Design of Smart Adhesive Films for Bondline Integrity Monitoring

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Bolted Joints

Bolted joints create stress concentrations that lead to failures, and contribute a large portion of aircraft weight.

“A 747-400 has six million parts, half of which are fasteners” Boeing 747 Fun Facts

Solution: bonding aircraft components with adhesives
## Bolted vs. Bonded

<table>
<thead>
<tr>
<th></th>
<th>Bolted Joint</th>
<th>Bonded Joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress Concentration</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Weight</td>
<td>Heavy</td>
<td>Light</td>
</tr>
<tr>
<td>Total Cost</td>
<td>Expensive</td>
<td>Relatively Low</td>
</tr>
<tr>
<td>Primary Structure</td>
<td>Current Application</td>
<td>Secondary Structure</td>
</tr>
</tbody>
</table>

**Result:** Current standards require fasteners even with adhesive → *reduced benefit!!!*
Introduction

• Three major failure modes

Expected failure mode:
Load exceeds adhesive strength

Kissing Bond

Unexpected failure mode:
Load exceeds the substrate strength, not adhesive
Boeing Samples

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What happened

- Insufficient bond developed between adhesive and adhered

Traditional NDE technique can only pick gross defects

Typical defects found in Bondline

A review of defect types and nondestructive testing techniques for composites and bonded joints

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Methods of Approach

- Embed the sensors in the bondline
  - Close to adhesive-adhered interface
  - Local excitation → local bondline property
Vision and Challenges

Adhesive Films

Fiber Dimension: dia. 15~20 um

Nylon Fabrics in adhesive material (BMS 5-121, TY1)

Fibers of 15µm dia

Feature Dimension ~25 um

How to detect

How to embed

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Feasibility Study

- Surface contaminates to simulate Kissing Bond
- Embedded PZT sensors
- Impedance Measured

Imediance Analyzer

- 1/8” Embedded PZT Disc
- 4 adhesive films

Static load

Shear Strength (Psi)

<table>
<thead>
<tr>
<th>Material</th>
<th>3%</th>
<th>23%</th>
<th>37%</th>
<th>84%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDMS</td>
<td></td>
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<tr>
<td>Graphite</td>
<td>3%</td>
<td>23%</td>
<td>37%</td>
<td>84%</td>
<td>90%</td>
<td>100%</td>
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<tr>
<td>Teflon</td>
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<td>23%</td>
<td>37%</td>
<td>84%</td>
<td>90%</td>
<td>100%</td>
</tr>
<tr>
<td>Smooth</td>
<td>3%</td>
<td>23%</td>
<td>37%</td>
<td>84%</td>
<td>90%</td>
<td>100%</td>
</tr>
<tr>
<td>Silicone</td>
<td>3%</td>
<td>23%</td>
<td>37%</td>
<td>84%</td>
<td>90%</td>
<td>100%</td>
</tr>
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Feasibility Study

Damage Threshold = 20%
Next Step

- Study the repeatability and uncertainties
- Understand the underlining physics
- Miniaturize the sensors
  - Screen-Printed sensors (40um vs 250um)
- Design the sensors network
Summary

• Kissing Bond is a big challenge in adhesive implementation
• By embedding sensors inside the bondline, we can detect Kissing Bond
• Develop appropriate diagnostic algorithms
• Design the smart adhesive film to monitor bondline integrity