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Development of a Building Block Approach for Crashworthiness Testing of Composites

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University of Utah

FAA JAMS 2018 Technical Review
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FAA Sponsored Project Information

- Principal Investigators:
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  Allan Abramowitz
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  Boeing: Mostafa Rassaian, Kevin Davis
  Engenuity, LTD: Graham Barnes
  Hexcel: Audrey Medford

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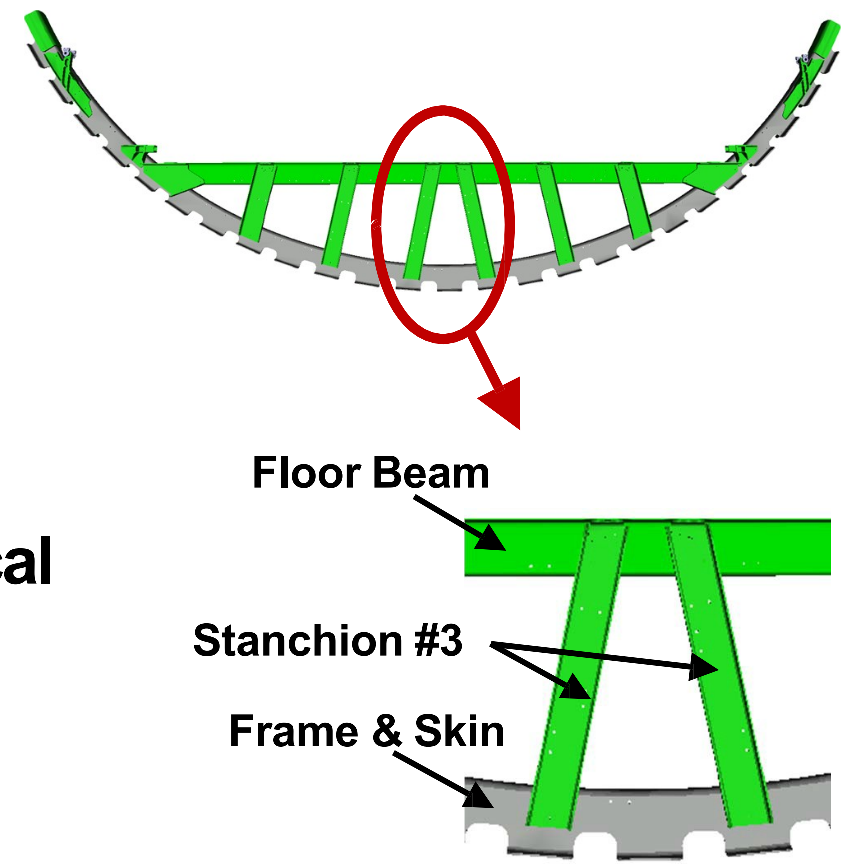
Overview:
CMH-17 Crashworthiness Working Group

- 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



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Primary Crush Member:
C-Channel Stanchion

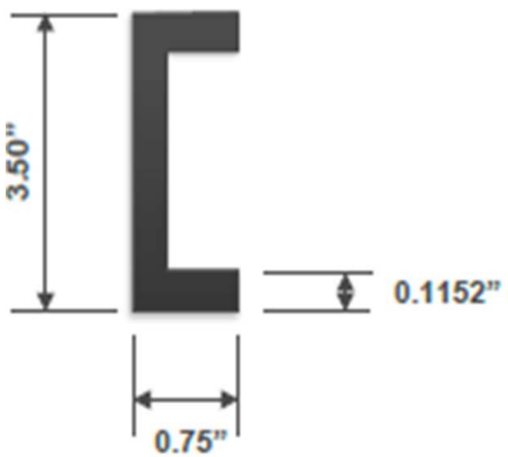
Traditional Design: Use of 0°, ±45°, and 90° plies

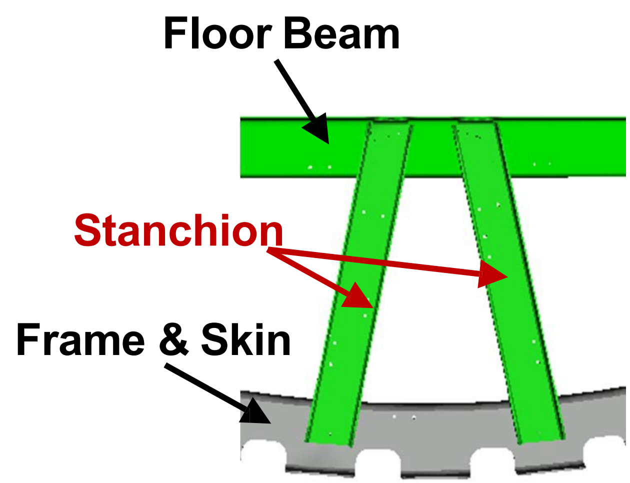
Material: IM7/8552 unitape prepreg

Geometry: C-channel

Laminate: "Hard" laminate

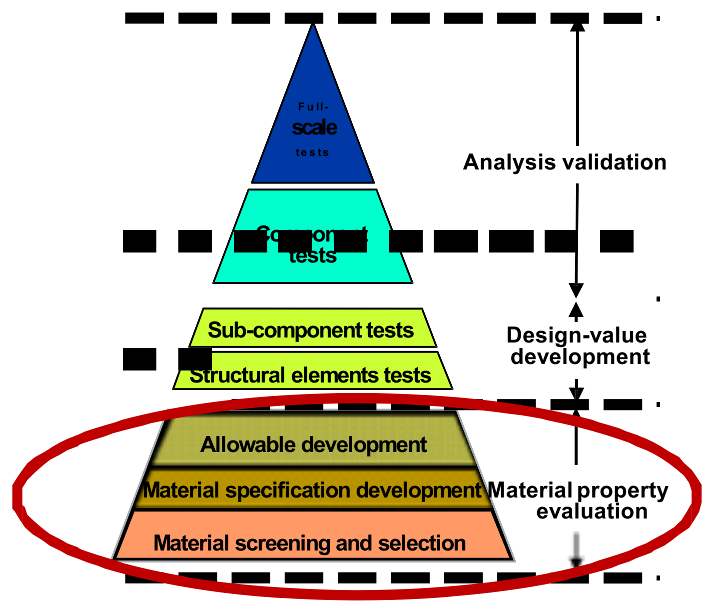
- 50% 0°, 25% ±45°, 25% 90° (50/25/25)
- 16 plies (@ 0.0072 in.), 0.115 in. thickness

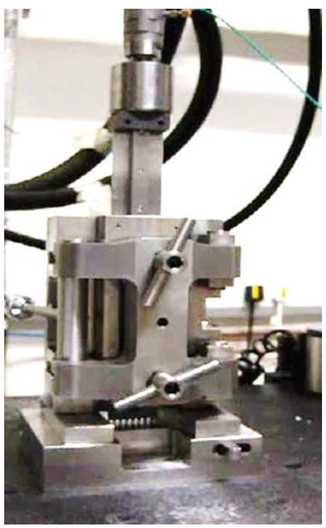


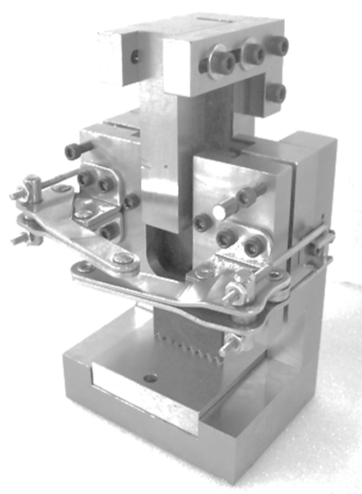


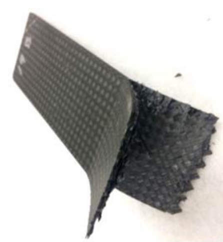
Initial Testing Activities: Laminate Design for Crashworthiness

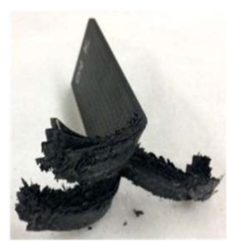
- **Flat-coupon crush testing**
- **Tailor laminate to achieve stable crush, high energy absorption**
- **Mini round-robin to evaluate proposed crush test fixtures and draft standard**











Flat Coupon Crashworthiness Testing:
What will these tests provide?

Specific Energy Absorption (SEA):
Energy absorbed per unit mass of crushed material

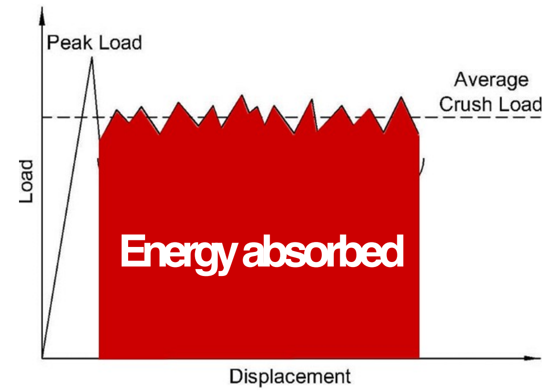
- Usefulness typically limited to material/laminate screening and ranking purposes

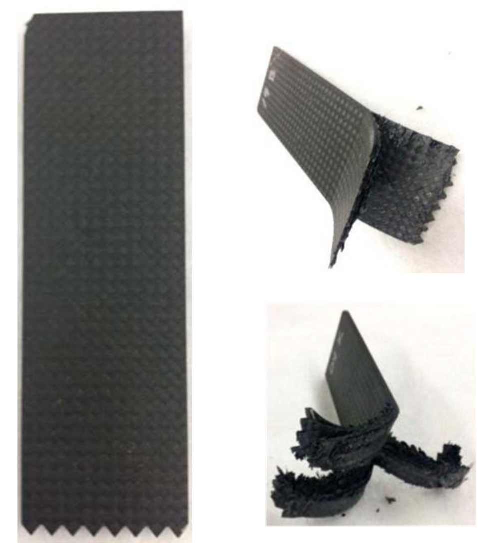
Sustained Crush Stress: Average crush load divided by the specimen cross sectional area

- A measure of the crashworthiness of a composite material/laminate
- Useful in the design of crush structures

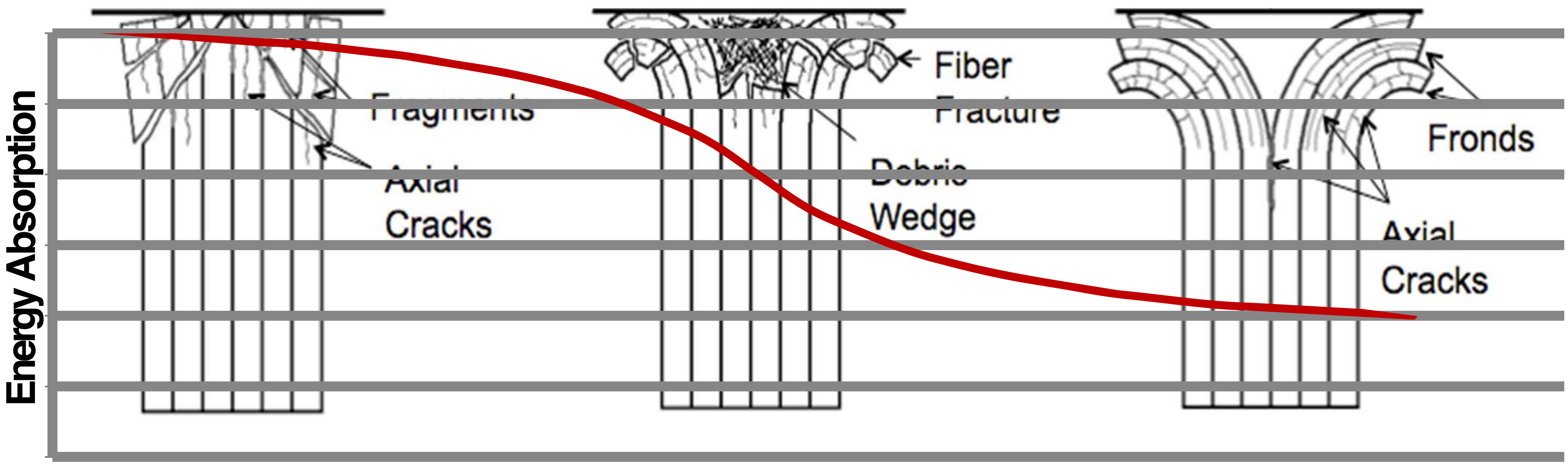
Compression Crush Ratio: Ratio of compression strength to the sustained crush stress

- An indicator of the likelihood of the composite material crushing in a stable manner





Previous Research Results:
Crush Modes Affect Energy Absorption



Fragmentation

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

Brittle Fracture

- Intermediate length cracks
- Combines characteristics from other failure modes

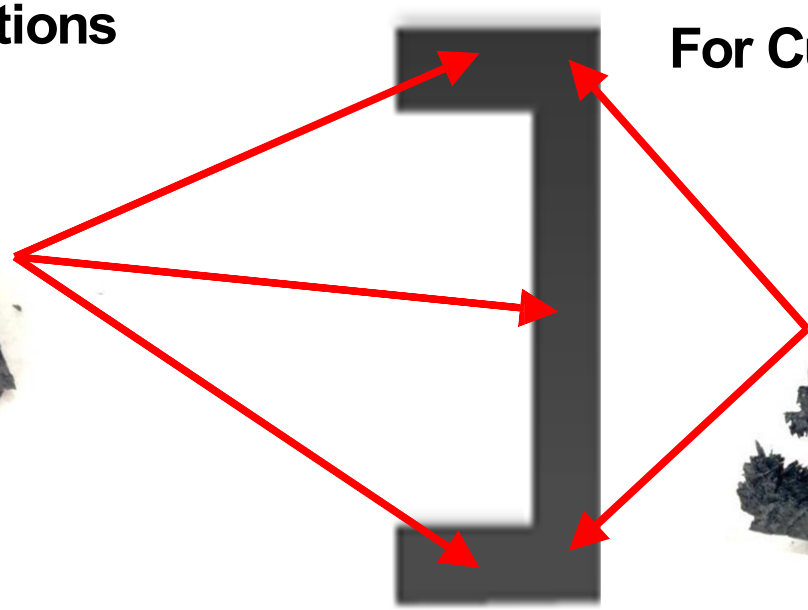
Fiber Splaying

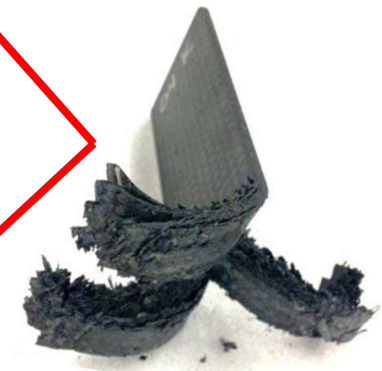
- Long axial cracks
- Frond formation
- Delamination dominated

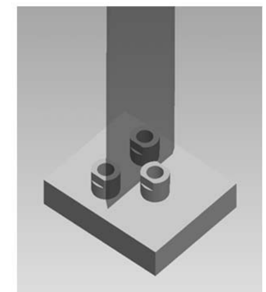
Flat Coupon Crush Testing:
Unsupported and Pin-Supported

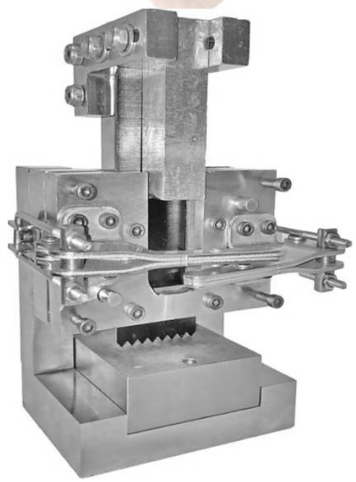
Unsupported Testing
For Flat Sections

Pin-Supported Testing
For Curved Sections & Corners









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

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

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

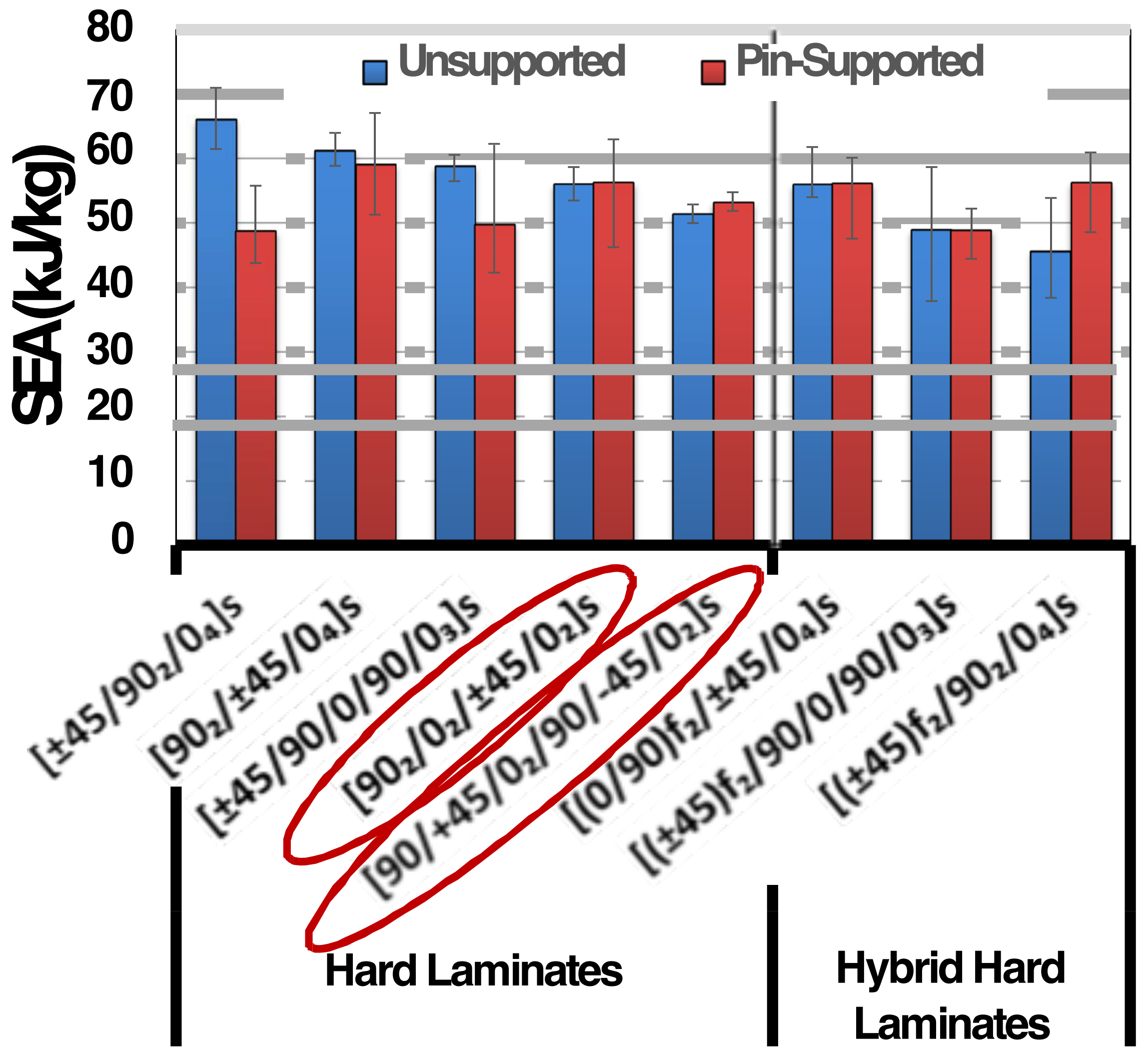
- $[90_2/\pm45/0_4]_s$ — *Stiffest plies at midplane*
- $[90_2/0_2/\pm45/0_2]_s$ — *High SEA in previous study*
- $[90/+45/0_2/90/-45/0_2]_s$ — *Ply dispersion while maintaining SEA*
- $[\pm45/90_2/0_4]_s$ — *45's on outside, high SEA previous study*
- $[\pm45/90/0/90/0_3]_s$ — *45's on outside, greater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

Hybrid laminates – 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*

Flat Coupon Crush Test Results:
Hard Laminates

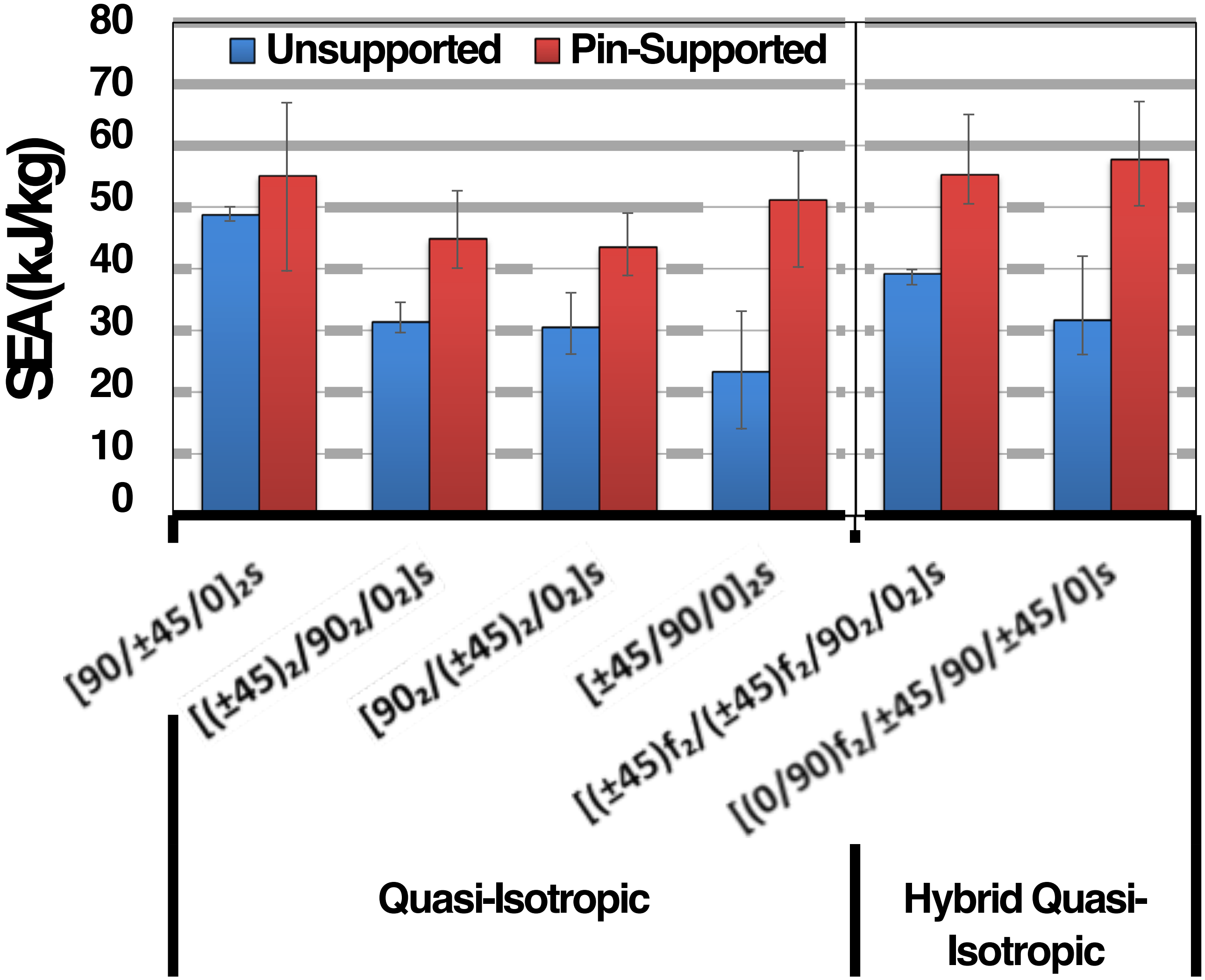
All laminates produced good energy absorption



- **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**

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

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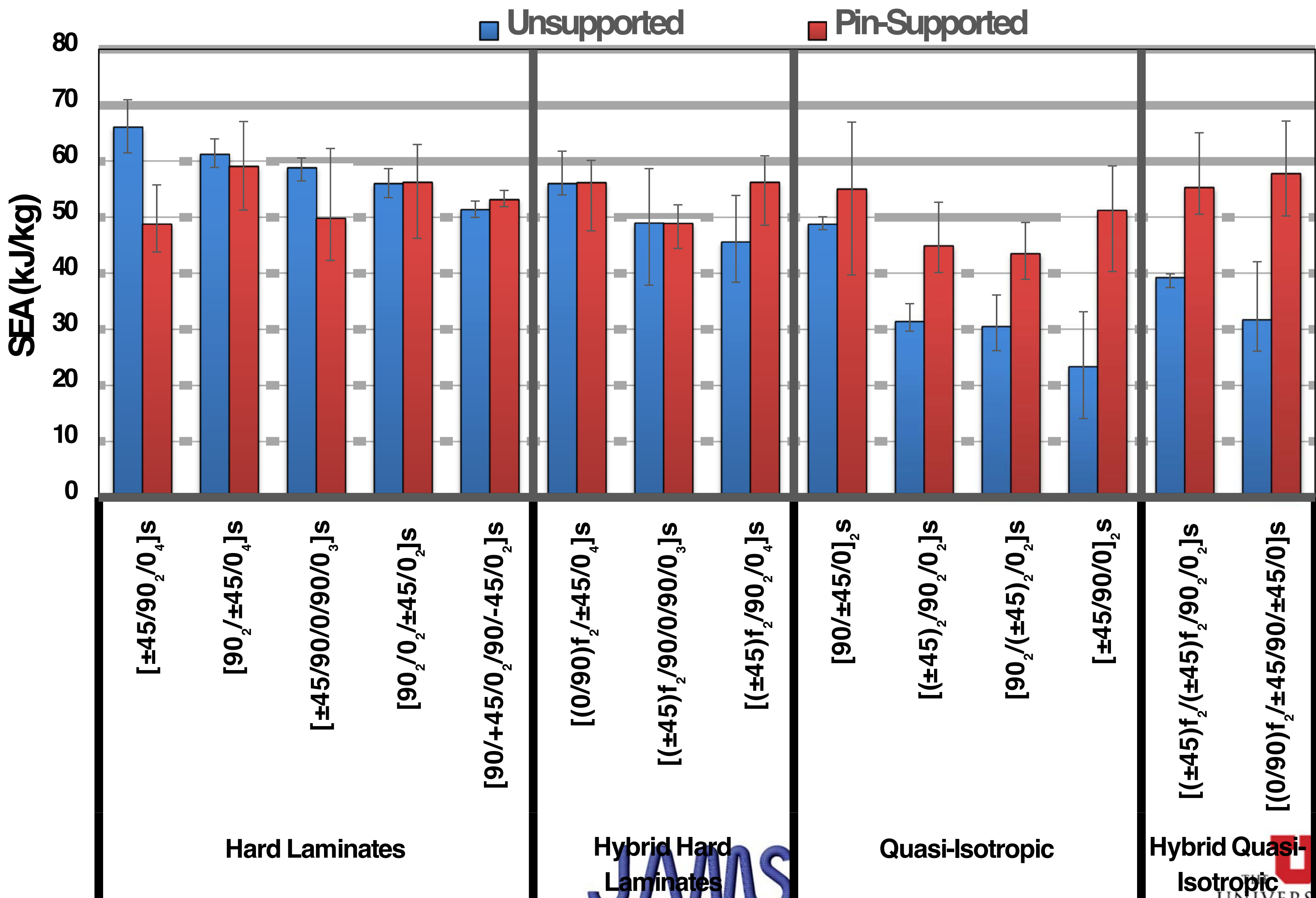
Flat Coupon Crush Test Results:
Laminate Comparison



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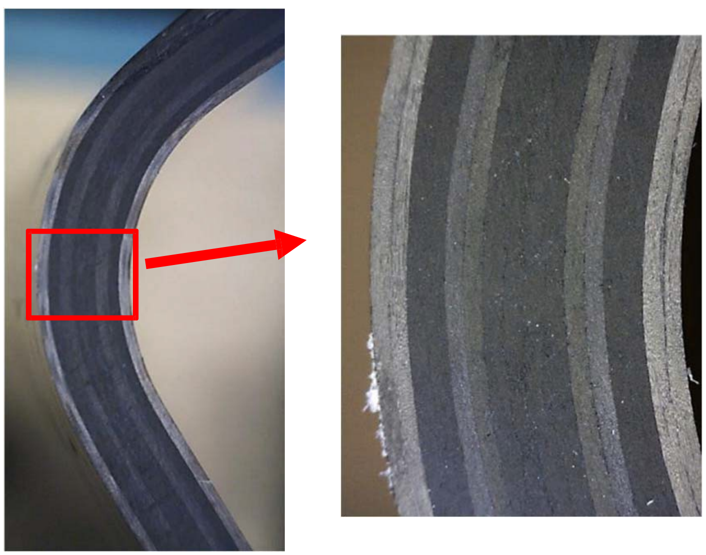
C-Channel Stanchion Crush Testing:
Specimen Manufacturing

- **IM7/8552 unitape prepreg, 190 gsm**
- **$[90_2/0_2/\pm45/0_2]_s$ 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**

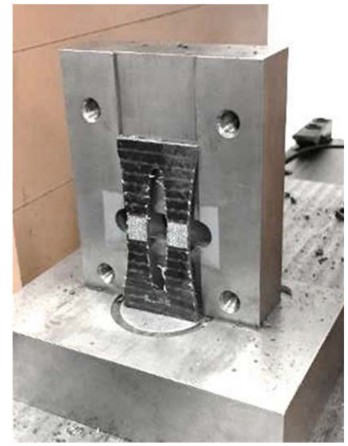


Current Focus:
C-Channel Crush Testing

- University of Utah instrumented drop-weight impact tower
- High-speed video of crush process
- $[90_2/0_2/\pm45/0_2]_s$ and $[90/+45/0_2/90/-45/0_2]_s$ "hard" laminates
- Results to be used to assess numerical modeling capabilities

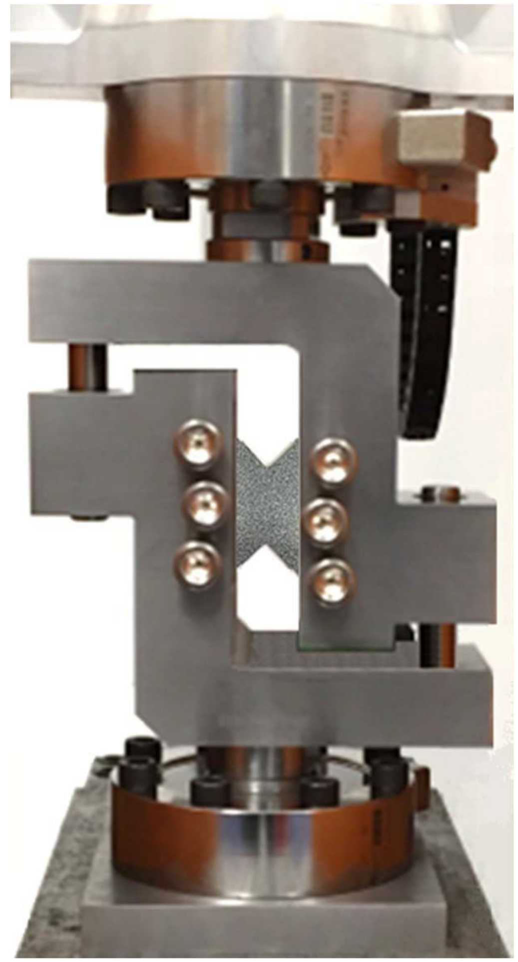
Dynamic Materials Characterization: Compression Testing

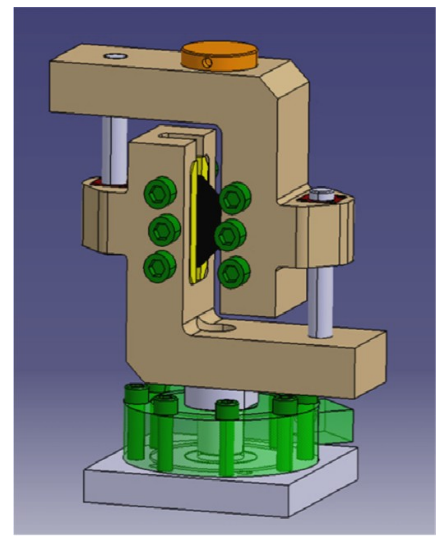
- Use of "double dog-bone" specimen
- Dynamic compression test fixture similar to crush fixture
- Variable drop height to control strain rate
- High crosshead mass used to ensure constant strain rate over test duration
- Digital Image Correlation used to determine strain rate
- Used to investigate changes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



Dynamic Materials Characterization:
V-Notched Shear Testing

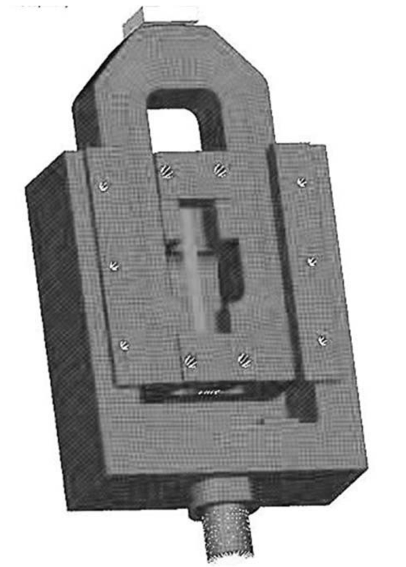
- **Modification to V-Notched Rail Shear Test, ASTM D7078**
    - **Compression loaded**
    - **Use in drop tower**
- **Allows for testing of various laminates**
- **Use of Digital Image Correlation (DIC) to measure strains during testing**
- **Challenges with inertial effects producing load oscillations**





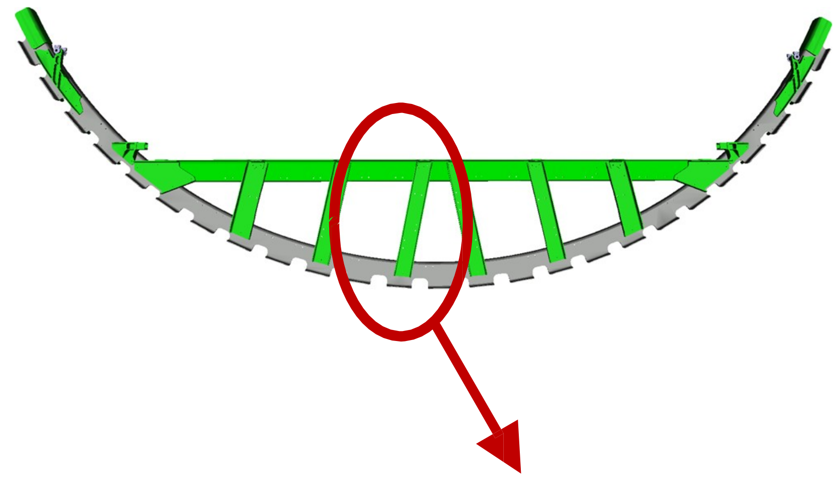
Dynamic Materials Characterization:
±45° Tensile Shear Testing

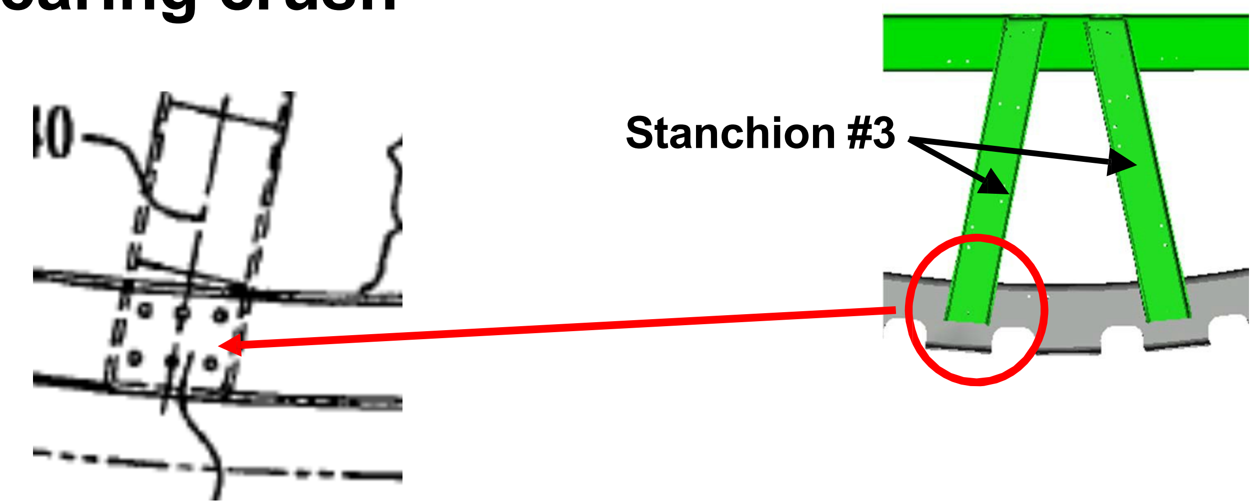
- Compression-loaded fixture produces tension load in specimen
- Dynamic analog to ASTM D3518
  - Use of ±45° laminate
  - Tension loaded
  - Load using drop tower
- Use of Digital Image Correlation (DIC) to measure strains during testing



Current Focus:
Dynamic Bearing Testing

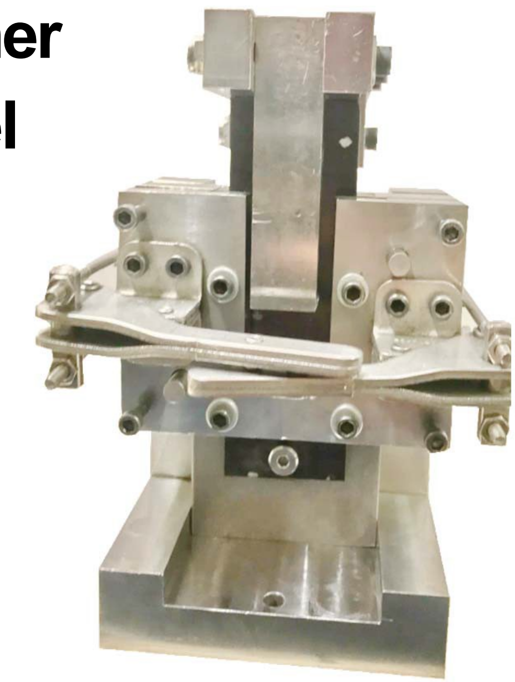
- **Stanchion bolted to the upper floor and lower frame**
- **Bearing failure possible at bolted connection**
- **Investigate dynamic bearing strength and bearing crush behavior**

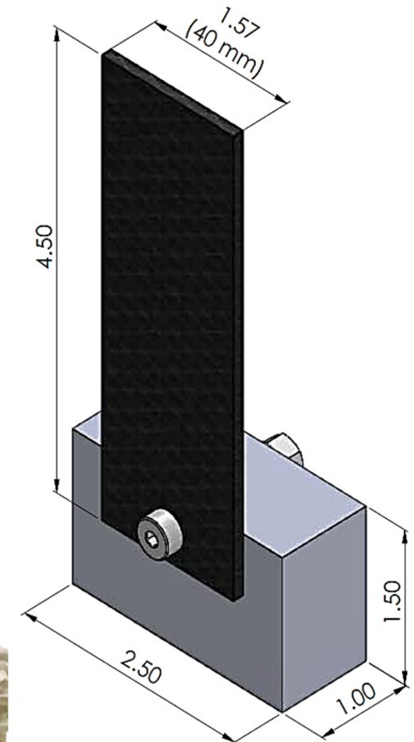




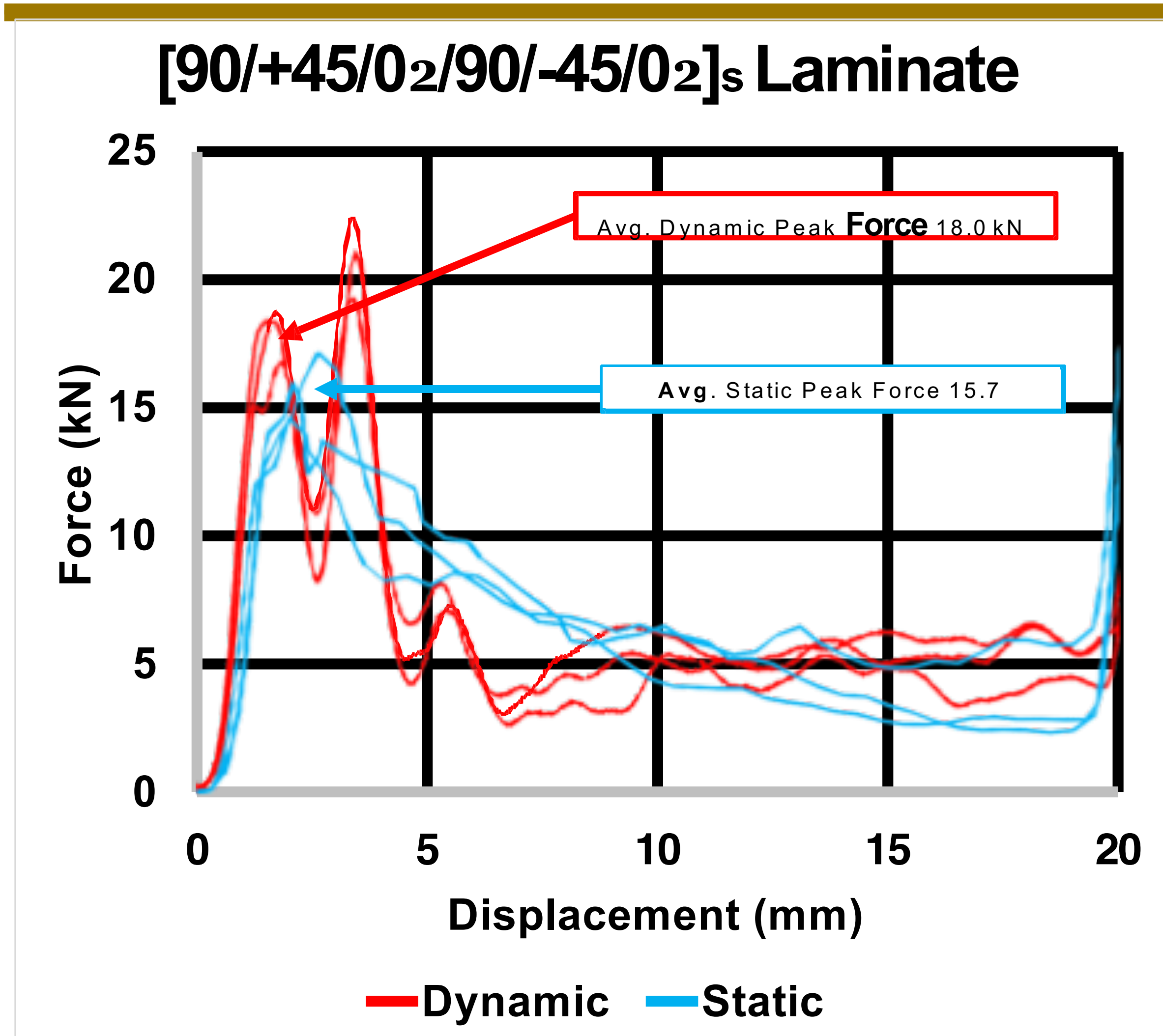
Test Procedure:
Dynamic Bearing Testing

- 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)



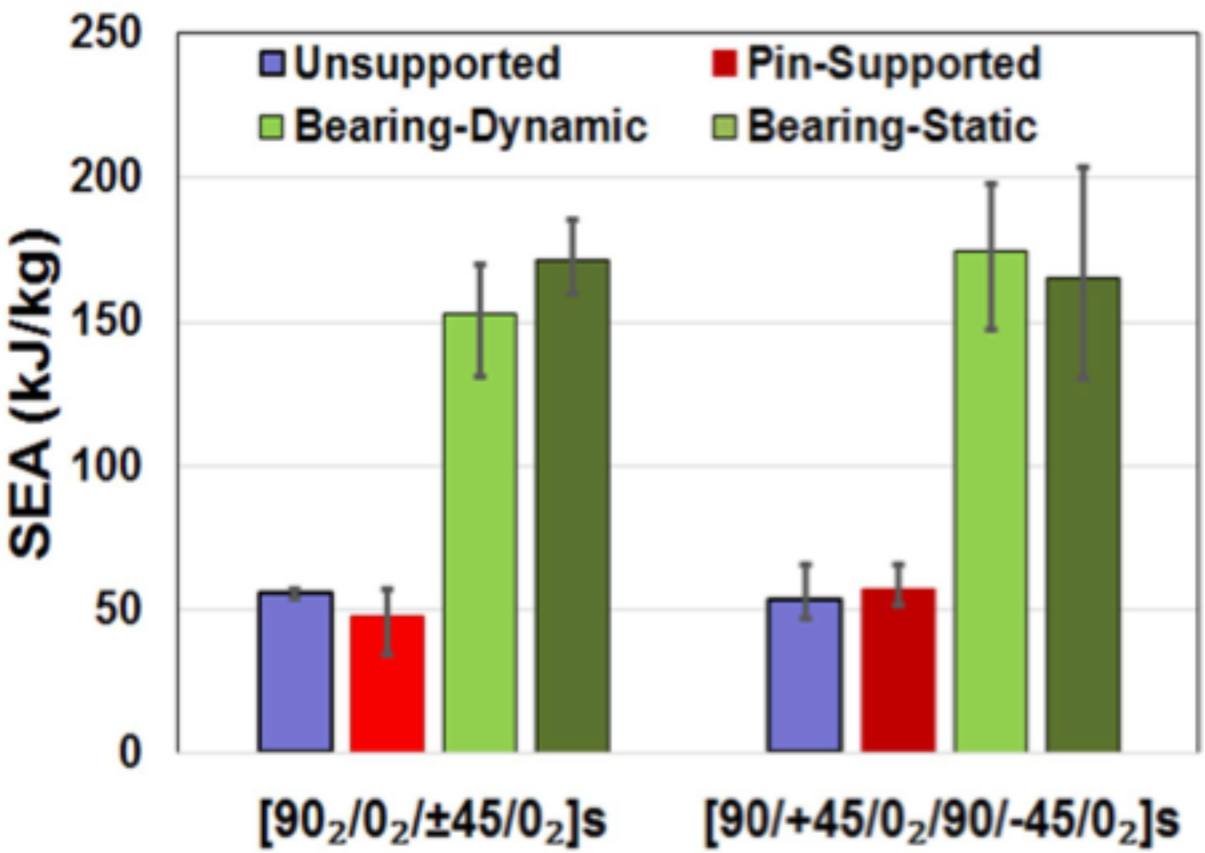


Initial Test Results:
Dynamic Bearing Testing



- 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

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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?