Development of a Building Block Approach for Crashworthiness Testing of Composites

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FAA Sponsored Project Information

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Overview:
CMH-17 Crashworthiness Working Group

• Founded in 2005
• Original focus on automotive composites
• Current focus on aviation applications
• Testing, Analysis, and Certification subgroups
• Two previous exercises/phases in testing & analysis
• Current focus: Phase III crashworthiness building block exercise
  – Monthly teleconferences
  – Meet at CMH-17: Charleston, SC, Tues July 31, 1:30-5:45
Current CMH-17 Challenge Problem: Composite Cargo Floor Stanchion

- Central assembly consisting of four primary members
  - Stanchion #3 (primary crush member)
  - Floor beam
  - Frame
  - Skin

- Initial sizing based on 6g vertical loading condition (Altair Engineering)
  - Cross section geometry
  - Laminate ply orientations
  - Laminate thickness
Primary Crush Member: C-Channel Stanchion

Traditional Design: Use of 0°, ±45°, and 90° plies
Material: IM7/8552 unitape prepreg
Geometry: C-channel
Laminate: “Hard” laminate
- 50% 0°, 25% ±45°, 25% 90°  (50/25/25)
- 16 plies (@ 0.0072 in.), 0.115 in. thickness
Initial Testing Activities: Laminate Design for Crashworthiness

- Flat-coupon crush testing
- Tailor laminate to achieve stable crush, high energy absorption
- Mini round-robin to evaluate proposed crush test fixtures and draft standard
Flat Coupon Crashworthiness Testing: *What will these tests provide?*

**Specific Energy Absorption (SEA):**
Energy absorbed per unit mass of crushed material
- Usefulness typically limited to material/laminate screening and ranking purposes

**Sustained Crush Stress:** Average crush load divided by the specimen cross sectional area
- A measure of the crashworthiness of a composite material/laminate
- Useful in the design of crush structures

**Compression Crush Ratio:** Ratio of compression strength to the sustained crush stress
- An indicator of the likelihood of the composite material crushing in a stable manner
Previous Research Results: Crush Modes Affect Energy Absorption

**Fragmnetation**
- Short axial cracks
- Shear failure from compressive stresses
- Extensive fiber fracture

**Brittle Fracture**
- Intermediate length cracks
- Combines characteristics from other failure modes

**Fiber Splaying**
- Long axial cracks
- Frond formation
- Delamination dominated
Flat Coupon Crush Testing: **Unsupported and Pin-Supported**

**Unsupported Testing**
For Flat Sections

- Measure SEA and Crush Stress for both support conditions
- For use in crush predictions of structural members

**Pin-Supported Testing**
For Curved Sections & Corners
Laminate Design for Crashworthiness:
(50 25 25) Hard Laminate

“Hard” Laminates (50/25/25) to be tested:

- $[90_2/\pm 45/0_4]_S$: Stiffest plies at midplane
- $[90_2/0_2/\pm 45/0_2]_S$: High SEA in previous study
- $[90/+45/0_2/90/-45/0_2]_S$: Ply dispersion while maintaining SEA
- $[\pm 45/90_2/0_4]_S$: 45’s on outside, high SEA previous study
- $[\pm 45/90/0/90/0_3]_S$: 45’s on outside, greater ply dispersion

Hybrid laminates – with fabric layers

- $[(0/90)_f/\pm 45/0_2]_S$: 0/90 Fabric layer on outside
- $[(\pm 45)_f/90_2/0_4]_S$: $\pm 45$ fabric layer on outside
- $[(\pm 45)_f/90/0/90/0_3]$: Outer fabric layer, greater ply dispersion
Flat Coupon Crush Test Results: Hard Laminates

All laminates produced good energy absorption

- 50% 0°, 25% ±45°, 25% 90°
- No significant difference due to fabric layers in Hybrid laminates
- Minimal variation between laminates investigated
- Two laminates selected for further investigation

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<th>Hard Laminates</th>
<th>Hybrid Hard Laminates</th>
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SEA (kJ/kg)
Flat Coupon Crush Test Results: Quasi-Isotropic Laminates

Fewer 0° plies produces lower SEA

- No significant difference due to fabric layers in hybrid laminates
- Minimal variation in pin-supported tests

(Bar chart showing SEA values for different laminate configurations.)
Flat Coupon Crush Test Results: Laminate Comparison

SEA (kJ/kg)

Unsupported
Pin-Supported

Hard Laminates

Hybrid Hard Laminates

Quasi-Isotropic

Hybrid Quasi-Isotropic

Laminate Comparison

- [0°/90°/0°]s
- [90°/±45°/0°]s
- [±45°/90°/0°]s
- [90°/0°/±45°/90°]s
- [±45°/±45°/90°]s
- [0°/90°/±45°]s
- [90°/±45°/90°]s
- [±45°/±45°/90°]s
- [±45°/±45°/0°]s
- [(0/90°)]s
- [(±45°)/45°/90°/±45°]s
- [(0/90°)/45°/15°]/(45°/90°/±45°)
C-Channel Stanchion Crush Testing: Specimen Manufacturing

- IM7/8552 unitape prepreg, 190 gsm
- $[90_2/0_2/\pm 45/0_2]$s and $[90/+45/0_2/90/-45/0_2]$s
- “hard” laminate
- 0.25 in. corner radius
- Layup and cure in accordance with NCAMP specifications
Current Focus:
C-Channel Crush Testing

• University of Utah instrumented drop-weight impact tower

• High-speed video of crush process

• $[90_2/0_2/\pm 45/0_2]_s$ and $[90/+45/0_2/90/-45/0_2]_s$ “hard” laminates

• Results to be used to assess numerical modeling capabilities
Dynamic Materials Characterization: Compression Testing

- Use of “double dog-bone” specimen
- Dynamic compression test fixture similar to crush fixture
- Variable drop height to control strain rate
- High crosshead mass used to ensure constant strain rate over test duration
- Digital Image Correlation used to determine strain rate
- Used to investigate changes in modulus and strength at strain rates between 5-30 $\varepsilon$/sec
Dynamic Materials Characterization: V-Notched Shear Testing

- Modification to V-Notched Rail Shear Test, ASTM D7078
  - Compression loaded
  - Use in drop tower
- Allows for testing of various laminates
- Use of Digital Image Correlation (DIC) to measure strains during testing
- Challenges with inertial effects producing load oscillations
Dynamic Materials Characterization: ±45° Tensile Shear Testing

- Compression-loaded fixture produces tension load in specimen
- Dynamic analog to ASTM D3518
  - Use of ±45° laminate
  - Tension loaded
  - Load using drop tower
- Use of Digital Image Correlation (DIC) to measure strains during testing
Current Focus: Dynamic Bearing Testing

- Stanchion bolted to the upper floor and lower frame
- Bearing failure possible at bolted connection
- Investigate dynamic bearing strength and bearing crush behavior
Test Procedure: Dynamic Bearing Testing

- Single fastener/single shear bearing test
- Use of Univ. of Utah flat coupon crush test fixture
- 0.25 in. diameter steel fastener
- Test specimen bolted to steel block
- Compression loaded
  - Quasi-static: 0.4 in/min
  - Dynamic: 12 ft/sec (drop-weight impact)
Initial Test Results: Dynamic Bearing Testing

[90/+45/0₂/90/-45/0₂]ₚ Laminate

- Initial load peak (bearing strength) followed by progressive crush
- Dynamic bearing strength 10-20% higher than quasi-static
Dynamic Bearing Testing: Energy Absorption

- Minimal difference in SEA value from static and dynamic testing
- Significantly higher SEA than obtained for laminate crush
Dynamic Bearing Testing:
Energy Absorption

• Minimal difference in SEA value from static and dynamic testing
• Significantly higher SEA than obtained for laminate crush
• SEA based on width of fastener (0.25 in.) and crush displacement
BENEFITS TO AVIATION

• Building block approach for composite crashworthiness
• Development of coupon-level testing to assess crashworthiness of composite materials and laminates
• Documentation of building block exercise in CMH-17
• Dissemination of research results through FAA technical reports and conference/journal publications
Thank you for your attention!

Questions?