Response of the Adhesive Interlayer Loaded in Shear

B. Allik, J. W. Gillespie Jr., R. E. Jensen

University of Delaware, Center for Composite Materials, Department of Material Science and Engineering
*U.S. Army Research Laboratory, Weapons and Materials Research Directorate, Aberdeen Proving Ground, MD 21005

Background

Layered composites allow for the most optimal materials to be chosen for a given part of a structure, and can usually offer significant weight savings.

Adhesives offer several advantages over mechanically fastened joints:
- Decrease in stress concentrations
- Increased flexibility of the part
- Delamination is a common source of failure when using adhesives
- It is therefore beneficial to understand the mechanical response of the adhesive layer to be able to predict when delamination will occur.

Fracture Mechanics Approach

- High velocity ballistic impact of layered composite tank armor induces mixed mode fracture of the adhesive
- The adhesive layers of interest are the polyurea VPS 2.2 and C100
- Mixed mode can be understood by understanding pure Mode I and Mode II
- This study focuses on pure Mode II
- LEFM is not applicable due to large scale non-linear deformation in thin adhesive layers
- J-Integral approach is used to measure the energy release rate
- Differentiation of the energy release rate will yield the traction separation (shear stress vs. shear deformation) law of the adhesive

End Notched Flexure Test

- In order to develop a mode II traction separation law, the end notched flexure test (ENF) will be used to simulate pure shear. In the specimen there is an adhesive layer in between two adherends and a starter crack denoted as “a”, with “P” being the applied load.

- Reduced energy release rate (left) and traction separation law (right). “W” and “E” are width and elastic modulus of the adherends respectively.

\[ J(v) = \frac{9P^2a^2}{16EW^2H^3} + \frac{3Pv}{WH} \]

\[ \tau(v) = \frac{dJ(v)}{dv} \]

Stability of ENF Design

- In order to use the reduced \( J(v) \) expression, certain conditions must be obtained:
  1. Small deflections (\( \Delta < H \))
  2. Stable crack growth (\( a > a_{\text{critical}} \))
  3. Negligible friction between the adherends at the crack “a”
  4. Elastic deformation of the adherends
  5. Deformation in front of the crack tip cannot be affected by the load

Process Zone

- The zone of deformation in front of the crack tip, the process zone “d”, as well as the critical crack length “\( a_{\text{critical}} \)” can be predicted through knowledge of the adhesive and adherends.
- If \( d \gg a \) then the specimen needs to be redesigned (violation of condition 5).
- In order estimate the size of the process zone and critical crack length, an expected traction separation law is required.
- The VPS 2.2 mode II traction separation law is estimated from the current model I law, and the epoxy law is cited in literature.

<table>
<thead>
<tr>
<th>VPS 2.2</th>
<th>Epoxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \nu )</td>
<td>0.37</td>
</tr>
<tr>
<td>( E )</td>
<td>31 GPa</td>
</tr>
<tr>
<td>( d )</td>
<td>154.6 mm</td>
</tr>
<tr>
<td>( a_{\text{critical}} )</td>
<td>55.13 mm</td>
</tr>
</tbody>
</table>

Calculations for VPS 2.2 compared to epoxy

- Sample calculation of process zone and critical crack length for VPS 2.2 and toughened epoxy with adherend properties E=190 GPa, W=H=32.6 mm, a=30 mm, b=15 mm, and L=1 m

- More flexible adhesives give larger process zones and shorter critical crack lengths as expected
- \( d-b \) for the VPS 2.2, so this specimen design will not work
- The best way to ensure \( d-b \) would be to reduce the crack length to a value still above \( a_{\text{critical}} \), so that \( b \) can be longer
- Samples which pass all design criteria are currently being created

FUTURE WORK

- Conduct ENF tests at different rates with properly designed samples currently being made
- Use the mode II traction separation law developed here and the already developed mode I law to formulate a mixed mode traction separation law

ACKNOWLEDGEMENTS

The work was supported in part under the Cooperative Agreement between Air Products and Chemicals, Inc. and the US Army Research Laboratory.

© 2011, University of Delaware, all rights reserved.