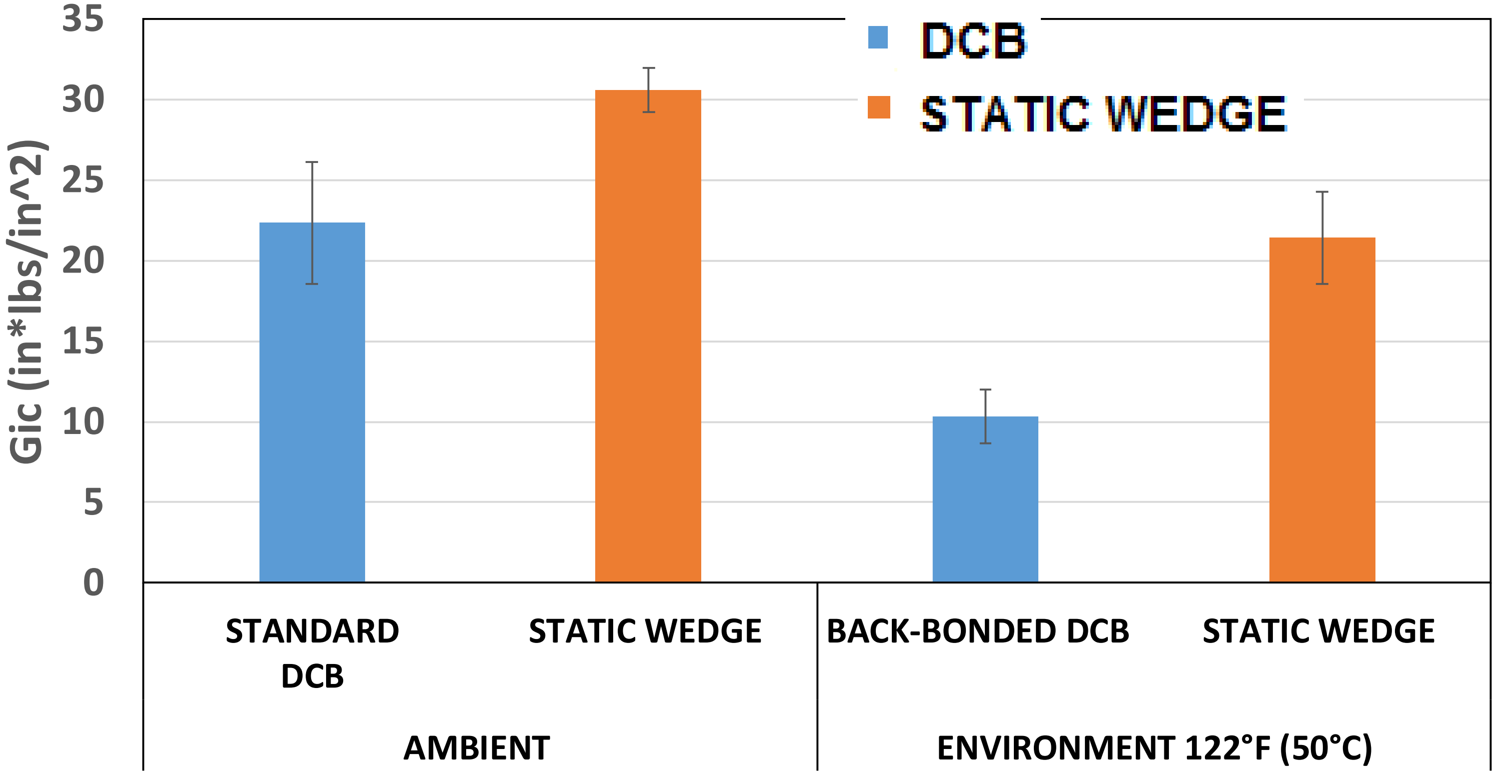




Van Voast, Blohowiak, Osborne and Belcher,
"Rapid Test Methods for Adhesives and Adhesion" (SAMPE 2013)

Fracture Toughness Comparison: Back-Bonded DCB vs. Static Wedge

- **Higher fracture toughness values with static wedge**
- **Greater reductions in DCB due to environment**
- **Further investigation underway**



Environmental Durability Testing of Composites: Summary

In summary…

- **Composite Wedge test appears promising**
  - **Simple test to assess environmental durability**
  - **Small bond area is evaluated**
- **Interest continues in Traveling Wedge test**
  - **Relatively large bond area may be evaluated**
- **Boeing Back-Bonded DCB test serves as a baseline**
  - **Accurate, well accepted measure of Gc**
  - **Moisture conditioning of thin adherends appears feasible**

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 candidate test methods for assessing the environmental durability of adhesively bonded aircraft structures**
- **Dissemination of research results through FAA technical reports and conference/journal publications**