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Development of a Building Block Approach for Crashworthiness Testing of Composites

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University of Utah

AMTAS Autumn 2017 Meeting

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A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

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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

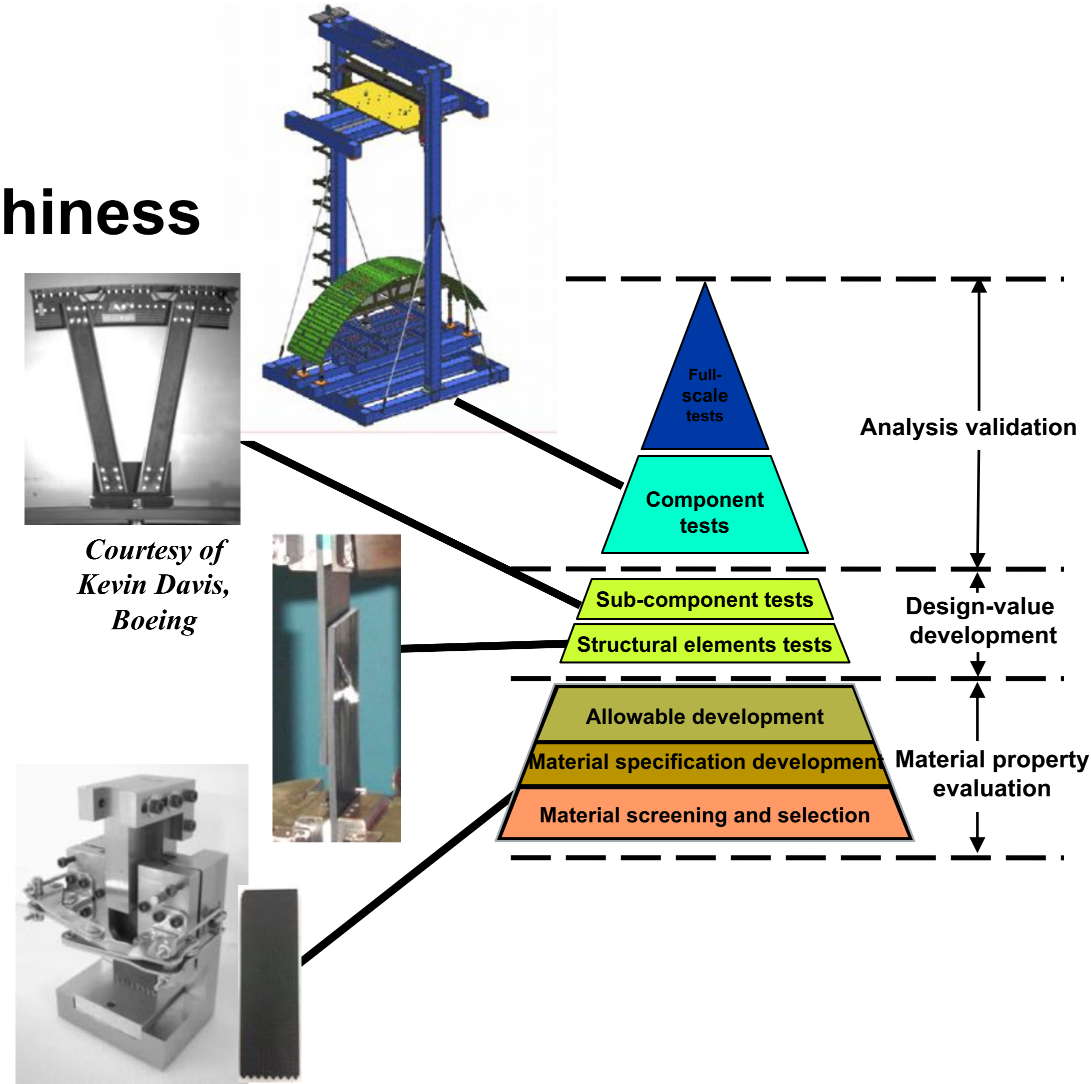
Overview:
CMH-17 Crashworthiness Working Group

- 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 16^{th}, 10:15-12:15, 1:30-3:30

Current Focus:
Crashworthiness Building Block Development

<u>Phase III Activity</u>

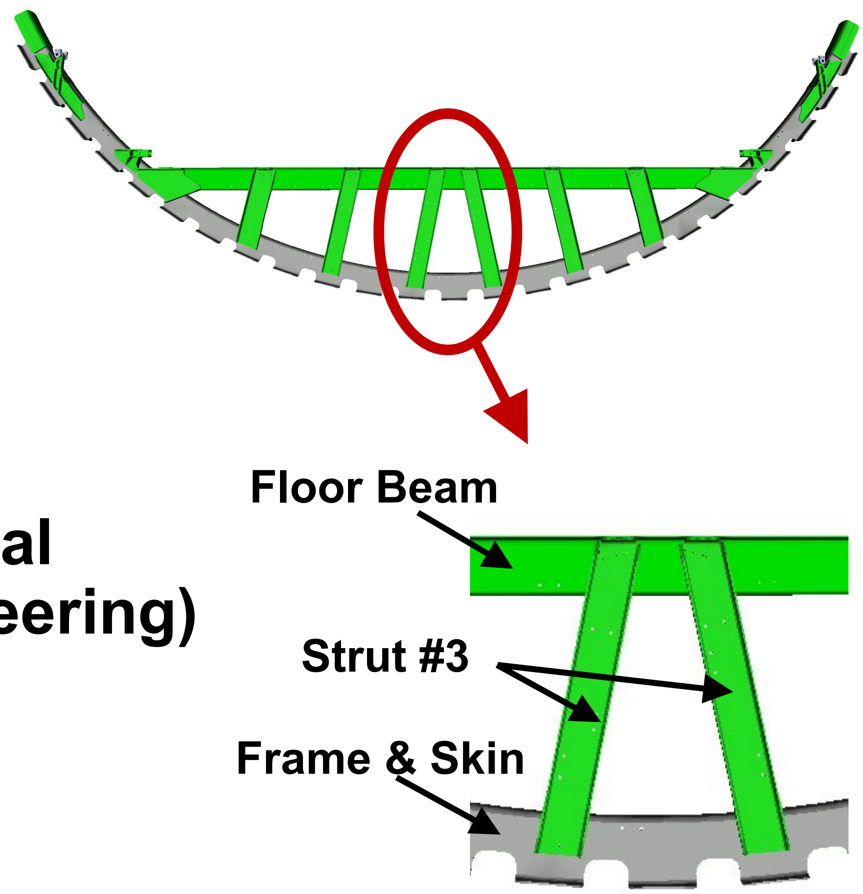
- Focus on FAA Crashworthiness Certification
- Building on Phase I & II activities
- Testing to support analysis development and evaluation



Courtesy of Kevin Davis, Boeing

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

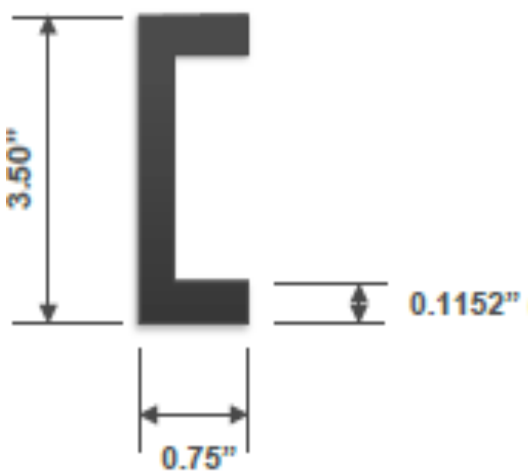
Traditional Design: Use of 0°, ±45°, and 90° plies

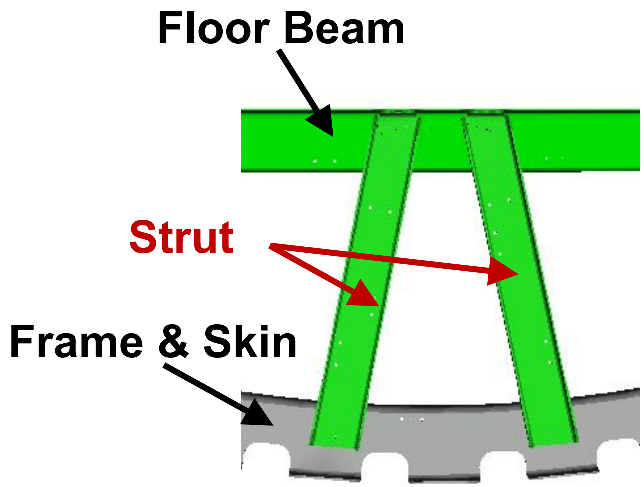
Material: IM7/8552 unitape prepreg

Geometry: C-channel

Laminate: "Hard" laminate

- 50% 0°, 25% ±45°, 25% 90° (50/25/25)
- 16 plies (@ 0.0072 in.), 0.115 in. thickness





Laminate Summary: Altair Traditional Design:

Two laminates of interest:

1) (50/25/25) 50% 0°, 25% ±45°, 25% 90°

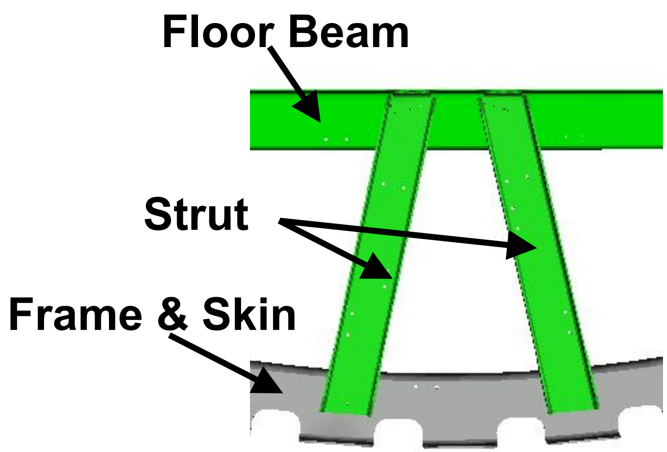
   16 ply thickness: 8 0's 4 ±45's 4 90's

   - Strut #3 (primary crush member)
   - Floor Beam

2) (25/50/25) 25% 0°, 50% ±45°, 25% 90°

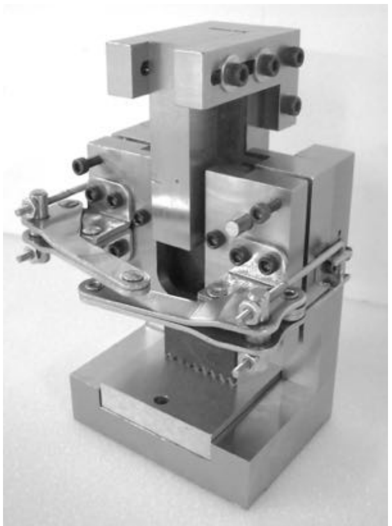
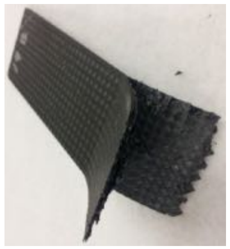
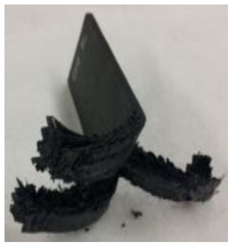
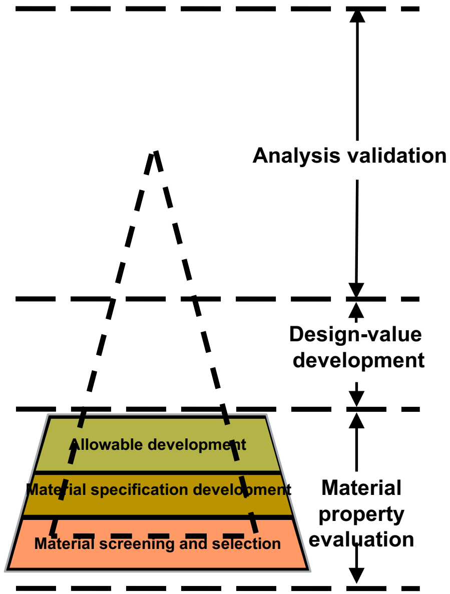
   24 and 64 ply thickness

   - 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

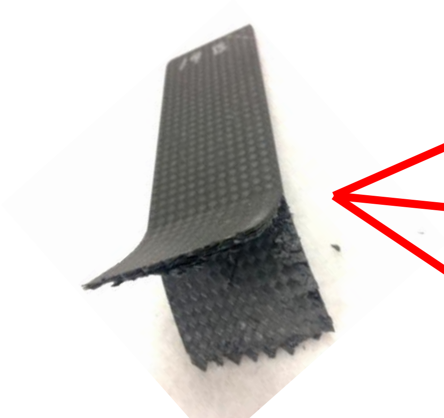






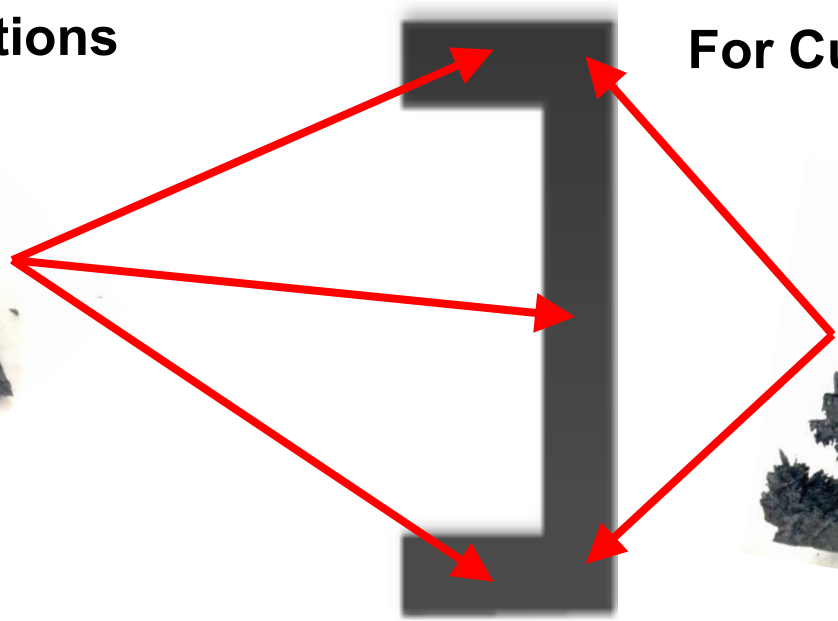
Flat Coupon Crush Testing:

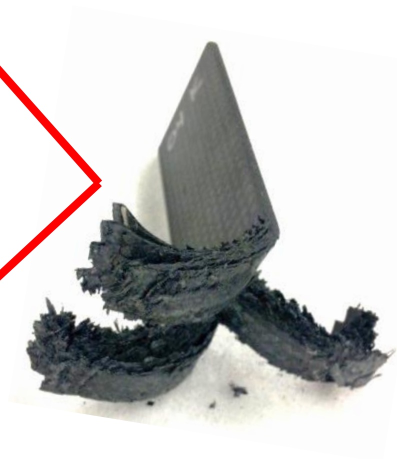
Unsupported and Pin-Supported

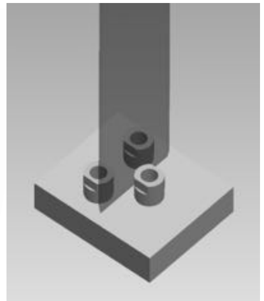
Unsupported Testing
For Flat Sections

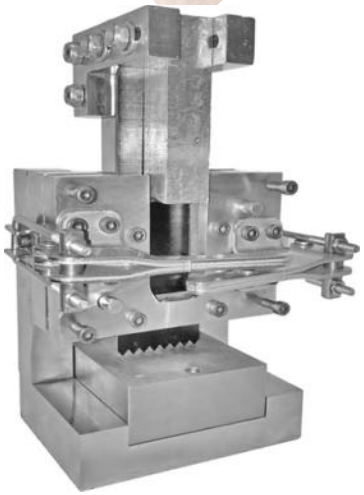
Pin-Supported Testing
For Curved Sections & Corners





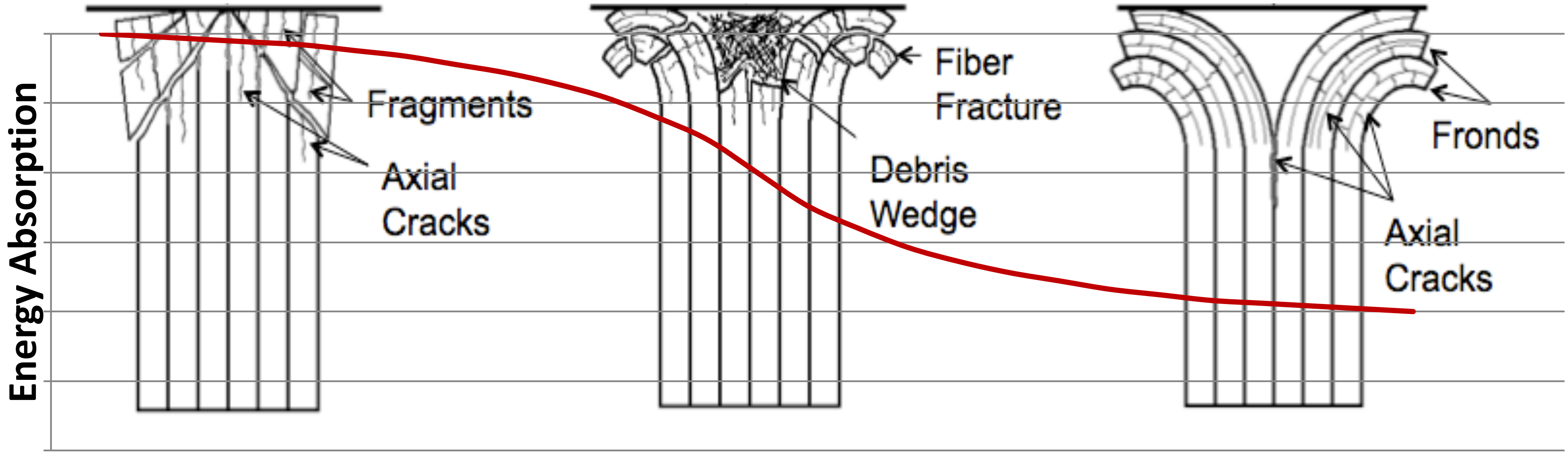






- **Measure SEA and Crush Stress for both support conditions**
- **For use in crush predictions of structural members**

Previous Research Results: Crush Modes Affect Energy Absorption



Fragmentation [F]

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

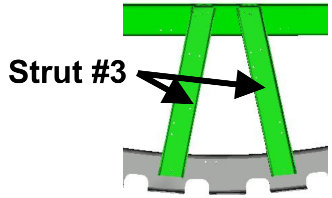
Brittle Fracture [B]

- Intermediate length cracks
- Combines characteristics from other failure modes

Fiber Splaying [S]

- Long axial cracks
- Frond formation
- Delamination dominated

Laminate Design for Crashworthiness:
(50 25 25) Hard Laminate



"Hard" Laminates (50/25/25) to be tested:

- $[90_2/\pm45/0_4]_S$ — *Stiffest plies at midplane*
- $[90_2/0_2/\pm45/0_2]_S$ — *High SEA in previous study*
- $[90/+45/0_2/90/-45/0_2]_S$ — *Ply dispersion while maintaining SEA*
- $[\pm45/90_2/0_4]_S$ — *45's on outside, high SEA previous study*
- $[\pm45/90/0/90/0_3]_S$ — *45's on outside, greater ply dispersion*

<u>Hybrid laminates</u> – with fabric layers

- $[(0/90)_f/\pm45/0_2]_S$ — *0/90 Fabric layer on outside*
- $[(\pm45)_f/90_2/0_4]_S$ — *±45 fabric layer on outside*
- $[(\pm45)_f/90/0/90/0_3]$ — *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:

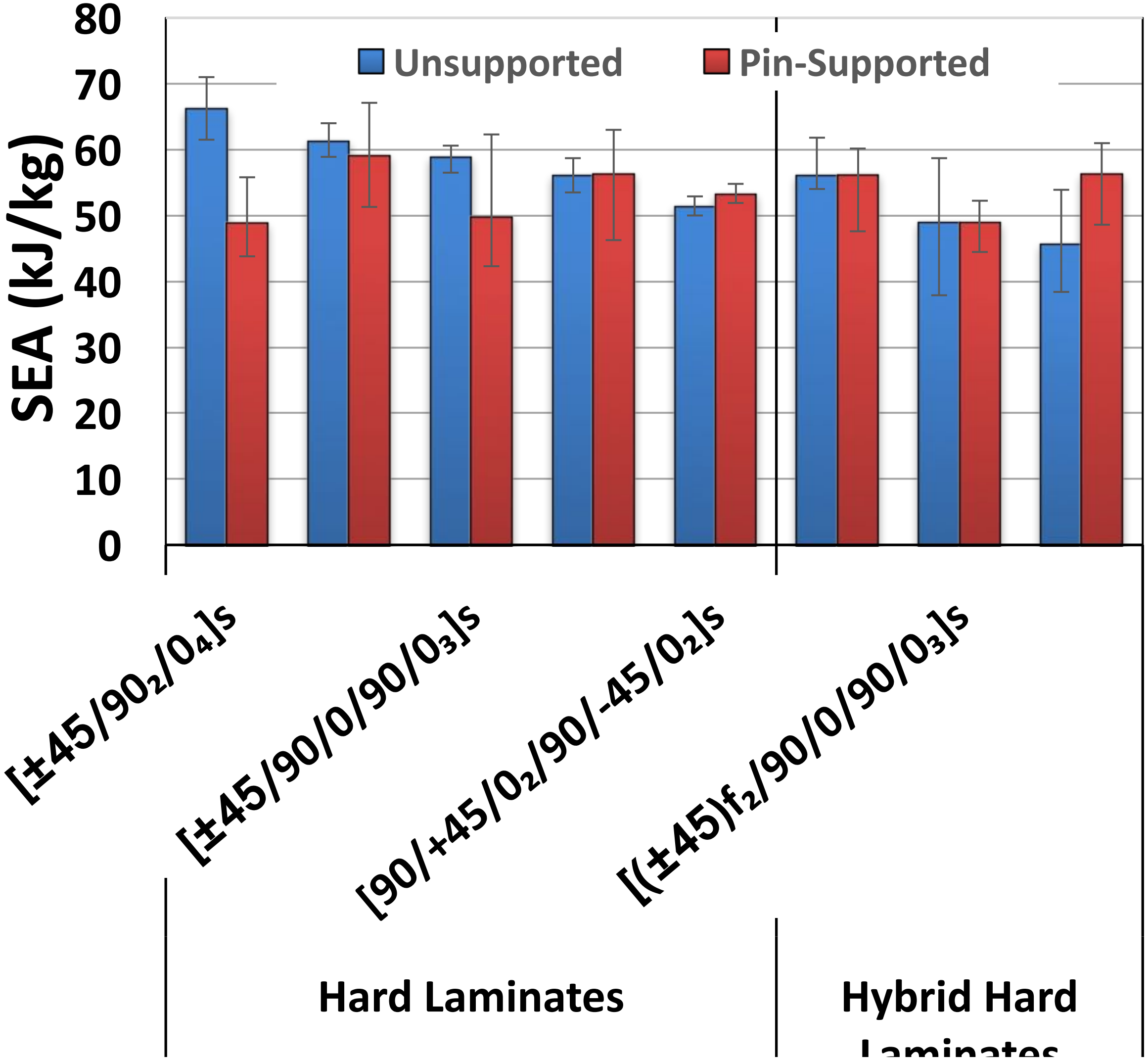
- $[90/\pm45/0]_{2S}$ *Dispersed plies, stiffest plies at midplane*
- $[90_2/(\pm45)_2/0_2]_S$ *Blocked plies, stiffest plies at midplane*
- $[(\pm45)_2/90_2/0_2]_S$ *45's on outside*
- $[\pm45/90/0]_{2S}$ *45's on outside, greater ply dispersion*

Hybrid laminates – with fabric layers

- $[(0/90)_f/\pm45/90/\pm45/0]_S$ *0/90 fabric layer on outside*
- $[(\pm45)_f/(\pm45)_f/90_2/0_2]_S$ *±45 fabric layer on outside*

Flat Coupon Crush Test Results: Hard Laminates

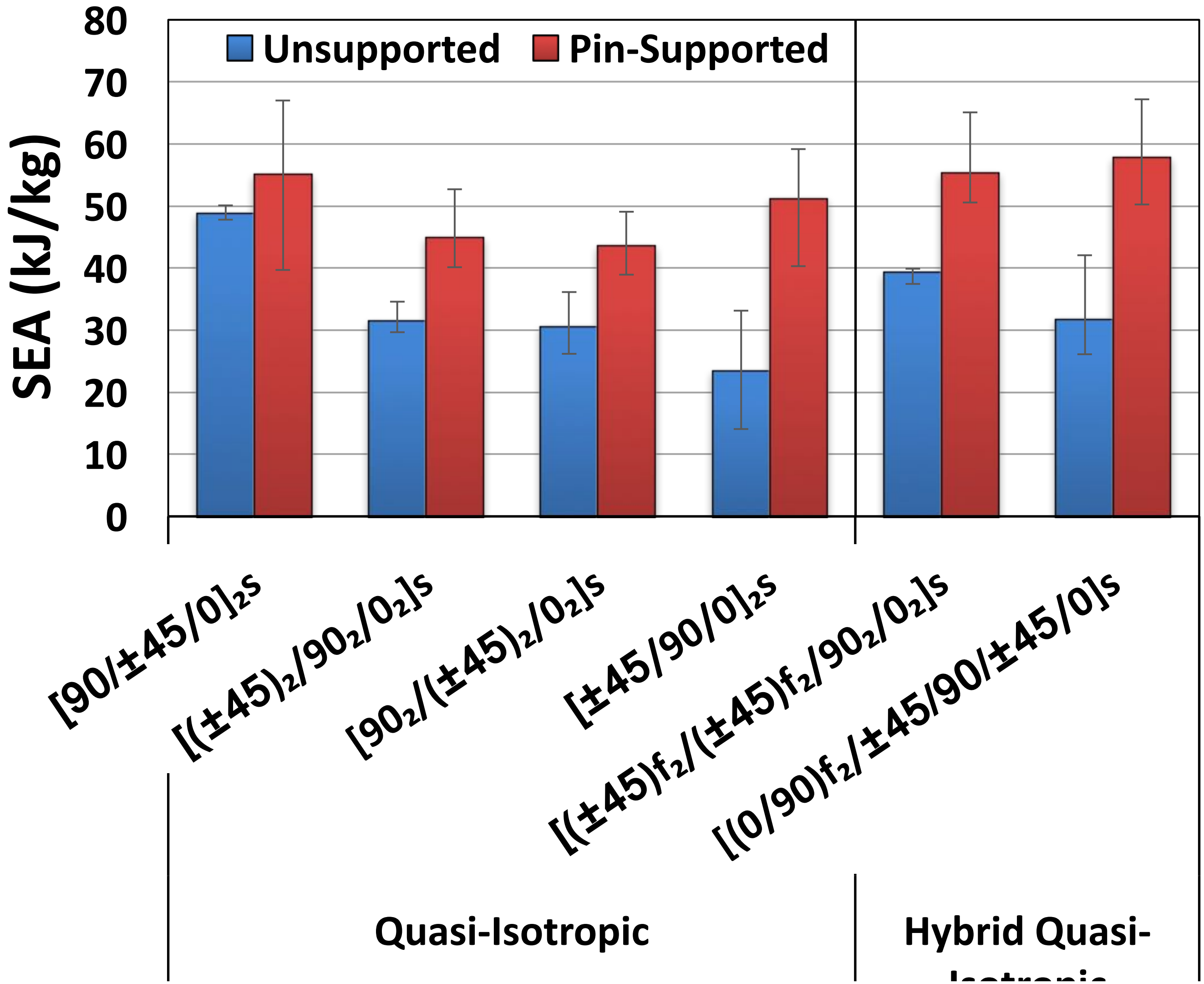
All laminates produced good energy absorption



- 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

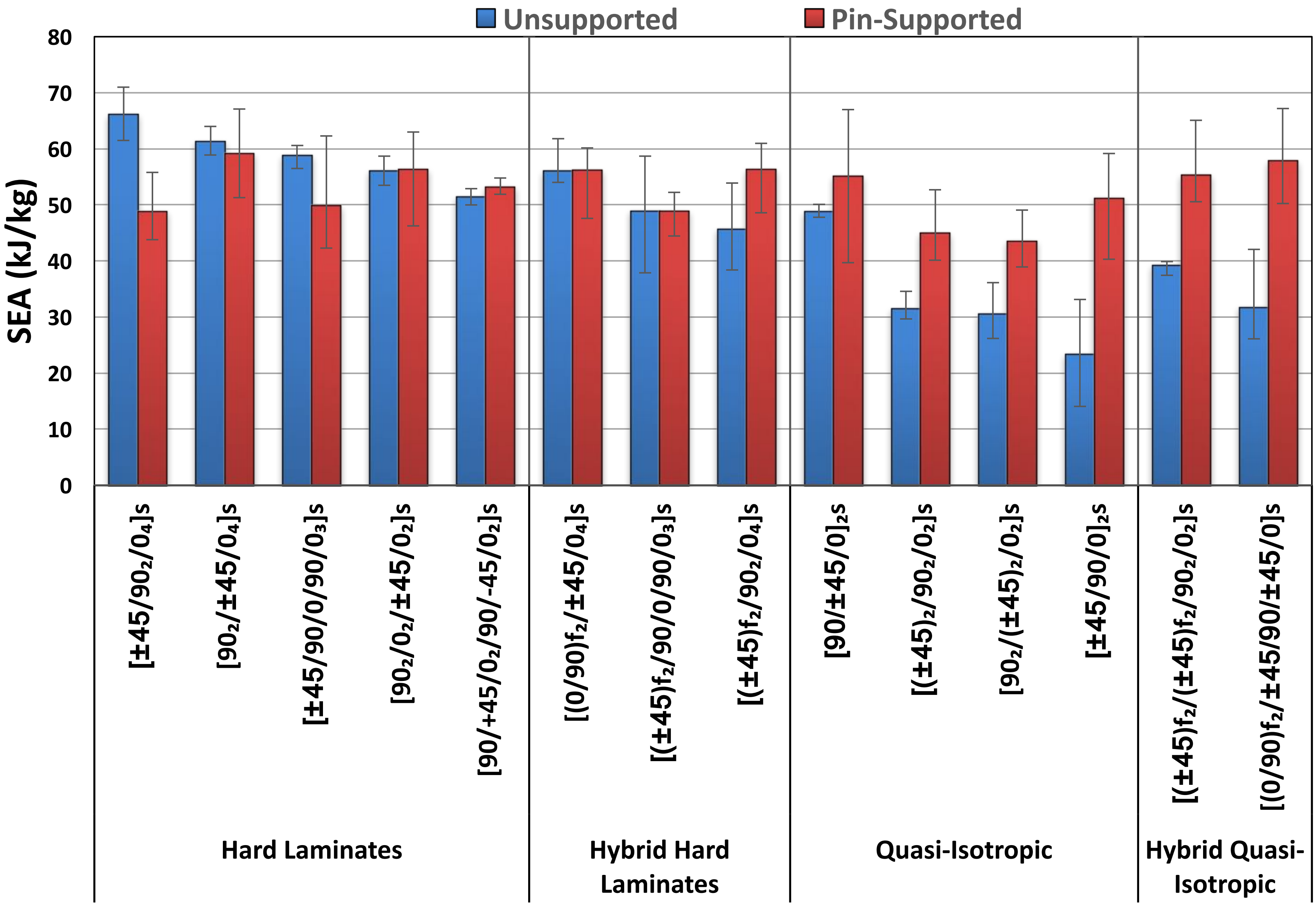
Flat Coupon Crush Test Results: Quasi-Isotropic Laminates

Fewer 0° plies produces lower SEA

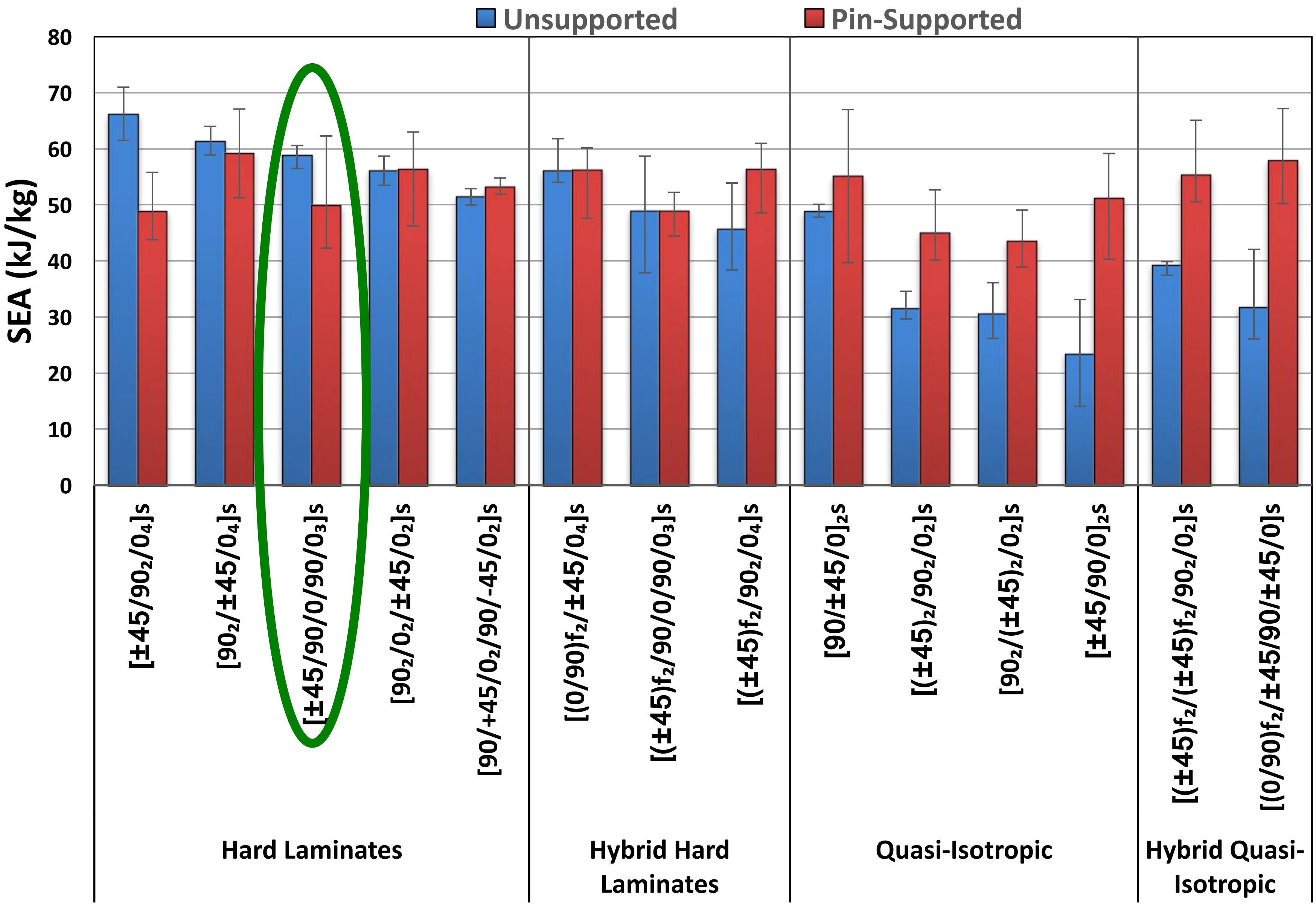


- Fabric placed on exterior of laminate
- No significant difference due to fabric layers in Hybrid laminates
- Minimal variation in pin-supported tests
  - Laminates preselected based on past experiences

Flat Coupon Crush Test Results:
Laminates Comparison

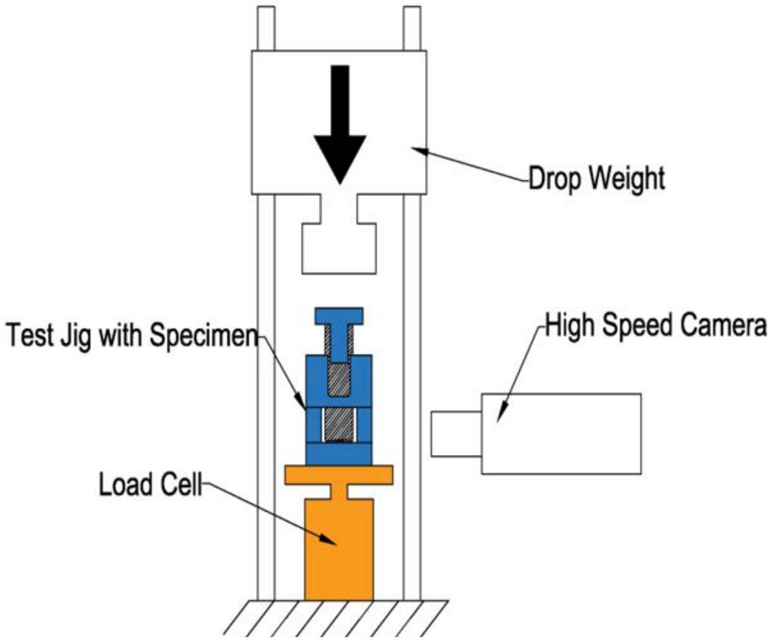


High Speed Video Examination: $[90_2/0_2/\pm45/0_2]_s$

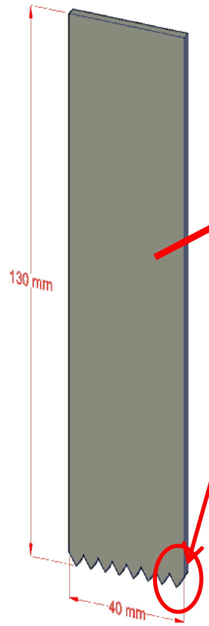


High Speed Video Examination: $[90_2/0_2/\pm45/0_2]_s$

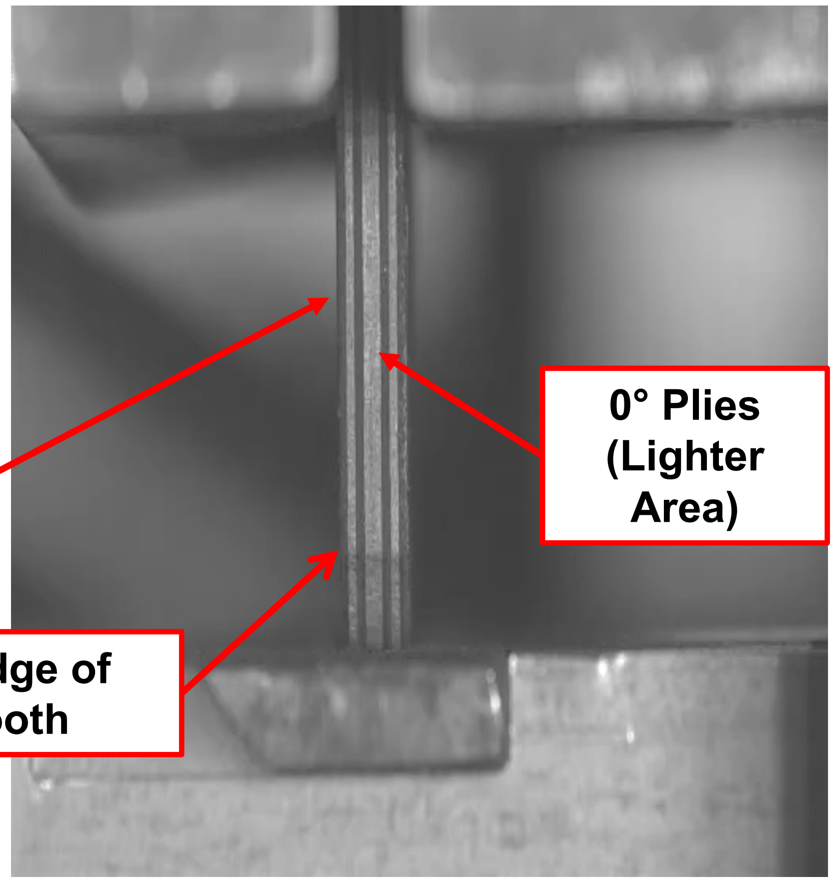
Test Configuration



Test Specimen

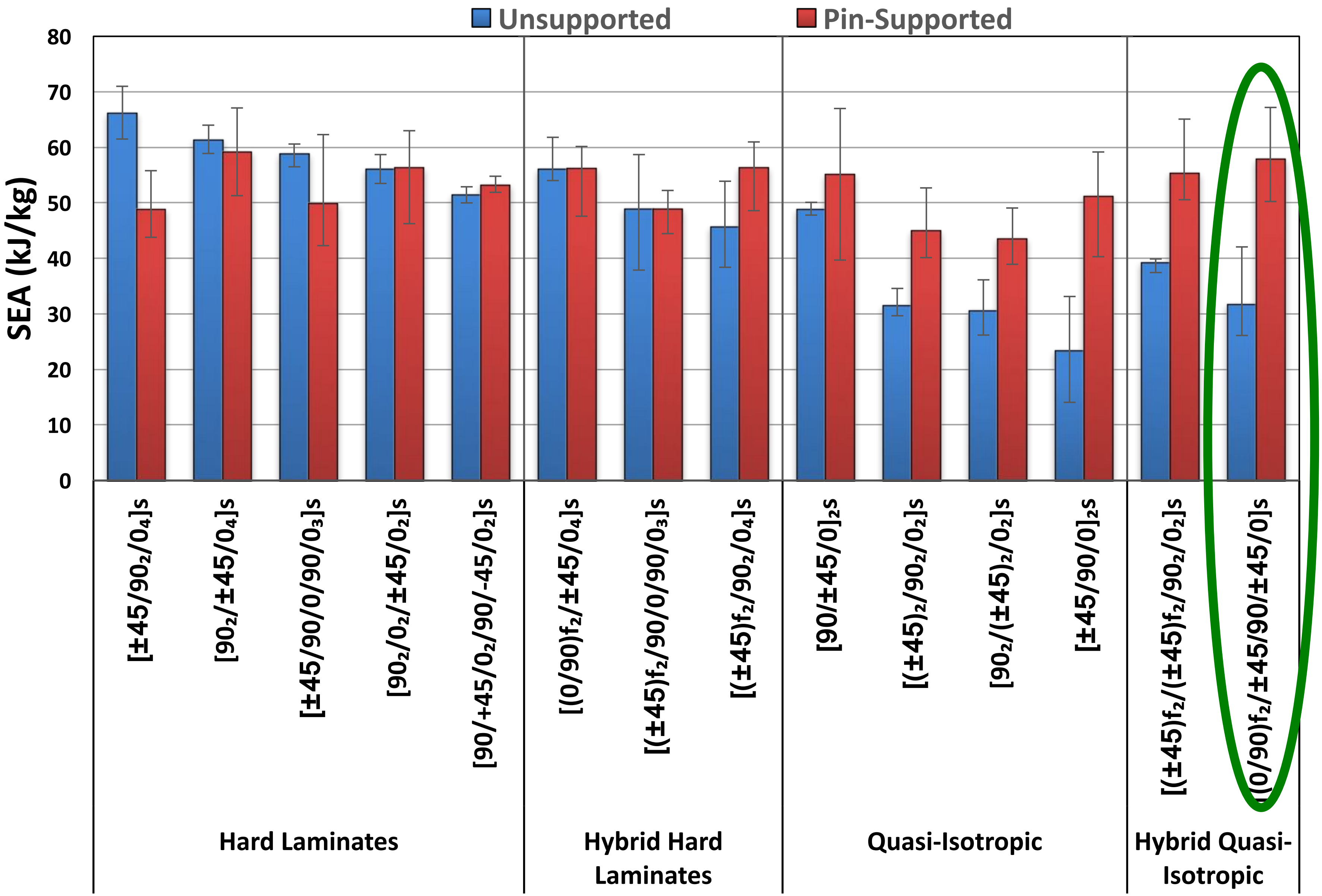


High Speed Camera View

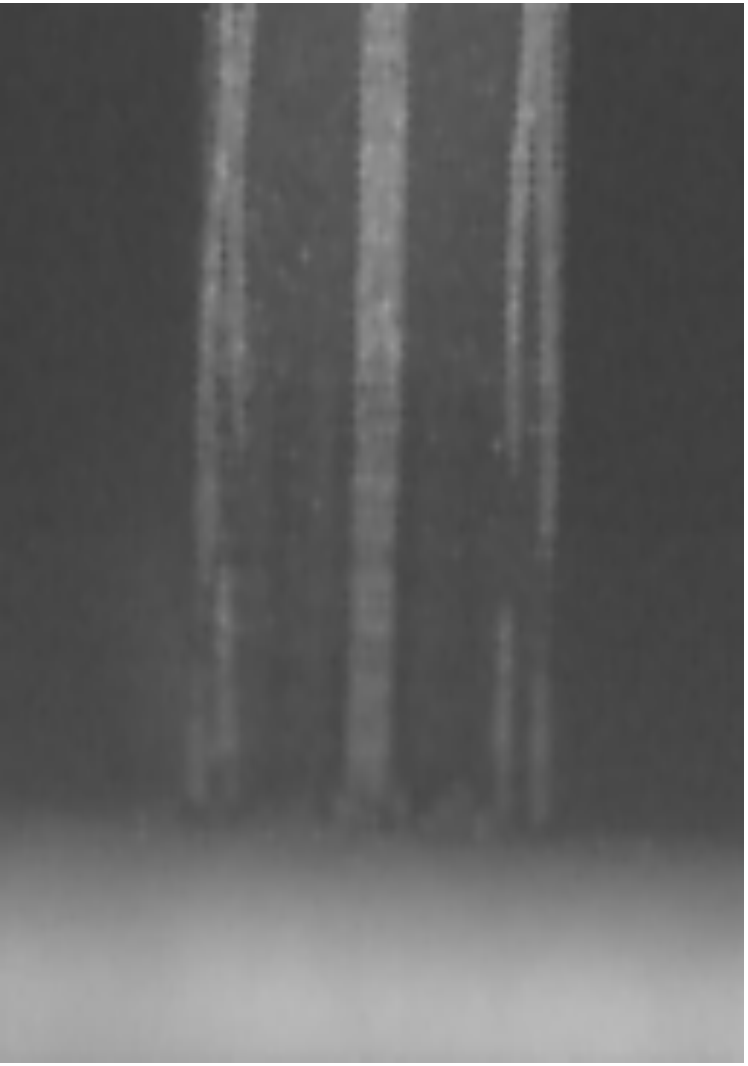


$[90_2/0_2/\pm45/0_2]_s$ Hard Laminate, Unsupported Condition

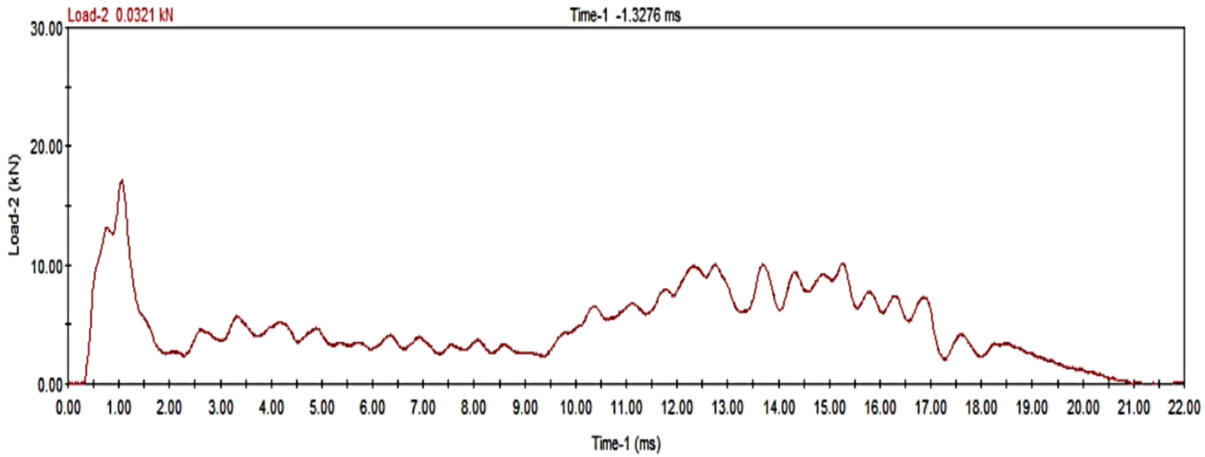
High Speed Video Examination: $[(0/90)_{f2}/\pm45/90/\pm45/0]$ Quasi-Isotropic Laminate



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



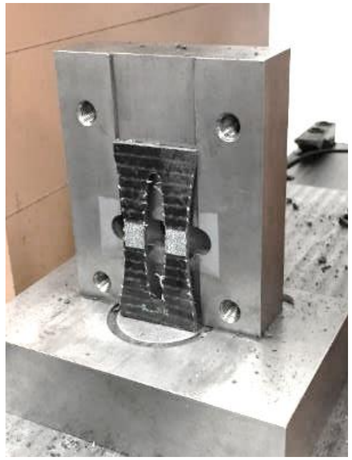
- High percentage of laminate exhibits splaying
- Unstable crush
- Reduced energy absorption
- Minimal debris cloud



$[(0/90)_{f2}/\pm45/90/\pm45/0]_s$

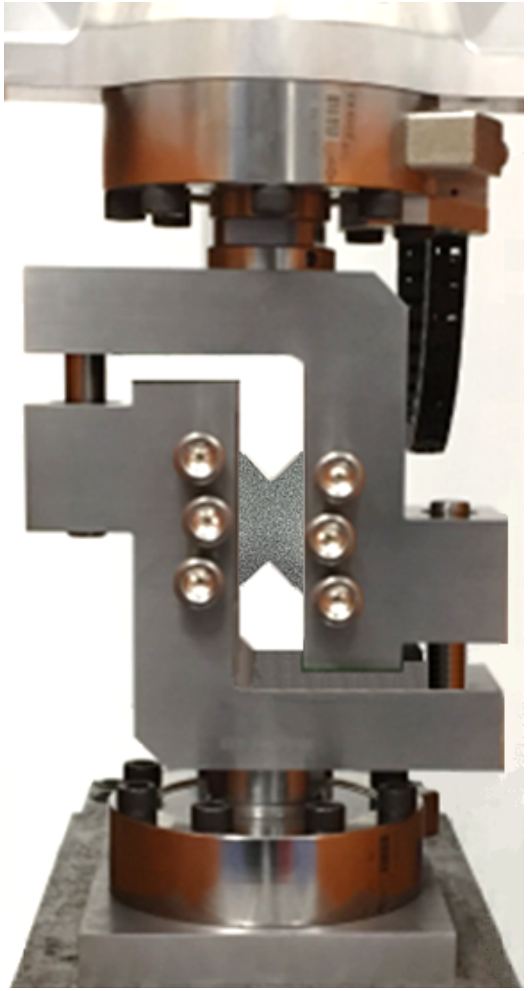
Dynamic Materials Characterization: Compression Testing

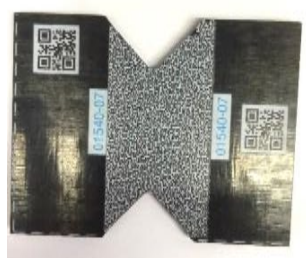
- Use of “double dog-bone” specimen
- Dynamic compression test fixture similar to crush fixture
- Variable drop height to control strain rate
- High crosshead mass used to ensure constant strain rate over test duration
- Digital Image Correlation used to determine strain rate
- Used to investigate changes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

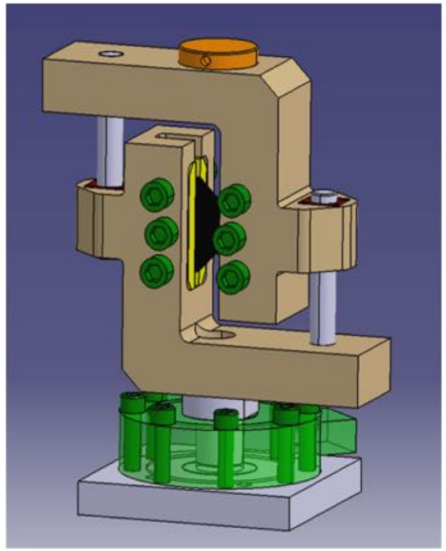


Dynamic Materials Characterization: V-Notched Shear Testing

- 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







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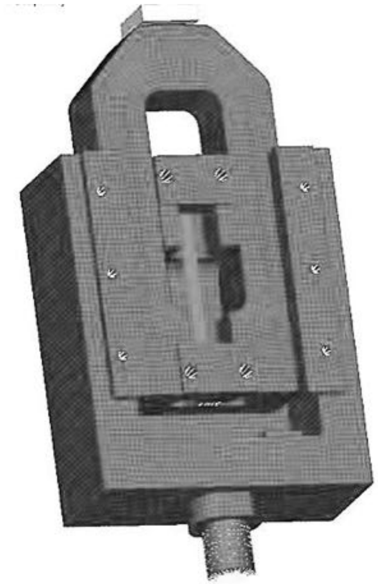
Dynamic Materials Characterization: ±45° Tensile Shear Testing

- 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?

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