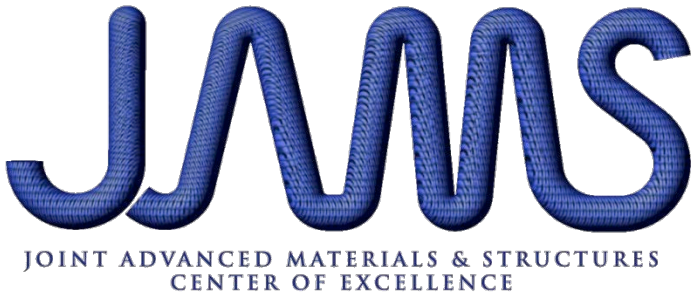


# Durability of Adhesively Bonded Joints For Aircraft Structures

2012 Technical Review

Dan Adams, Larry DeVries, Clint Child
University of Utah

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# FAA Sponsored Project Information

- **Principal Investigators:**
  - Dr. Dan Adams  Dr. Larry DeVries
- **Graduate Student Researcher:**
  - Clint Child
- **FAA Technical Monitor:**
  - David Westlund
- **Primary Collaborators:**
  - Boeing
  - Air Force Research Lab
  - National Research Council – Canada

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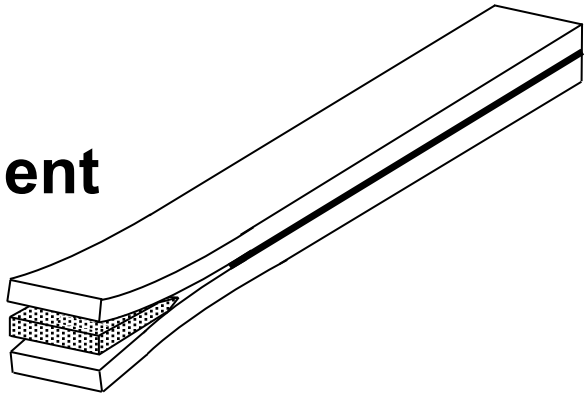
# BACKGROUND:

## 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**

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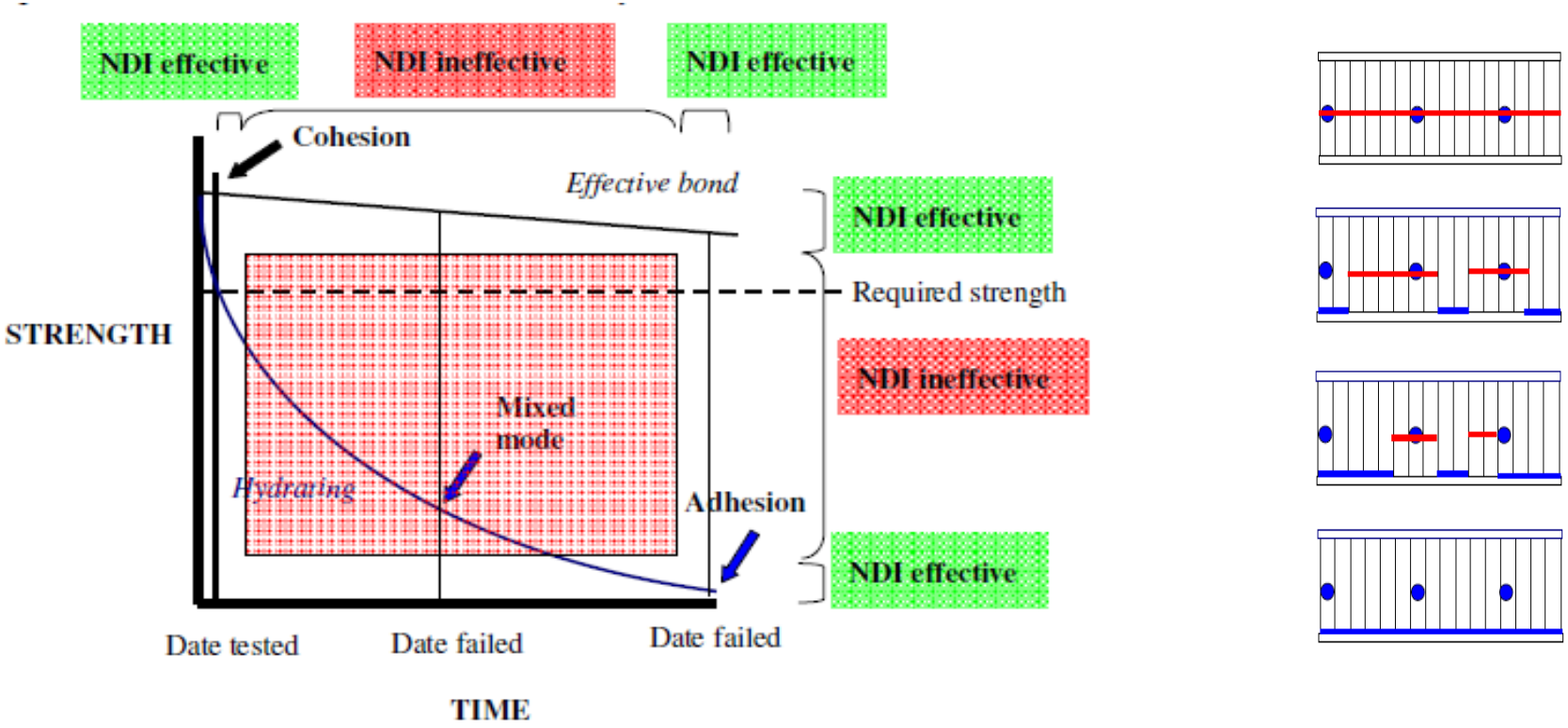
# AREA OF CONCERN:

## Reduction in Bond Strength Through Hydration




*Davis, M.J., and McGregor, A. "Assessing Adhesive Bond Failures: Mixed-Mode Bond Failures Explained," I SASI Australian Safety Seminar, Canberra, 4-6 June 2010.*

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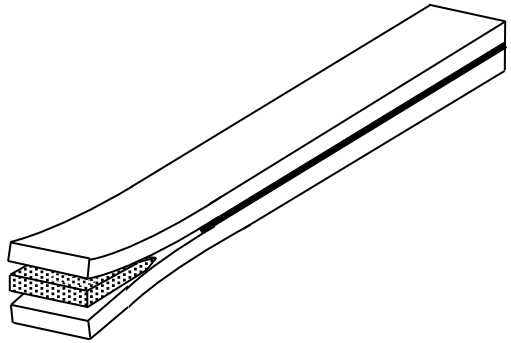
# GENERAL PERCEPTIONS:

## 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

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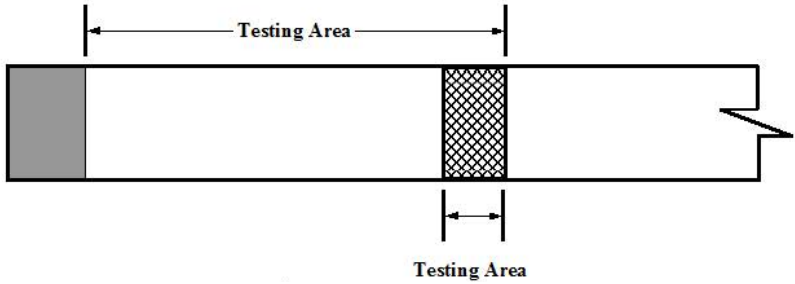
# REVISION OF WEDGE TEST METHOD :

## Primary Areas Identified

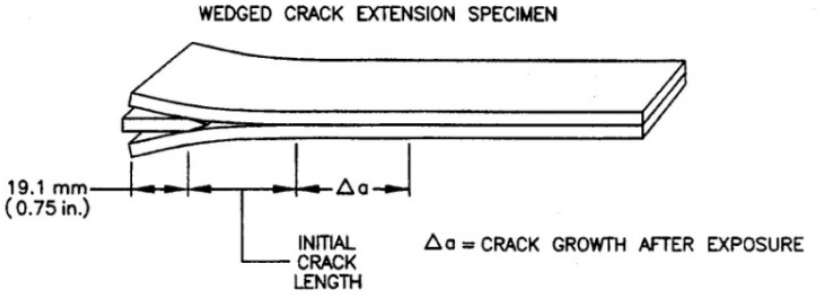
### Specimen Preparation

- Controlling bondline thickness
- Machining specimens from panel




### Testing Procedure

- Method of wedge insertion
- Measurement of initial crack length
- Specification of test environment
- Identification of failure mode




### Interpretation of Results

- Role of Initial Crack Length
- Role of Crack Growth
- Role of Failure Mode in Test Area

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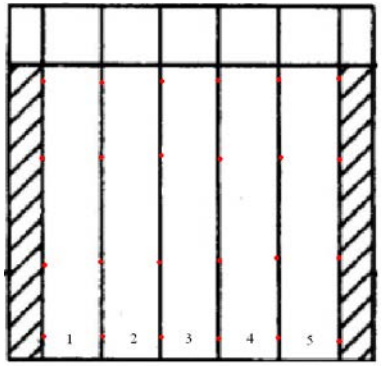
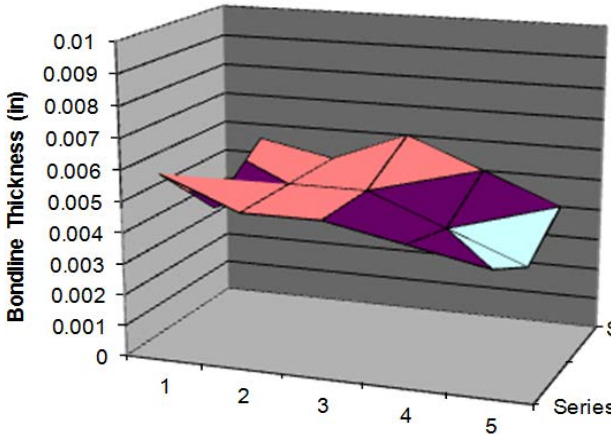
# SPECIMEN PREPARATION ISSUES:

## Controlling Bondline Thickness

- Uniform bondline thickness believed to be important for durability testing
- Without precautions, different bondline thicknesses will likely result across panel

➡ **Place guidance into standard**

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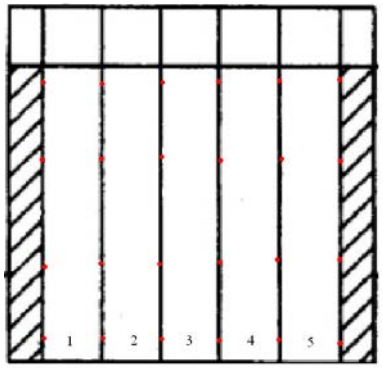
# SPECIMEN PREPARATION ISSUES:

## Cutting Panel into Test Specimens

- Many methods in use
  - Band saw and mill
  - Gang saw
  - Water jet cutting
  - Others?
- Establish best practices

➡ **Place guidance into standard**



# TEST PROCEDURE ISSUES:

## Method of Wedge Insertion

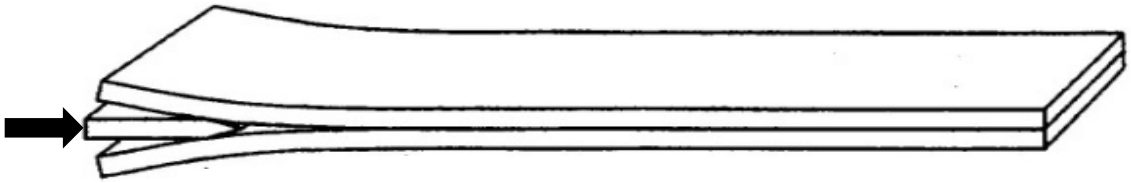
- Guidance from ASTM D 3762:

  *"Open the end of the test specimen that contains the separation film, and **insert the wedge**"*

- "Tappers" vs. "Thumpers"

**Encourage gentle hammering or pressing?**

**Effect on initial crack length?**



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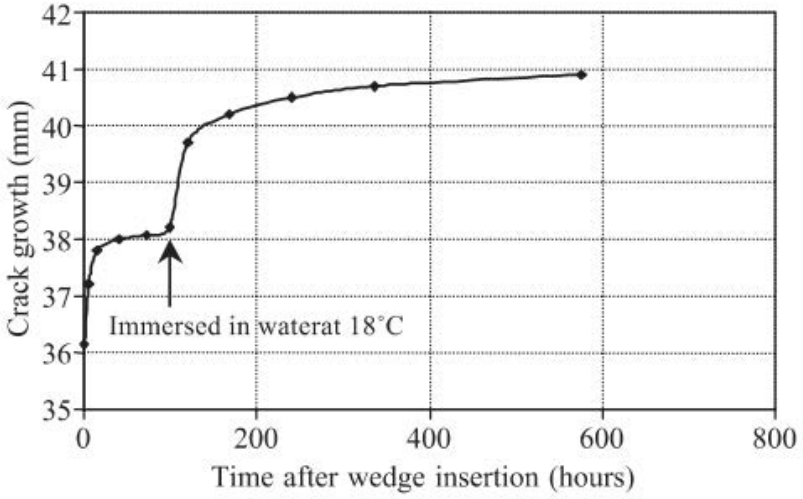
# TEST PROCEDURE ISSUES::

## Measurement of Initial Crack Length

***When should "initial" crack length measurement made?***

- **ASTM D3762**
  - Immediately after wedge insertion
- **TTCP AG13**
  - One hour after wedge insertion




***Sargent (2005)***

**Investigate time required for $a_0$ to stabilize**

**Revisit standard: Establish time following wedge insertion for crack measurement to be made**

# TEST PROCEDURE ISSUES:

## Guidance on Suitable Test Environment

- ASTM D3762:
  - ***"A typical accelerated aging environment commonly used is 50°C (122°F) and condensing humidity."***
- TTCP AG13
  - ***50°C (122°F), 95% RH (non-condensing)***
- Industry users (aerospace):
  - **Dependent on intended use, type of adhesive being tested**
    - **120°F, 140°F, 160°F**
    - **24 hrs, 7 days, 1 month**

**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) |

***From ASTM D3762***

- **How should user choose environment?**
- **Place guidance into standard**

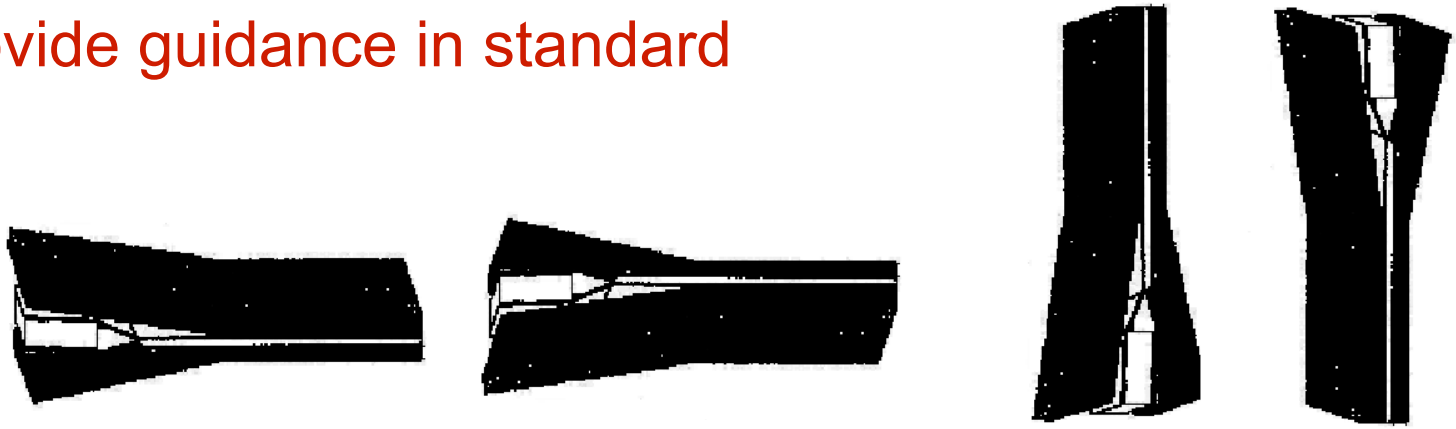
# TEST PROCEDURE ISSUES:

## Specimen Orientation During Testing

- Orientation of specimen during testing is not specified in ASTM D3762
- TTCP AG13 suggests that orientation be specified

## Four Possible Orientations…

- Investigate orientation effect on resulting crack length
- Provide guidance in standard



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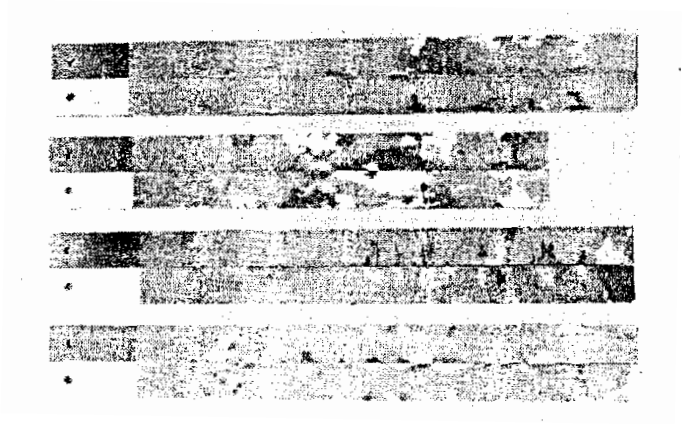
# INTERPRETATION OF RESULTS ISSUES:

## Failure Mode as Part of Acceptance Criteria

- **ASTM D 3762:**
  - **"*Failure mode is to be reported*"**
  - **No mention of failure mode in regards to acceptance criteria**
- **TTCP AG13:**
  - **"*The surface generated during exposure must not exhibit greater than 10% adhesion (interfacial) failure.*"**



McMillan (1979)

**Modify acceptance criteria: Emphasis on failure mode**

- **What percentage of adhesion failure is acceptable?**
- **How should failure mode percentage be determined?**

# INITIAL EXPERIMENTAL PROGRAM

## Investigate Issues with Testing Procedure

- Effect of wedge insertion method
- Measurement of initial crack length
- Effect of specimen orientation during testing

**Specimen Fabrication**

- Adherend: 2024-T3 aluminum alloy
- Multiple Surface Preparations
  - "Ideal" Bonding
    - Phosphoric acid anodized with BR 6747-1 bond primer
  - Intentional "Weak" Bonding
    - Grit Blast with BR 6747-1 bond primer
    - Phosphoric acid anodized without bond primer
- Adhesive: AF 163-2K film adhesive

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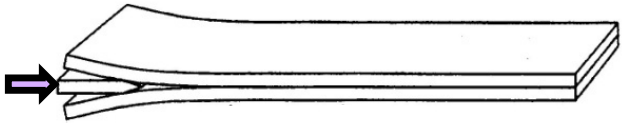
# EXPERIMENTAL PROGRAM:

## Method of Wedge Insertion

**Investigate "*Tappers*" vs. "*Thumpers*" - Wedge insertion rate**

- "Tappers" (Pressed)
  - Use of drill press (0.2 in/sec)
- "Thumpers" (Hammered)
  - Single strike
- Effect on initial crack length, $a_0$
- Compare crack growth of *tapped* and *thumped* specimens
  - After wedge insertion in lab environment
  - After environmental exposure



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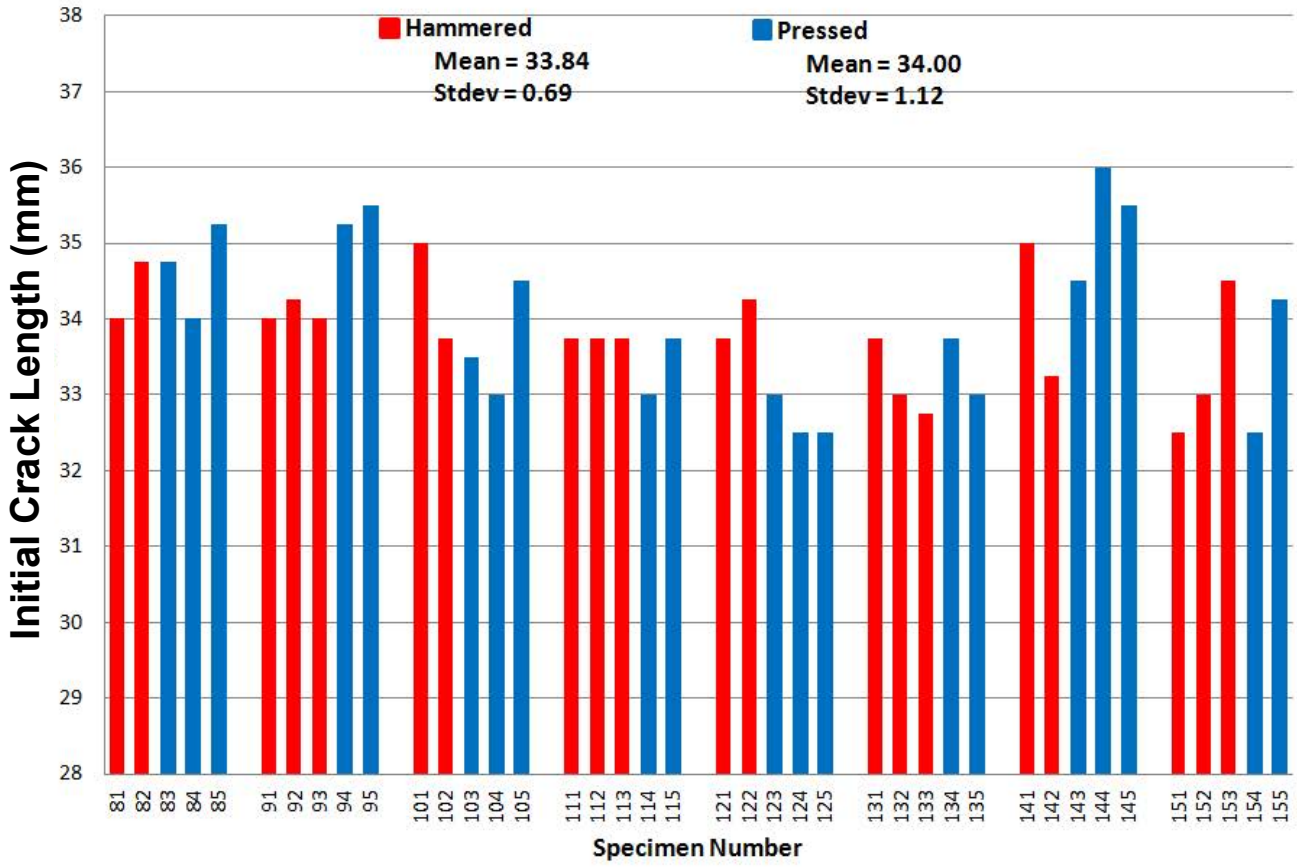
# EFFECTS OF WEDGE INSERTION METHOD:

## Initial Crack Length With "Ideal" Bonding




**Difference not statistically significant for "ideal" bonding**

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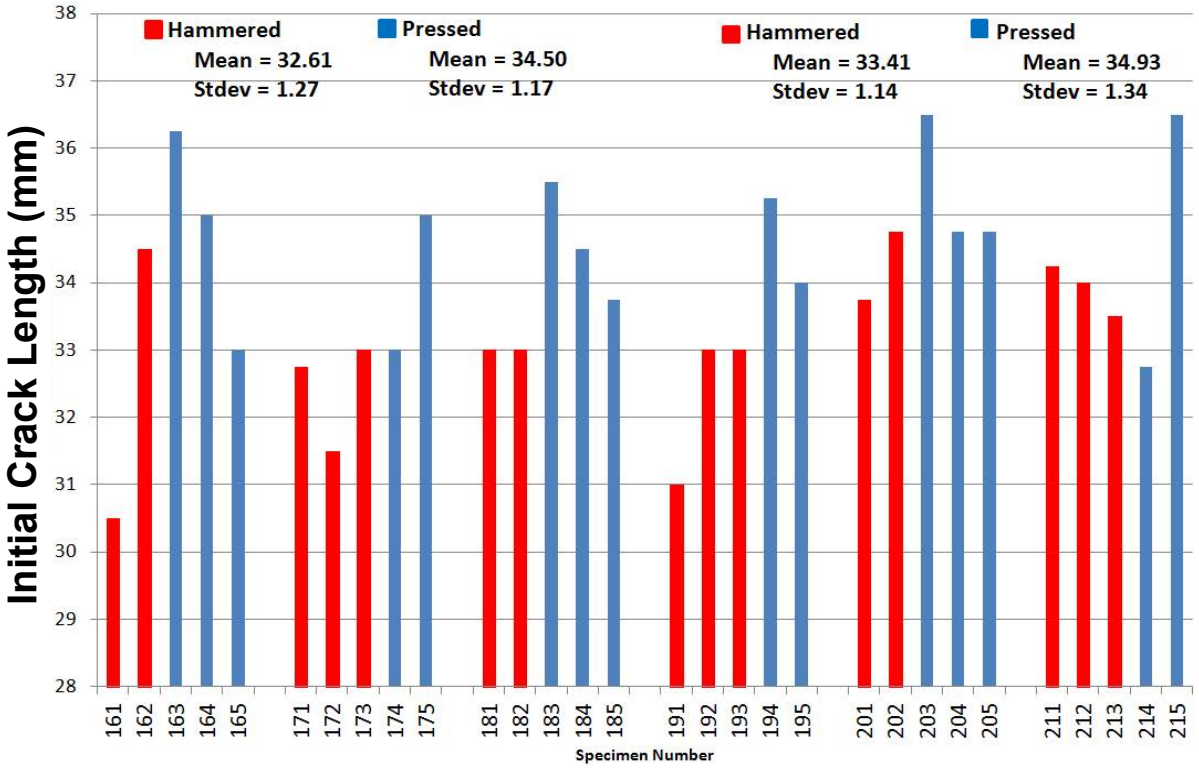
# EFFECTS OF WEDGE INSERTION METHOD:

## Initial Crack Length With "Weak" Bonding




- **Statistically significant differences for "weak" bonding**
- **Longer initial crack lengths for pressed than hammered specimens**

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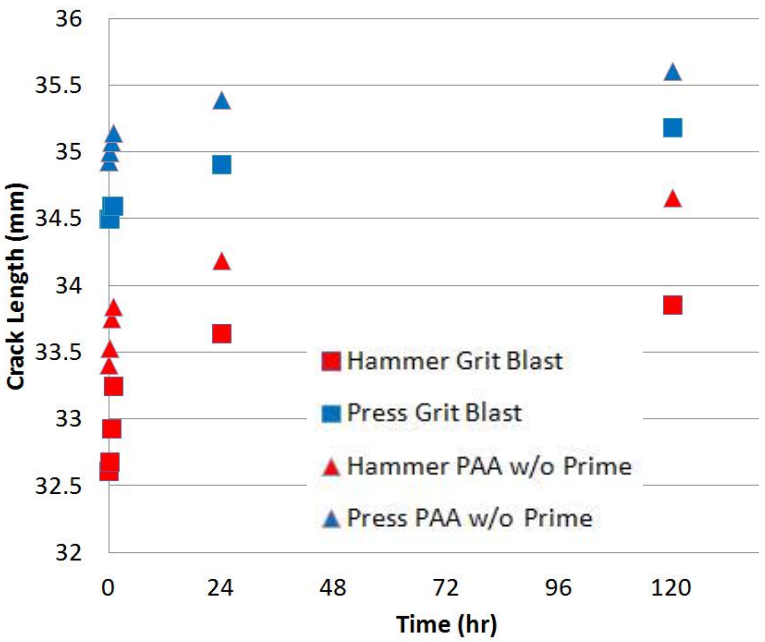
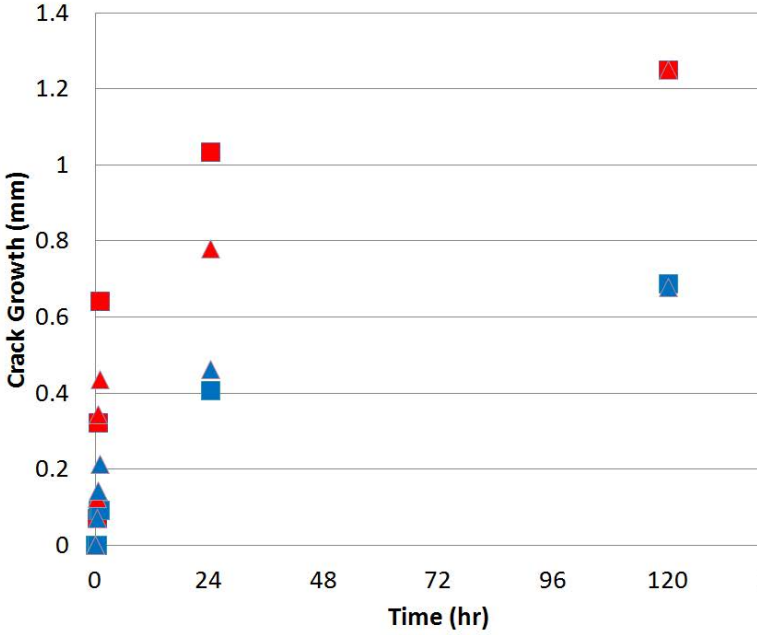
# EFFECTS OF WEDGE INSERTION METHOD:

## Crack Growth During Five Days at Ambient Conditions




- **Difference not statistically significant for "ideal" bonding**
- **Statistically significant differences for "weak" bonding**
  - **Pressed specimens had longer crack length after 5 days**
  - **Hammered specimens experienced greater crack growth after 5 days**

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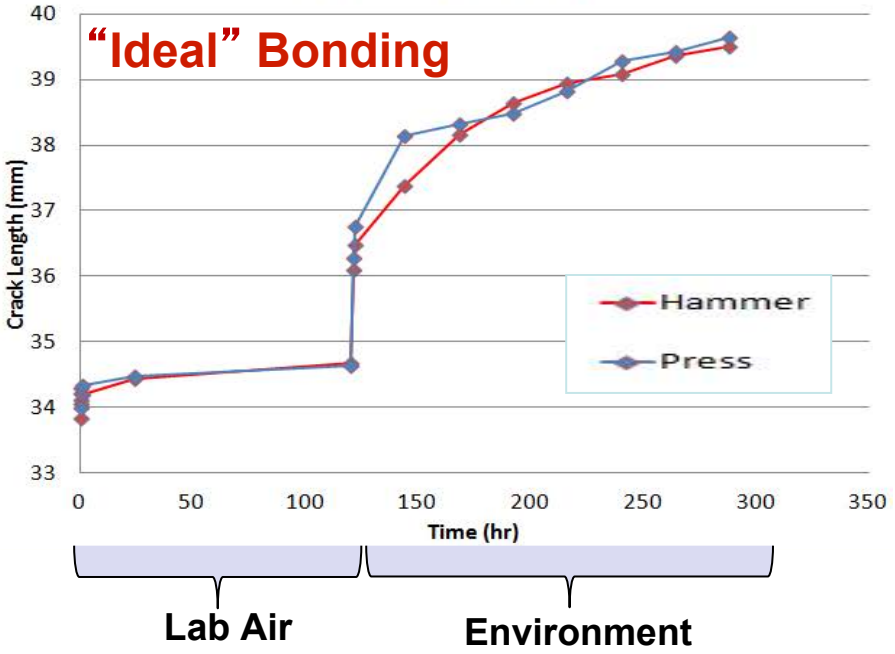
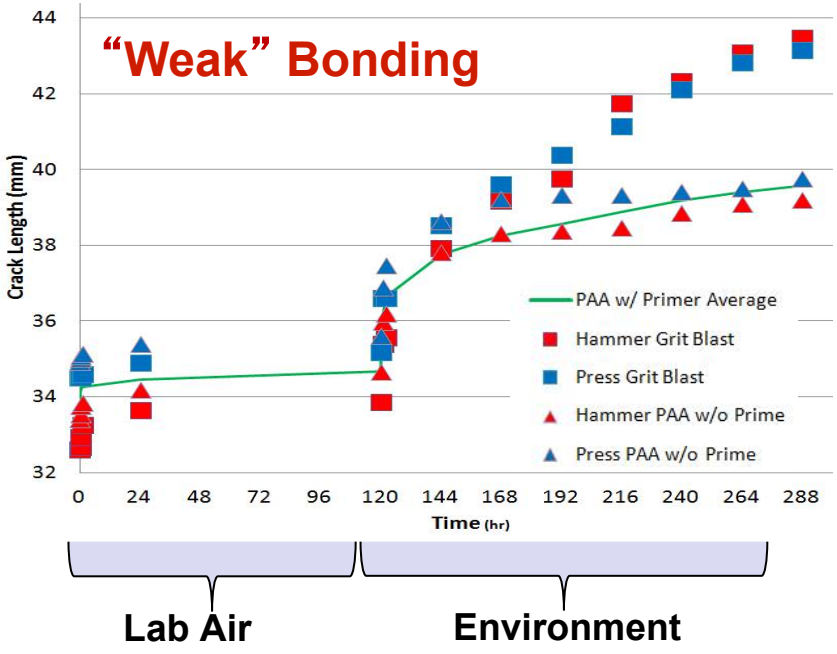
# EFFECTS OF WEDGE INSERTION METHOD:

## Crack Growth During 1 Week at 50℃ 100% Relative Humidity




- **Difference not statistically significant for "ideal" bonding**
- **Statistically significant differences for "weak" bonding**
  - **Different crack lengths at onset of conditioning**
  - **Similar crack lengths following conditioning**
  - **Different crack growths for pressed and hammered specimens**

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# EFFECTS OF WEDGE INSERTION METHOD:

## Summary of Findings

- **No significant effects with "ideal bonding"**
  - Initial Crack Length
  - Growth Before Environmental Exposure
  - Growth During Environmental Exposure
- **Significant effects for "weak bonding"**
  - Initial Crack Length
  - Growth Before Environmental Exposure
  - Growth During Environmental Exposure

**Place guidance into standard regarding insertion method**

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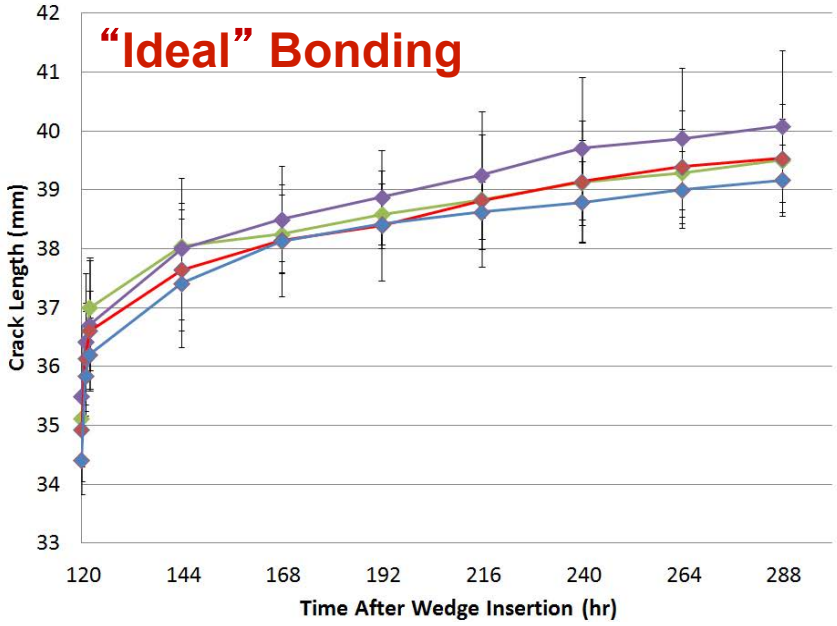
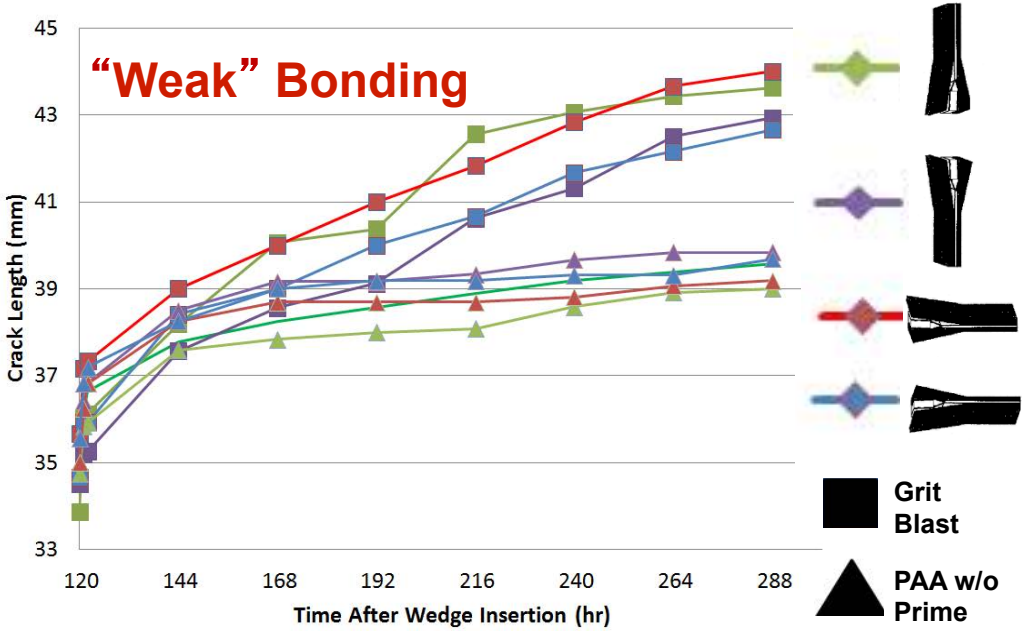
# SPECIMEN ORIENTATION EFFECTS:

## Crack Lengths For Four Orientations

***1 Week at 50 ℃ and 100% Relative Humidity***




**No discernible effects of specimen orientation on crack length**

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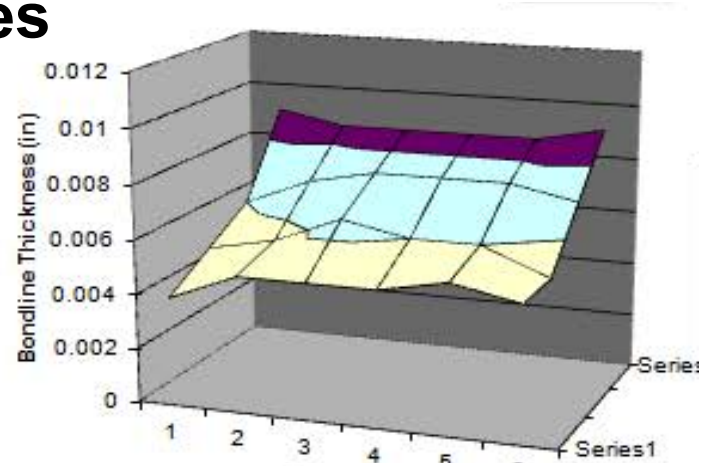
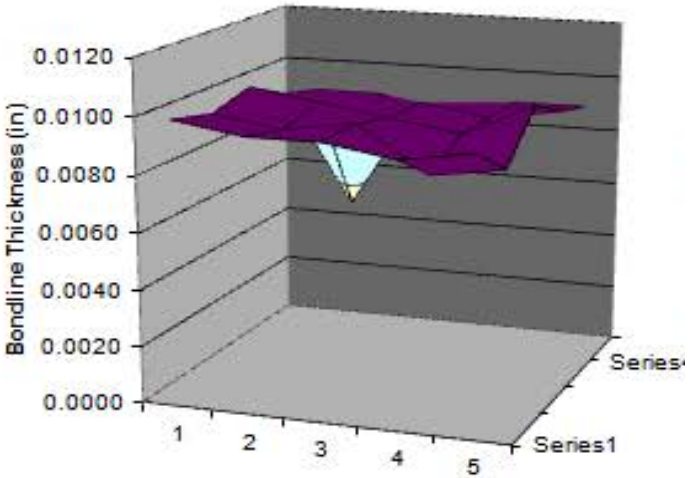
# CURRENT FOCUS:

## Bond Line Thickness Effects

- **Create multiple bond line thicknesses**
  - **Thickness gradient across panel**
  - **Thickness differences within multiple panels**
- **Investigate bond line thickness effects on:**
  - **Initial crack length**
  - **Crack growth during exposure**
  - **Failure mode**

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# SUMMARY

- Several areas of improvement to ASTM 3762 have been identified
- Experimental program underway to provide results required to support test method revisions
- Several key user groups of ASTM D 3762 are part of standard revision process
- Encouraging response from ASTM Committee D14 on Adhesives
  - Presentations by PI's at last two ASTM D14 Meetings
  - PI Adams leading Task Group to revise standard
  - Next ASTM D14 meeting: April 17th, Phoenix AZ

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# BENEFITS TO AVIATION

- Improved adhesive bond durability test method
- Improved acceptance criteria
- Method for assessing the durability of adhesively bonded aircraft structures
- Dissemination of research results through FAA technical reports and journal publications

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# Thank you for your attention!

# Questions?

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