DURABILITY OF ADHESIVELY BONDED JOINTS:

REVISING THE WEDGE CRACK DURABILITY TEST

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FAA Sponsored Project Information

- **Principal Investigators: Dr. Dan Adams**
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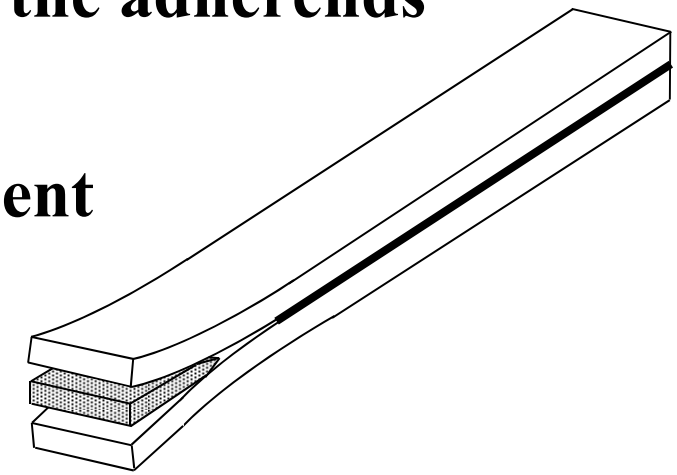
- **Primary Collaborators:**
  - **Boeing: Kay Blohowiak and Will Grace**
  - **Air Force Research Laboratory: Jim Mazza**

Background:
Metal Wedge Crack Durability Test

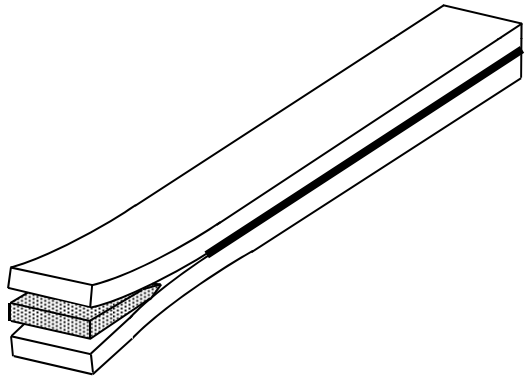
ASTM D 3762, "Standard Test Method for Adhesive-Bonded Surface Durability of Aluminum (Wedge Test)"

- **Bonded aluminum double cantilever beam specimen is loaded by forcing a wedge between the adherends**
- **Wedge is retained in the specimen**
- **Assembly placed into a test environment**
  - **Aqueous environment**
  - **Elevated temperature**



- **Further crack growth is measured following a prescribed time period**

GENERAL PERCEPTIONS: Current ASTM D 3762 Standard



- Well-suited test methodology for assessing adhesive bond durability
- Standard includes a good description of test specimen
- Additional guidance needed in specimen manufacturing
- More detail required in test procedure
- Lacking sufficient guidance regarding conditions and requirements that constitute an acceptable metal bonded joint

REVISION OF WEDGE TEST METHOD:
Primary Areas Identified

Editorial Revisions

- Clarification of geometry
- Correction of procedure problems
- Improvement of figures

Specimen Preparation

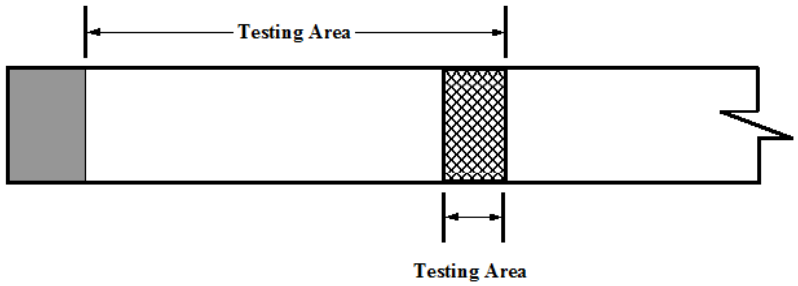
- Controlling bondline thickness
- Machining specimens from panel

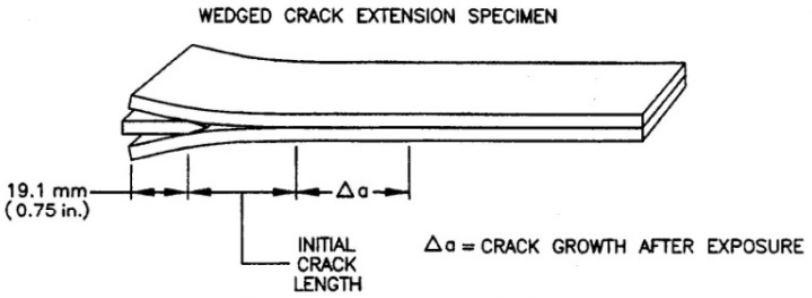
Testing Procedure

- Method of wedge insertion
- Measurement of initial crack length
- Specimen orientation during testing
- Specification of test environment

Interpretation of Results

- Role of initial crack length
- Role of crack growth
- Role of failure mode in test area





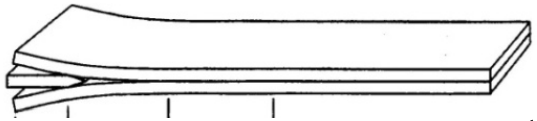
REVISION OF WEDGE TEST METHOD: Possible Levels of Additional Guidance

For the specimen/test parameter of interest, options include…

- **Inform users that variations can affect results**
- **Report the value of the parameter used**
- **Suggest a value or range of values of the parameter**
- **Require a value or range of values of the parameter**

REVISION OF WEDGE TEST METHOD: Wedge Insertion Method

- "*Tappers*" vs. "*Thumpers*" – Wedge Insertion Rate
  - Three surface preparations investigated:
    - Ideal: PAA & prime
    - Weak: PAA w/o prime, grit blast & prime



"Ideal" Bonding

- No statistically significant effect on:
  - Initial crack length
  - Ambient crack growth
  - Environmental crack growth

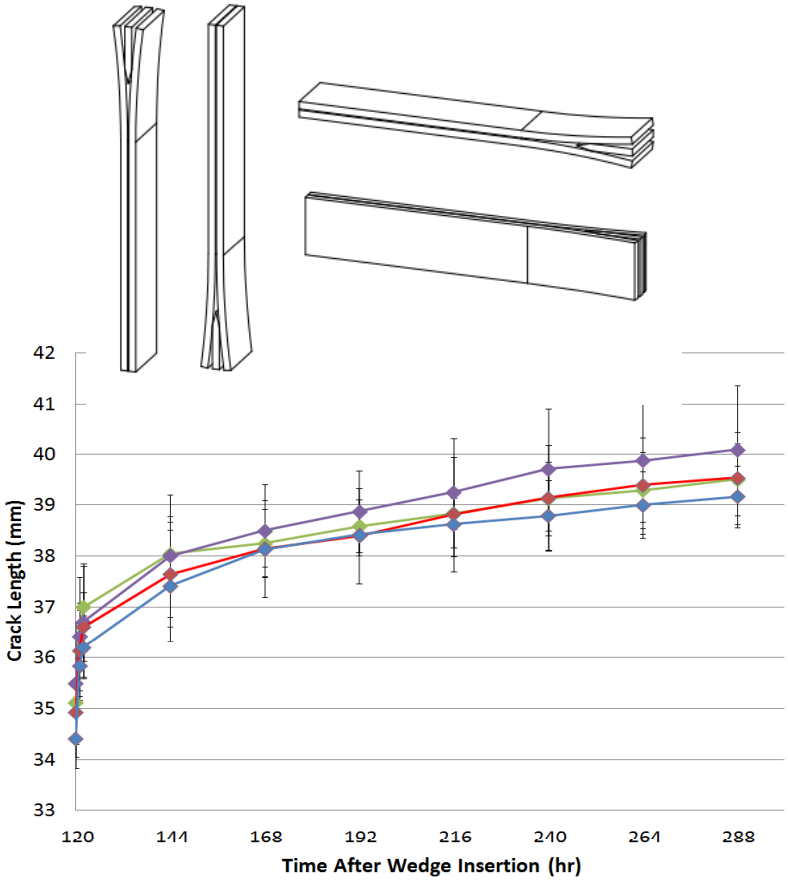
"Weak" Bonding

- Statistically significant effect on:
  - Initial crack length
  - Ambient crack growth
  - Environmental crack growth

Inform ***Report?*** ***Suggest?*** ***Require?***

REVISION OF WEDGE TEST METHOD: Specimen Orientation

- Investigate effect of specimen orientation during environmental exposure
  - Three surface preparations:
    - Ideal: PAA & prime
    - Weak: PAA w/o prime, grit blast & prime
- No statistically significant effect for any of the surface preparations



Inform *Report?* *Suggest* *Require?*

REVISION OF WEDGE TEST METHOD:
Guidance on Selection Of Test Environment

- **Humidity**
  - ASTM D3762
    - Condensing humidity
  - TTCP AG13 suggests
    - 95% RH noncondensing

  ➡ **What role does humidity play?**
- **Temperature**
  - 50°C, 60°C, or 70°C

  ➡ **What rode does temperature play?**
- **Duration**
  - Hour, day, week, month, or year

  ➡ **What role does duration play?**

TABLE 1 Standard Test Environments

Test Environment Number	Temperature, °C (°F)[A]	Moisture Conditions % Relative Humidity[B]
1	23 (73.4)	immersed in distilled or deionized water
2	23 (73.4)	50
3	23 (73.4)	15
4	35 (95)	90
5	35 (95)	100
6	50 (122)	90
7	50 (122)	100
8	60 (140)	100
9	71 (160)	100
10	35 (95)	5 % salt fog
11	ambient (outdoors)	ambient (outdoors)
12	other (specify)	other, including aqueous solutions or nonaqueous liquids (specify)

[A]The tolerance for test temperature shall be ± 1°C or 1.8°F for environments 1 to 10.

[B]The moisture condition may be provided by controlling the relative humidity of a box, room, or other chamber by any convenient means.

REVISION OF WEDGE TEST METHOD:
Acceptance Criterion

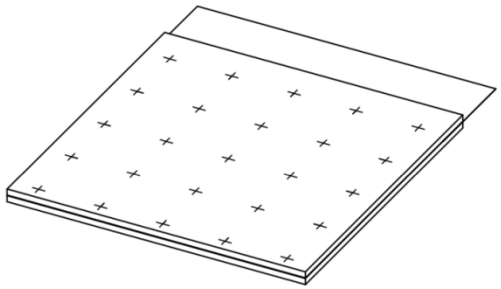
- **Current example acceptance criterion**
  - **"Typically good durability surface preparation is evidenced by no individual specimen having a crack extension, Δa, exceeding 19 mm (0.75 in.) with the average of all specimens not over 6.3 mm (0.25 in.), when placed in 50°C (122°F) condensing humidity for 1 h."**

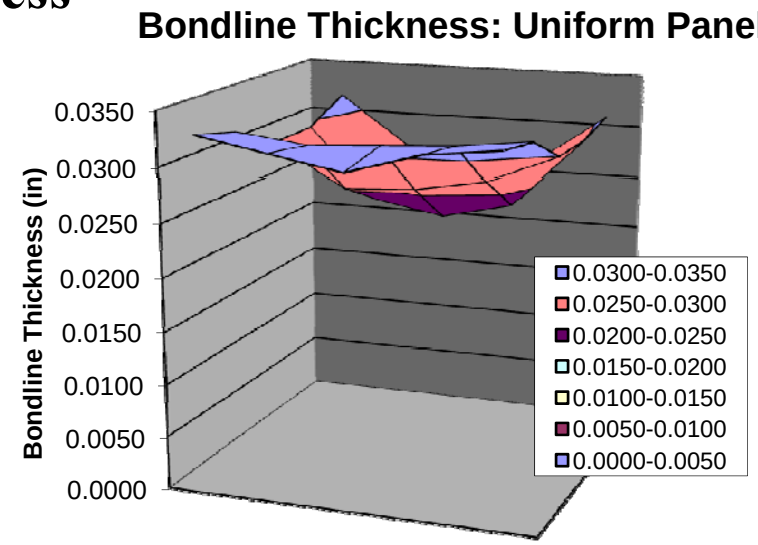
- **Crack Extension**
  - **Mentioned but not restrictive enough**
  - ➡ **What amount/range of growth is acceptable?**

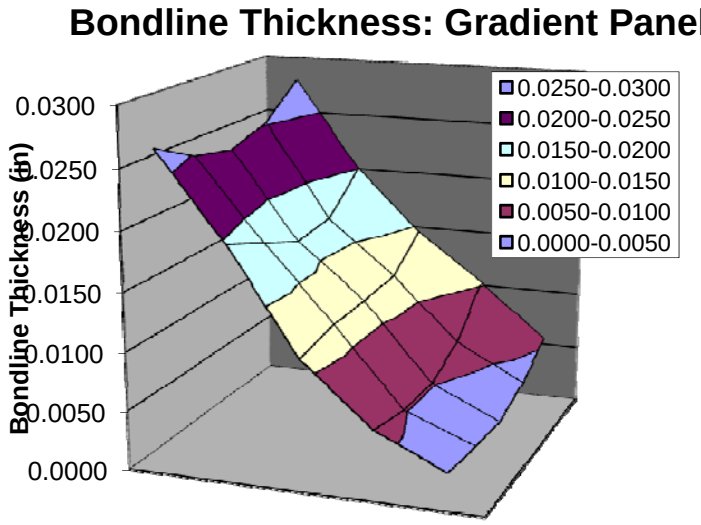
- **Failure Mode**
  - ***Not mentioned!***
  - **Strong indicator of a durable bond**
  - ➡ **What level (percentage) of cohesion failure acceptable?**

BONDLINE THICKNESS EFFECTS

- From literature review: Bondline thickness can affect specimen performance
- No mention of bondline thickness control in ASTM standard
- Approach: Create multiple bondline thicknesses
  - Thickness gradient across panel
  - Constant thickness in panel with multiple panels
  - Adhesive: AF 163-2K film adhesive
  - Surface Preparation: PAA with BR 6747-1 bond primer
- Document effects:
  - Crack growth
  - Failure mode

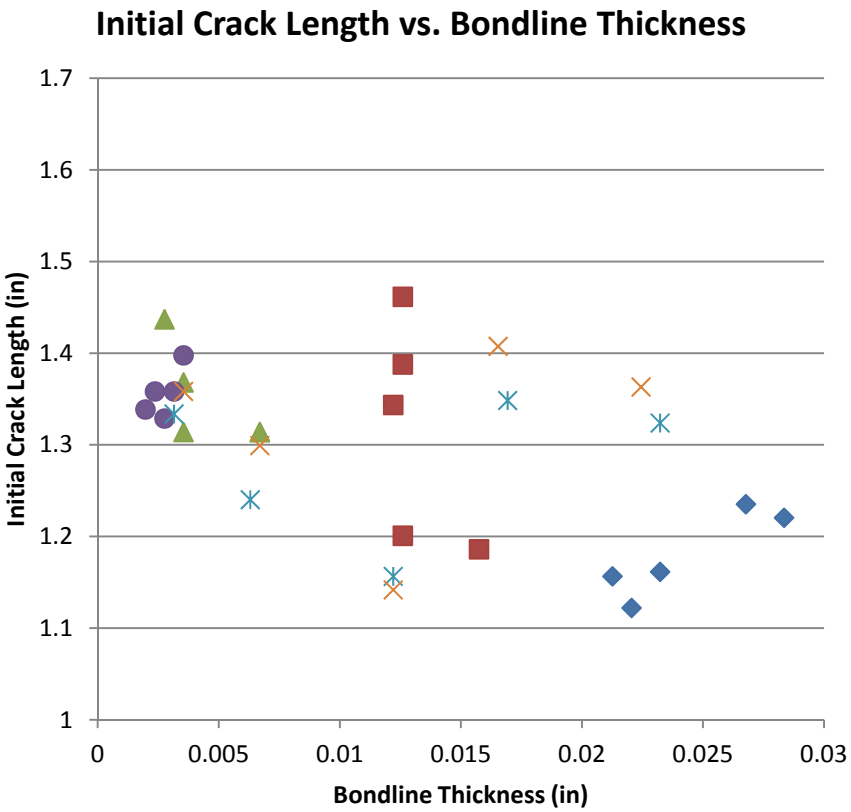


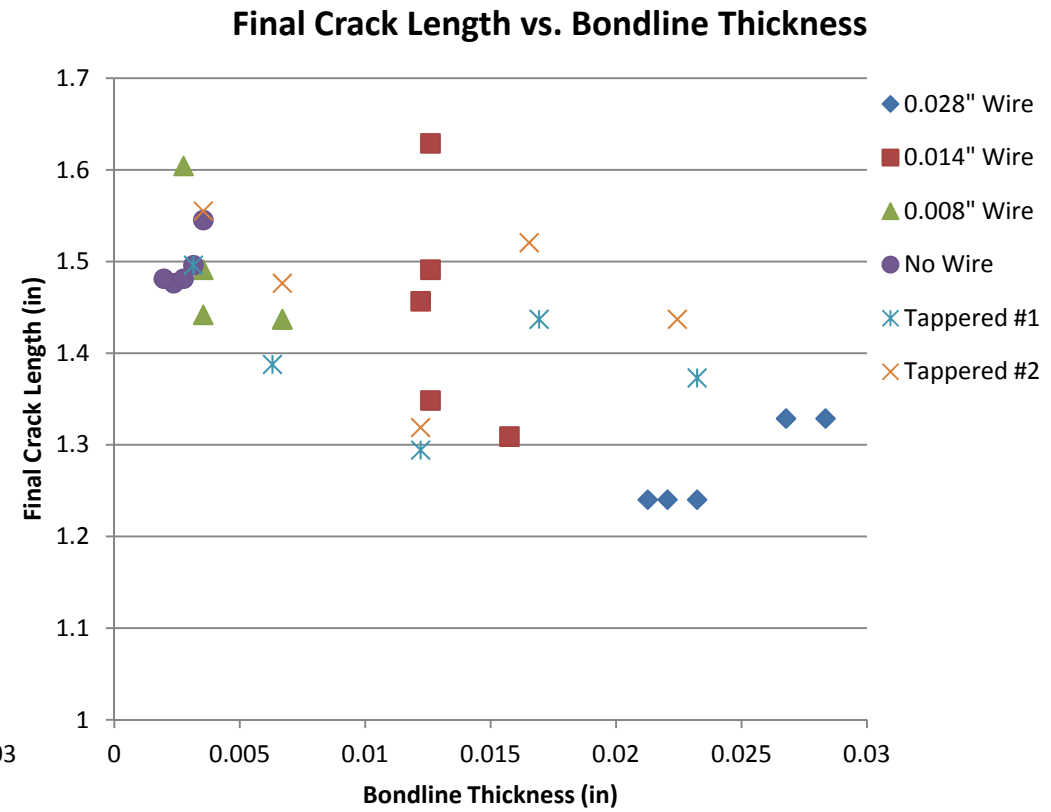




BONDLINE THICKNESS EFFECT: Initial & Final Crack Length

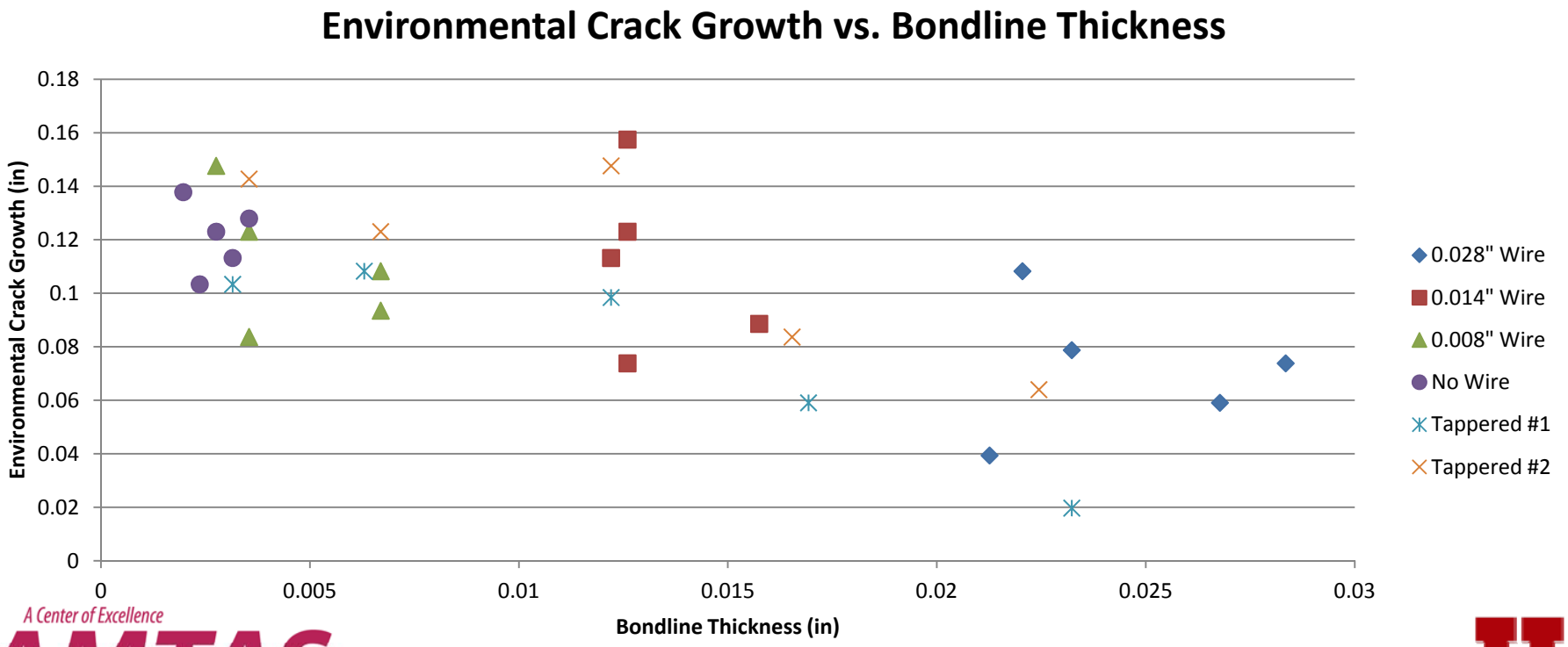
- **Increasing the bondline thickness results in:**
  - **Decreased initial crack length (Immediately following wedge insertion)**
  - **Decreased final crack length (7 day exposure @ 50° C, 100%RH)**





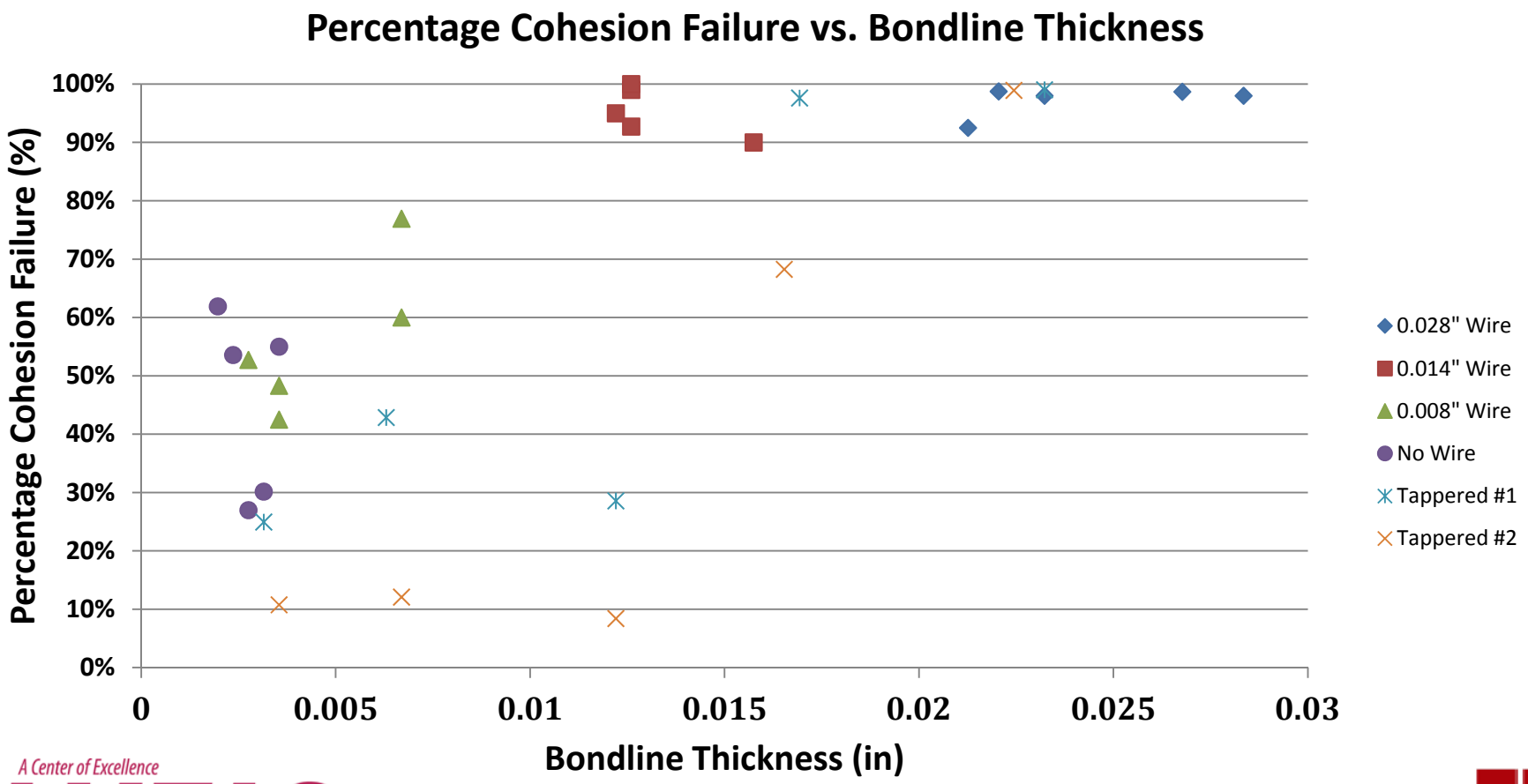
BONDLINE THICKNESS EFFECT: Environmental Crack Growth

- 7 day exposure at 50° C and 100%RH
- Increasing bondline thickness decreases environmental crack growth



BONDLINE THICKNESS EFFECT: Failure Mode

Increasing bondline thickness increases percent cohesion failure



BONDLINE THICKNESS EFFECT: Summary of Results

- **Increasing bondline thickness decreases:**
  - **Initial crack length**
  - **Final crack length**
  - **Environmental crack growth**
  - **Adhesion failure / interfacial failure**

- **Significant effect on acceptance criteria?**
  - **Environmental crack growth not greatly affected**
  - **Failure mode affected significantly**

Uniformity of bondline thickness is important!

Inform Report Suggest Require?

CURRENT FOCUS:
Use of Different Types of Adhesives

- **Perform wedge testing with a second adhesive: FM 300 film adhesive**
- **Investigate differences between *low toughness* (high strength) and *high toughness* adhesives**
  - **Different initial crack lengths**
  - **Differences in importance of specimen preparation and testing parameters**

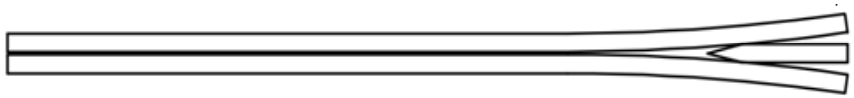
LOOKING AHEAD:

Development of a Wedge Test For Adhesively Bonded Composite Laminates

Complexities associated with a composite wedge test include:

- **Flexural stiffness of composite adherends**
  - **Must be within a specific range**

    OR
  - **Must tailor wedge thickness for specific composite adherends**
- **Fiber orientation adjacent to bonded interface**



The need for a bonded composites durability test is just as great as it was for metal bonding 20 years ago."

- John Hart-Smith

International Journal of Adhesion and Adhesives, 1999