Failure of Notched Laminates Under Out-of-plane Bending

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Objective: For out-of-plane bending of notched laminates, determine the modes of failure and evaluate the capability of current models to predict failure.

Experiments: Four-point bending

Modeling: Progressive Damage Development
Experiments: Four-point Bending Tests

Notch Lengths: $2a = 1$ inch & $2a = 4$ inches
BMS 8-276 Carbon Fiber Tape

Laminate Types
- 10% 0° Plies
- 30% 0° Plies
- 50% 0° Plies

Laminate Thicknesses
- 20 plies Thick
- 40 plies Thick

Notch Lengths
- 1 inch
- 4 inches
ABAQUS Progressive Damage Model

• Damage Initiation – Hashin Theory
  – Fiber Tension
  – Fiber Compression
  – Matrix Tension
  – Matrix Compression
Damage Evolution

Strain Softening

[Graph showing equivalent stress vs. equivalent displacement with labeled points A, B, C, D, O, and corresponding axes.

- Point A
- Point B
- Point C
- Point D
- Point O
- Axes labeled: Equivalent Stress (vertical) and Equivalent Displacement (horizontal)

Legend:
- OA: Damage Evolution
- AB: Strain Softening

Graph indicates the transition from damage evolution to strain softening as the equivalent stress increases and displacement changes.
Simulation of the 4-point Bend Test
Far Field Strains

Laminate N-1-5-2

Graph showing strain against crosshead displacement for Laminate N-1-5-2.
Notch Tip Strains

Laminate N-1-5-2 (Notch)

Strain

Crosshead Displacement (in)
FAILURE LOADS

10% 0-Degree Plies

Failure Moment (in-lb/in)

Notch Length

- 20 ply - Theory
- 20 Ply - Test
- 40 Ply - Theory
- 40 Ply - Test
FAILURE LOADS

30% 0-Degree Plies

Failure Moment (in-lb/in)

Notch Length

20 ply - Theory
20 Ply - Test
40 Ply - Theory
40 Ply - Test

1-inch
4-inch
FAILURE LOADS

50% 0-Degree Plies

<table>
<thead>
<tr>
<th>Notch Length</th>
<th>Failure Moment (in-lbf)</th>
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<tbody>
<tr>
<td>1-inch</td>
<td>400</td>
</tr>
<tr>
<td>4-inch</td>
<td>1000</td>
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Legend:
- 20 ply - Theory
- 20 Ply - Test
- 40 Ply - Theory
- 40 Ply - Test
Damage Model Performance

- Thin Laminates – average error=7%
- Thick Laminate – average error=16%
FUTURE WORK

• Delamination Modeling
• Mesh Dependence Effects
• Damage Parameter Sensitivity Study
• Evaluation of Semi-Empirical Models