**FAA Sponsored Project Information**

- **Principal Investigators:**
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- **Graduate Student Researcher:**
  - Clint Child

- **FAA Technical Monitor:**
  - David Westlund

- **Primary Collaborators:**
  - Boeing
  - Air Force Research Lab
  - National Research Council – Canada
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
AREA OF CONCERN:
Reduction in Bond Strength Through Hydration

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

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
- Identification of failure mode

Interpretation of Results
- Role of Initial Crack Length
- Role of Crack Growth
- Role of Failure Mode in Test Area
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
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?
Testing Procedure Issues:

**Measurement of Initial Crack Length**

*When should “initial” crack length measurement be made?*

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

*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>
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<tr>
<th>Test Environment Number</th>
<th>Temperature, °C (°F)</th>
<th>Moisture Conditions % Relative Humidity</th>
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<tr>
<td>1</td>
<td>23 (73.4)</td>
<td>immersed in distilled or deionized water</td>
</tr>
<tr>
<td>2</td>
<td>23 (73.4)</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>23 (73.4)</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>35 (95)</td>
<td>90</td>
</tr>
<tr>
<td>5</td>
<td>35 (95)</td>
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<td>9</td>
<td>71 (160)</td>
<td>100</td>
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<td>10</td>
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<td>5% salt fog</td>
</tr>
<tr>
<td>11</td>
<td>ambient (outdoors)</td>
<td>ambient (outdoors)</td>
</tr>
<tr>
<td>12</td>
<td>other (specify)</td>
<td>other, including aqueous solutions or nonaqueous liquids (specify)</td>
</tr>
</tbody>
</table>

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
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."

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
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, a₀
- Compare crack growth of tapped and thumped specimens
  - After wedge insertion in lab environment
  - After environmental exposure
EFFECTS OF WEDGE INSERTION METHOD:

Initial Crack Length With “Ideal” Bonding

Difference not statistically significant for “ideal” bonding
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
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
EFFECTS OF WEDGE INSERTION METHOD:

Crack Growth During 1 Week at 50 °C 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
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
SPECIMEN ORIENTATION EFFECTS:
Crack Lengths For Four Orientations

1 Week at 50 °C and 100% Relative Humidity

No discernible effects of specimen orientation on crack length

“Ideal” Bonding

“Weak” Bonding

Graphs showing crack length over time for different bonding conditions.
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
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
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
Thank you for your attention!

Questions?