Development of a Building Block Approach for Crashworthiness Testing of Composites

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AMTAS Autumn 2017 Meeting
November 8, 2017
FAA Sponsored Project Information

• Principal Investigators:
  Dr. Dan Adams

• Graduate Student Researchers:
  Mark Perl, Michael Terry, Dalton Ostler

• FAA Technical Monitor:
  Allan Abramowitz

• Collaborators:
  Boeing: Mostafa Rassaian, Kevin Davis
  Engenuity LTD: Graham Barnes
  Hexcel: Audrey Medford
Overview: CMH-17 Crashworthiness Working Group

- Founded in 2005
- Original focus on automotive composites
- Recent 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 - Wichita, KS, Thurs Nov 16th, 10:15-12:15, 1:30-3:30
Phase III Activity

- Focus on FAA Crashworthiness Certification
- Building on Phase I & II activities
- Testing to support analysis development and evaluation
Phase III Challenge Problem: Composite Cargo Floor Stanchion

- Central stanchion consisting of four primary members
  - Strut #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 Struts

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
Two laminates of interest:

1) (50/25/25) 50% 0°, 25% ±45°, 25% 90°
   16 ply thickness: 8 0’s 4 ±45’s 4 90’s
   - Strut #3 (primary crush member)
   - Floor Beam

2) (25/50/25) 25% 0°, 50% ±45°, 25% 90°
   24 and 64 ply thickness
   - Frame (64 plies)
   - Skin (24 plies)
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 Crush Testing: 
Unsupported and Pin-Supported

Unsupported Testing 
For Flat Sections

Pin-Supported Testing 
For Curved Sections & Corners

- Measure SEA and Crush Stress for both support conditions
- For use in crush predictions of structural members
Previous Research Results: Crush Modes Affect Energy Absorption

**Fragmentation [F]**
- Short axial cracks
- Shear failure from compressive stresses
- Extensive fiber fracture

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

**Fiber Splaying [S]**
- Long axial cracks
- Frond formation
- Delamination dominated
“Hard” Laminates (50/25/25) to be tested:

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

**Hybrid laminates** – with fabric layers

- \([(0/90)_f/\pm 45/0_2]_S\) \textit{0/90 Fabric layer on outside}
- \([(\pm 45)_f/90_2/0_4]_S\) \textit{±45 fabric layer on outside}
- \([(\pm 45)_f/90/0/90/0_3]\) \textit{Outer fabric layer, greater ply dispersion}
Laminate Design for Crashworthiness:
(25 50 25) **Quasi-Isotropic Laminate**

Quasi-isotropic laminates (25/50/25) to be tested:

- \([90/±45/0]_{2S}\)  *Dispersed plies, stiffest plies at midplane*
- \([90_2/(±45)_2/0_2]_S\)  *Blocked plies, stiffest plies at midplane*
- \([(±45)_2/90_2/0_2]_S\)  *45’s on outside*
- \([±45/90/0]_{2S}\)  *45’s on outside, greater ply dispersion*

Hybrid laminates – with fabric layers

- \([(0/90)_f/±45/90/±45/0]_S\)  *0/90 fabric layer on outside*
- \([(±45)_f/(±45)_f/90_2/0_2]_S\)  *±45 fabric layer on outside*
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
  - Laminates preselected based on past experiences
Flat Coupon Crush Test Results: Quasi-Isotropic Laminates

**Fewer 0° plies produces lower SEA**

- Fabric placed on exterior of laminate
- No significant difference due to fabric layers in Hybrid laminates
- Minimal variation in pin-supported tests
  - Laminates preselected based on past experiences
Flat Coupon Crush Test Results: Laminates Comparison

Hard Laminates

Hybrid Hard Laminates

Quasi-Isotropic

Hybrid Quasi-Isotropic

Un-supported

Pin-supported

SEA (kJ/kg)
High Speed Video Examination: $[90_2/0_2/\pm45/0_2]_s$

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**SEA (kJ/kg)**
High Speed Video Examination: $[90_2/0_2/\pm45/0_2]_s$

Test Configuration

High Speed Camera View

Test Specimen

$[90_2/0_2/\pm45/0_2]_s$ Hard Laminate, Unsupported Condition
High Speed Video Examination:
$$[(0/90)f_2/\pm 45/90/\pm 45/0]$$ Quasi-Isotropic Laminate

SEA (kJ/kg)

Hard Laminates

Hybrid Hard Laminates

Quasi-Isotropic

Hybrid Quasi-Isotropic
High Speed Video Examination:
Hybrid Quasi-Isotropic, Unsupported Condition

- High percentage of laminate exhibits splaying
- Unstable crush
- Reduced energy absorption
- Minimal debris cloud

\[(0/90)_{f2}/\pm 45/90/\pm 45/0\]_s
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
Thank you for your attention!

Questions?