DEVELOPMENT AND EVALUATION OF FRACTURE MECHANICS TEST METHODS FOR SANDWICH COMPOSITES

Brad Kuramoto
Josh Bluth
Joe Nelson
Dan Adams
Department of Mechanical Engineering
University of Utah
Salt Lake City, UT

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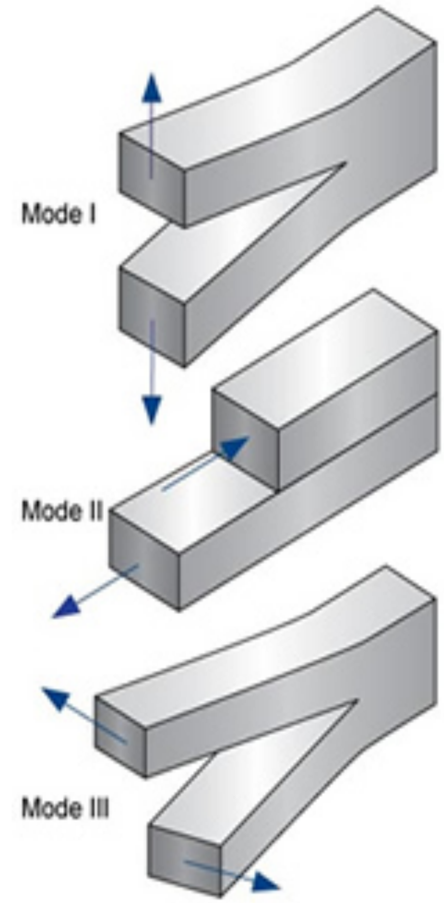
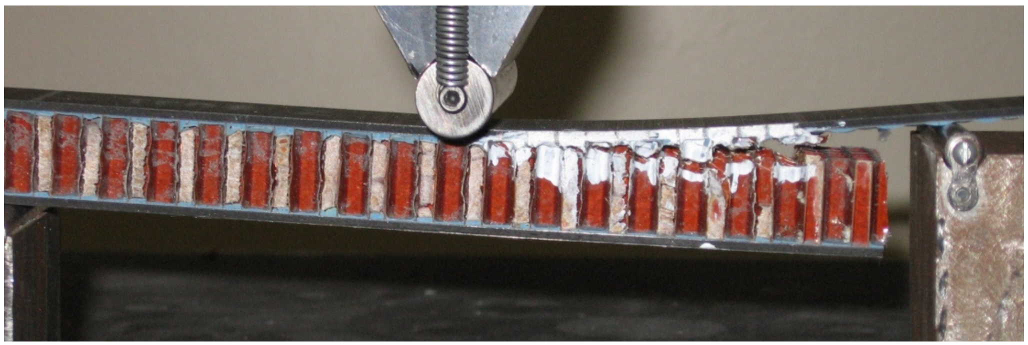
Research Objectives

Develop fracture mechanics test methods for sandwich composites

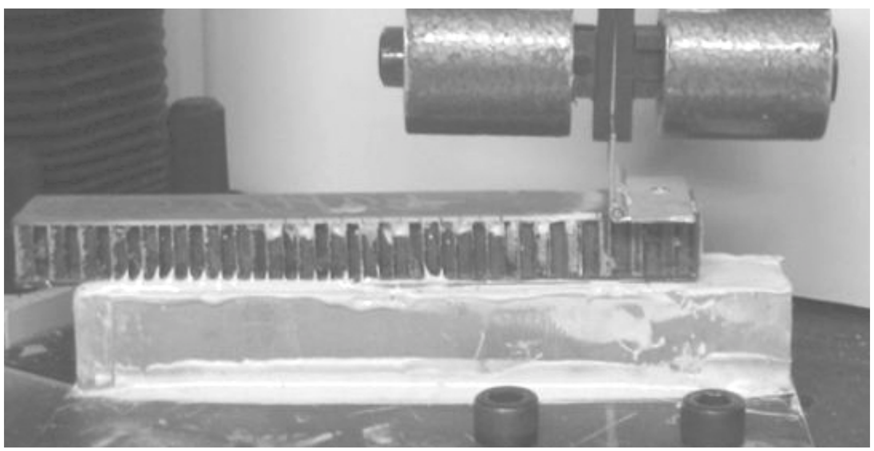
- **Focus on facesheet/core delamination**
- **Both Mode I and Mode II**
- **Suitable for ASTM standardization**

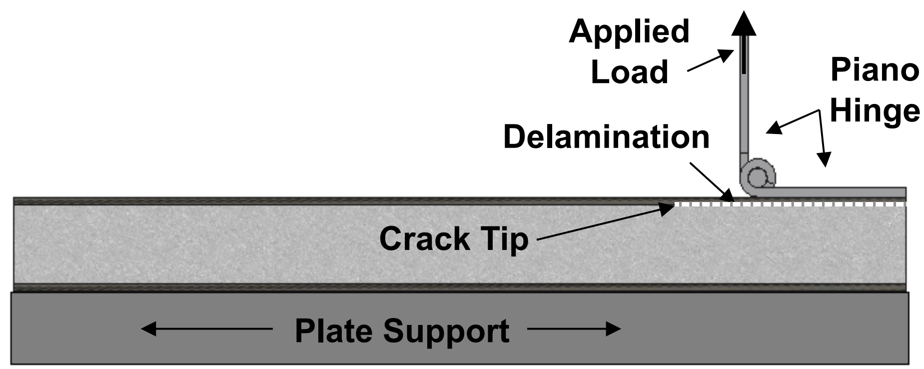




SELECTED MODE I CONFIGURATION:
Plate-Supported Single Cantilever Beam (SCB)

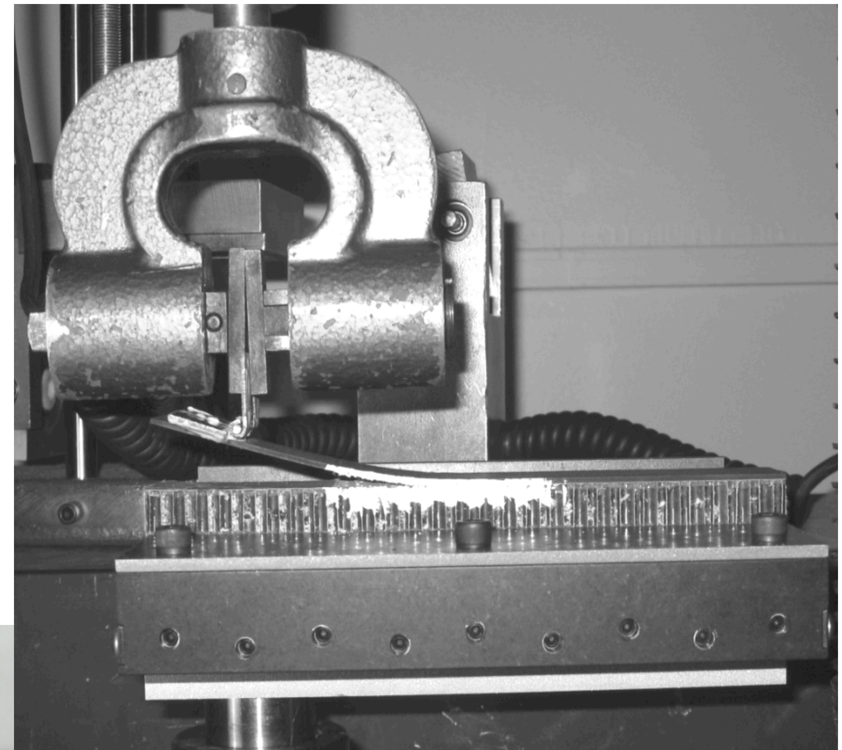
- **Elimination of bending of sandwich specimen**
- **Minimal Mode II component (less than 5%)**
- **No crack “kinking” observed**
- ***Appears to be suitable for a standard test method***

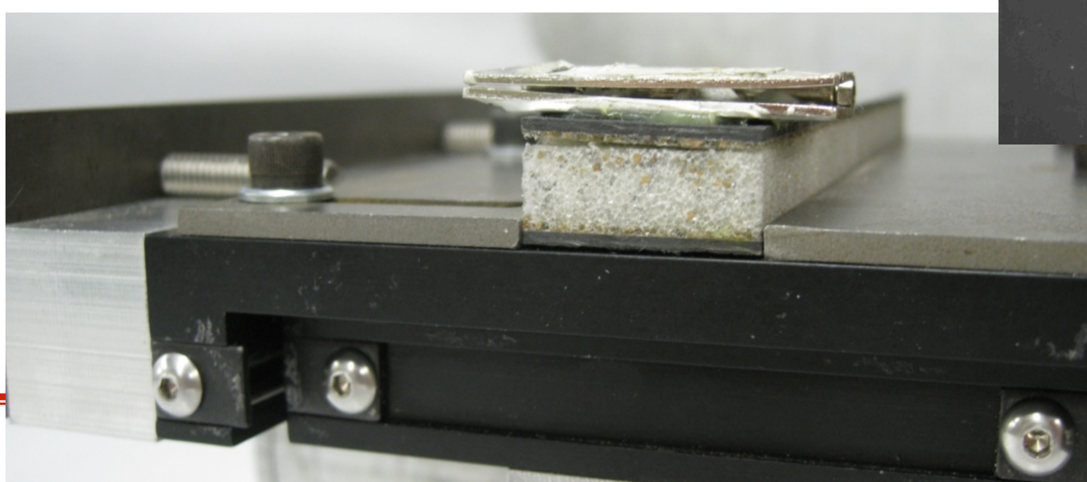




Current Prototype Mode I Test Fixture: Single Cantilever Beam (SCB)

- Translating fixture base maintains vertical loading
- Edge clamp restraints to lower panel support
- Fixture does not require bonding to a plate
- Ability to test 1 in. to 3 in. wide sandwich specimens





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Experimental Validation:
Mode I Sandwich Panel Selection

		Facesheets					
		Unidirectional Prepreg			Woven		
		3 Ply $[0/90/0]_{T}$	6 Ply $[0/90/0]_{2T}$	12 Ply $[0/90/0]_{4T}$	2 Ply $[(0/90)/(\pm45)]_{T}$	6 Ply $[(0/90)/(\pm45)]_{3T}$	10 Ply $[(0/90)/(\pm45)]_{5T}$
Cores	Nomex Honeycomb HRH10-1/8-8	X	X	X			
	Aluminum Honeycomb CR III-3/16-5052-.001	X	X	X			
	Balsa Wood Baltek S67					X	
	Polyurethane Foam FR-6703						X
	Polyurethane Foam FR-6710				X	X	

- **Secondary bond with film adhesive used on honeycomb cores**
- **Single-step VARTM process used with foam and balsa cores**

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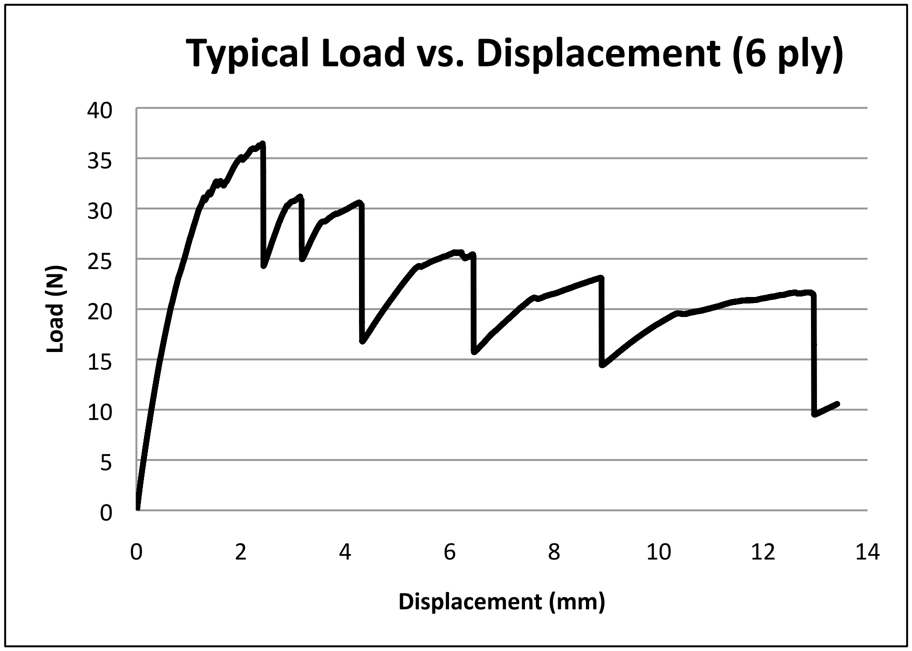
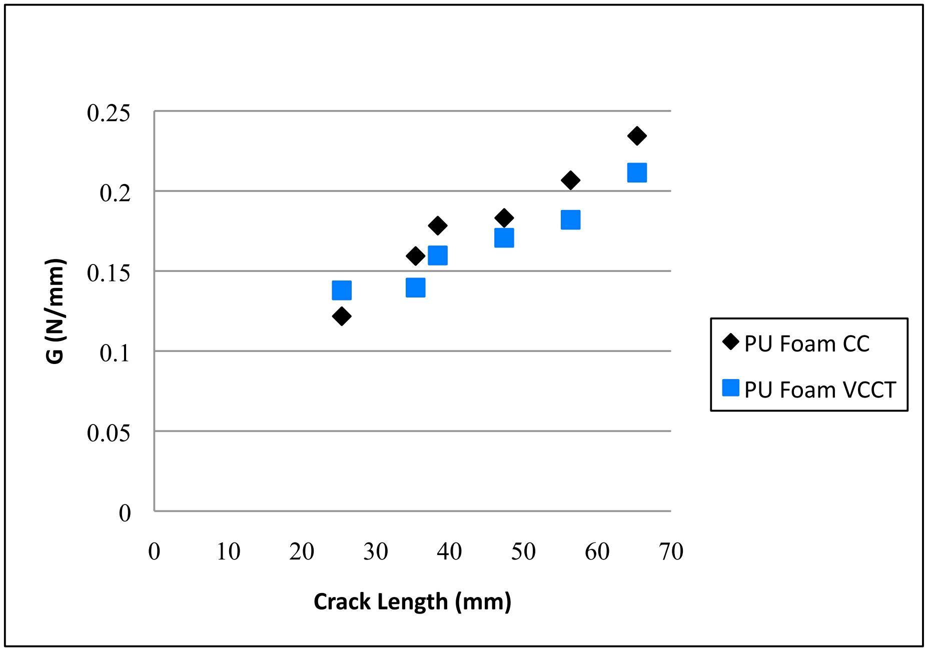
Mode I Results: Polyurethane Foam Core Sandwich

- Semi-stable delamination propagation
- No apparent effect of facesheet thickness on G_c





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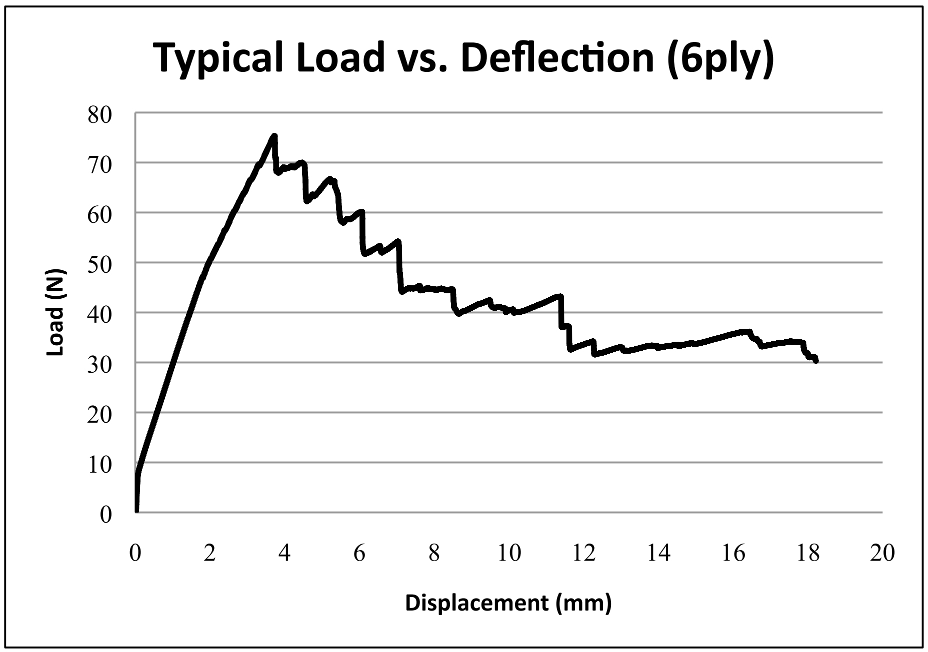
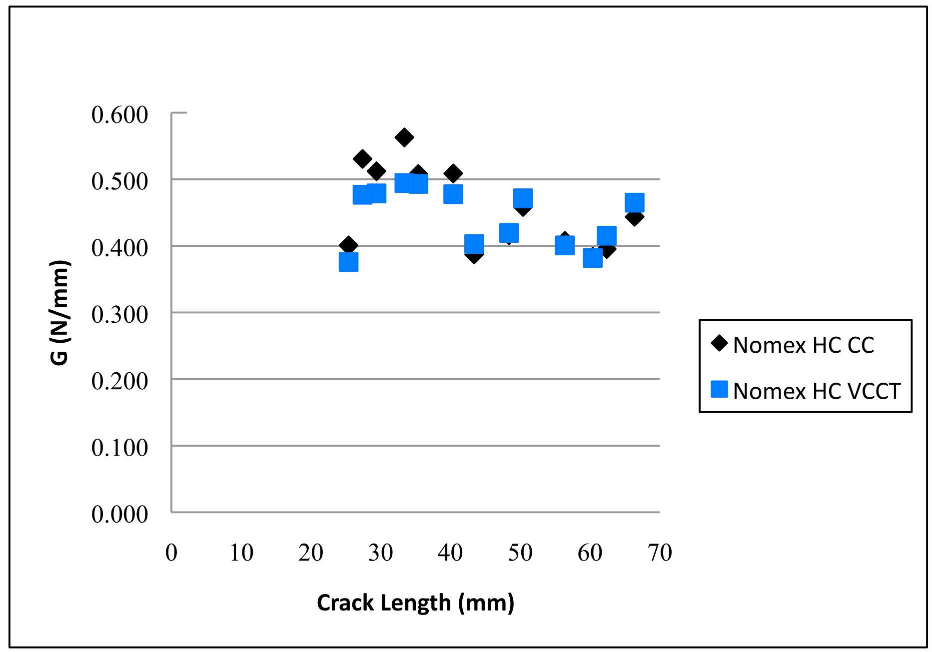
Mode I Results:
Nomex Honeycomb Core Sandwich

- Stable & Semi-stable delamination propagation
- No apparent effect of facesheet thickness on G_c





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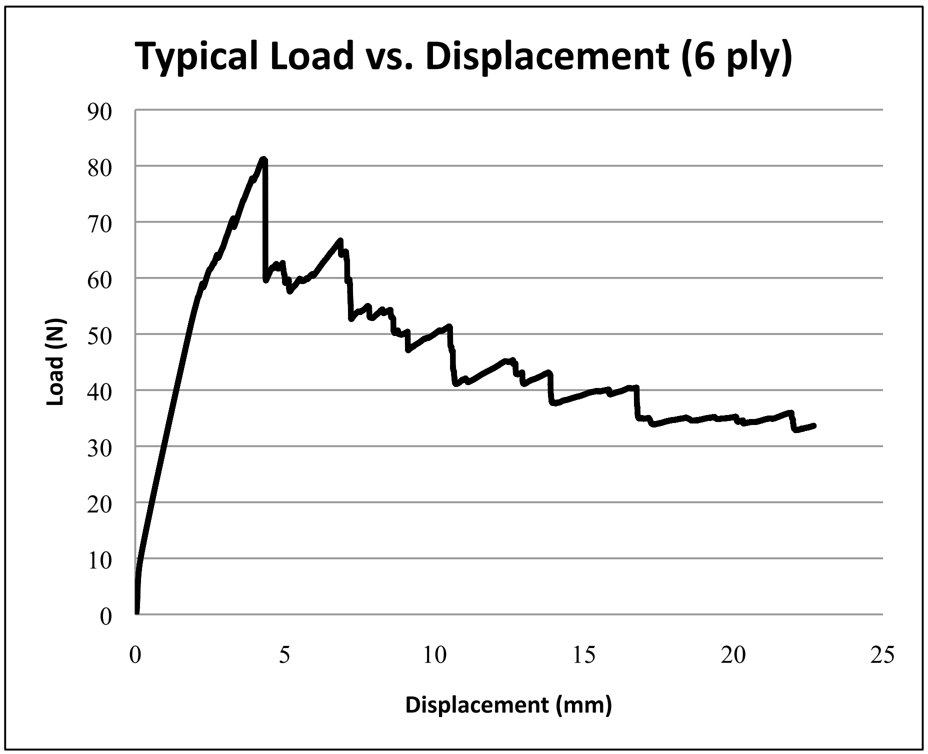
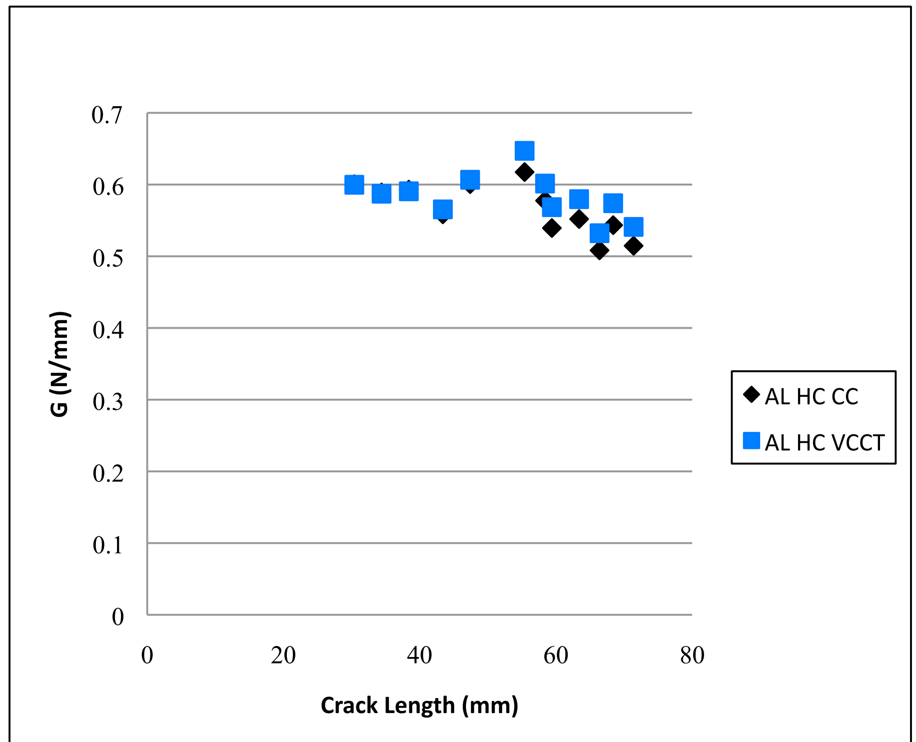
Mode I Results:
Aluminum Honeycomb Core Sandwich

- Stable & Semi-stable delamination propagation
- No apparent effect of facesheet thickness on G_c





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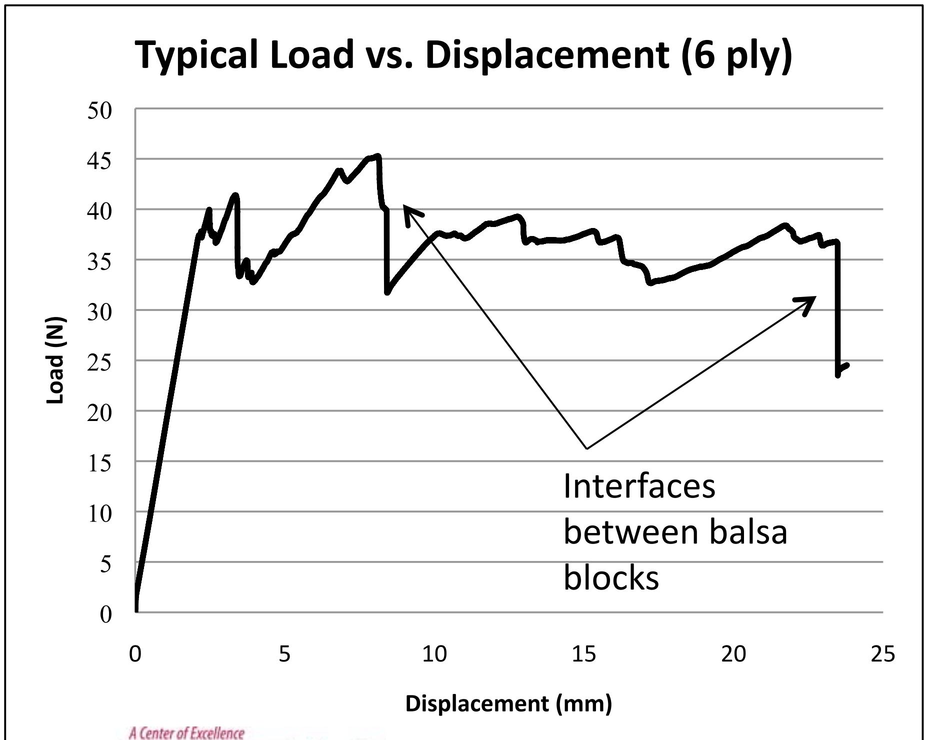
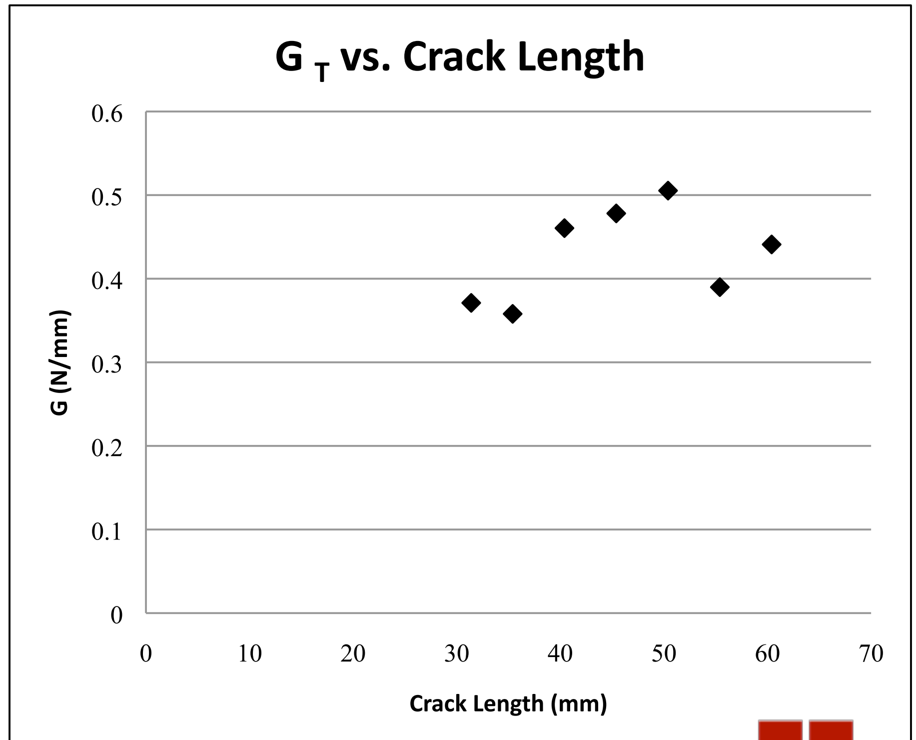
Mode I Results:
End-Grain Balsa Wood Core Sandwich

- Stable and Semi-stable delamination growth
- Growth arrested at breaks in interfaces between balsa core "blocks" (followed by unstable growth)



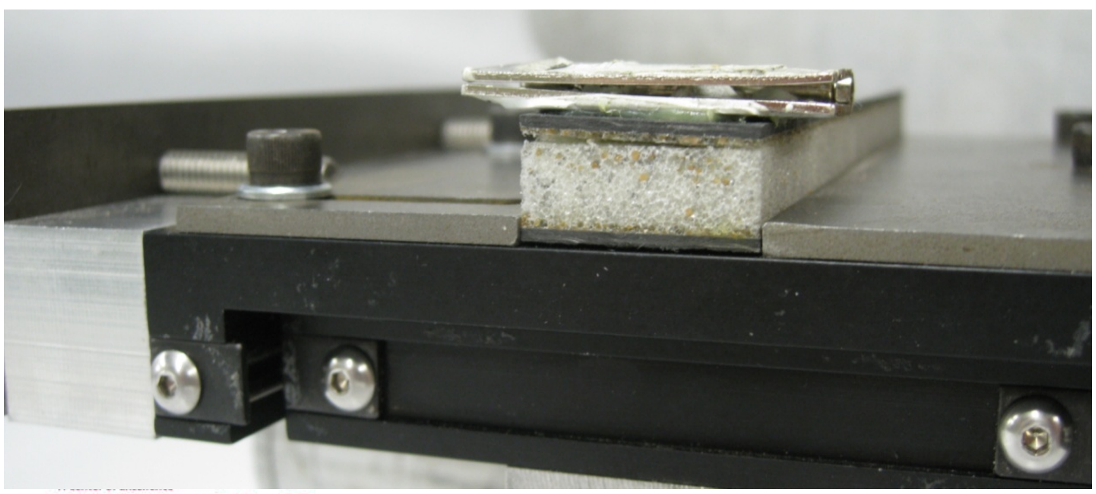


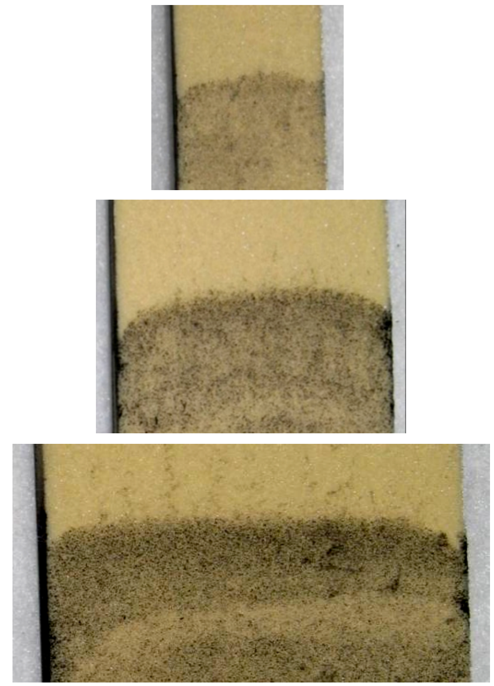
Mode I Single Cantilever Beam (SCB) Test: Specimen Width Effects

- Testing using three specimen widths

  1 in. 2 in. 3 in.

- Three core materials investigated
  - Aluminum honeycomb
  - Nomex honeycomb
  - Polyurethane foam





Crack front, polyurethane foam core

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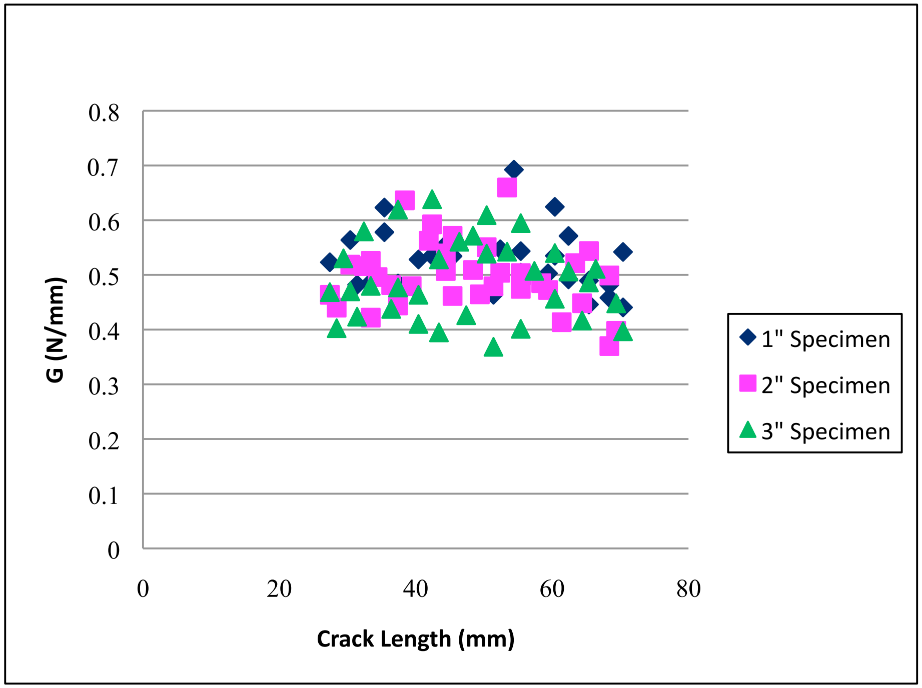
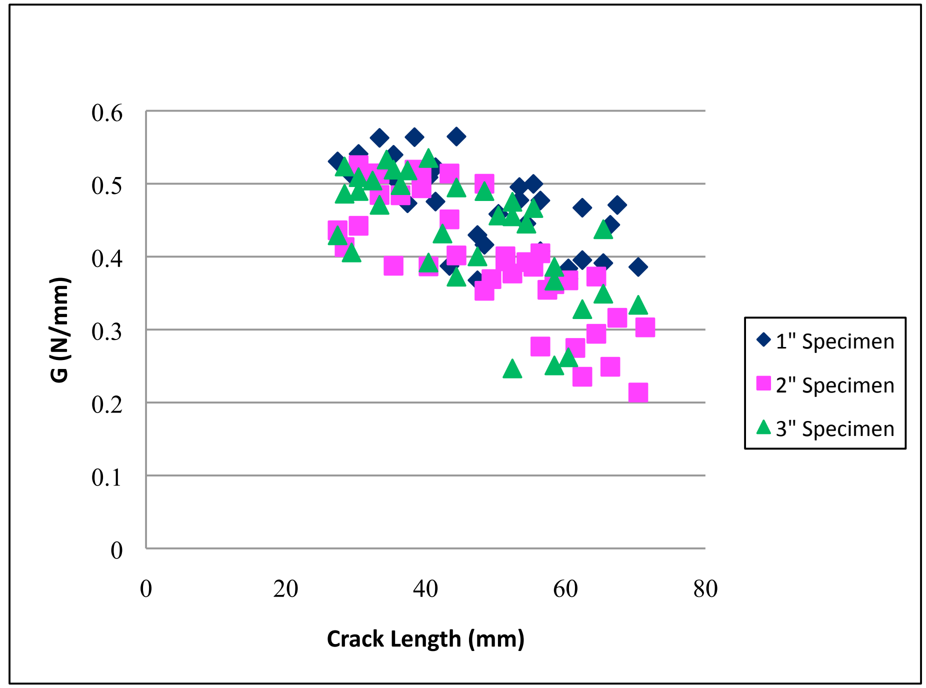
Mode I Single Cantilever Beam (SCB) Test: Width Effects With Honeycomb Cores

Aluminum honeycomb core



Nomex honeycomb core



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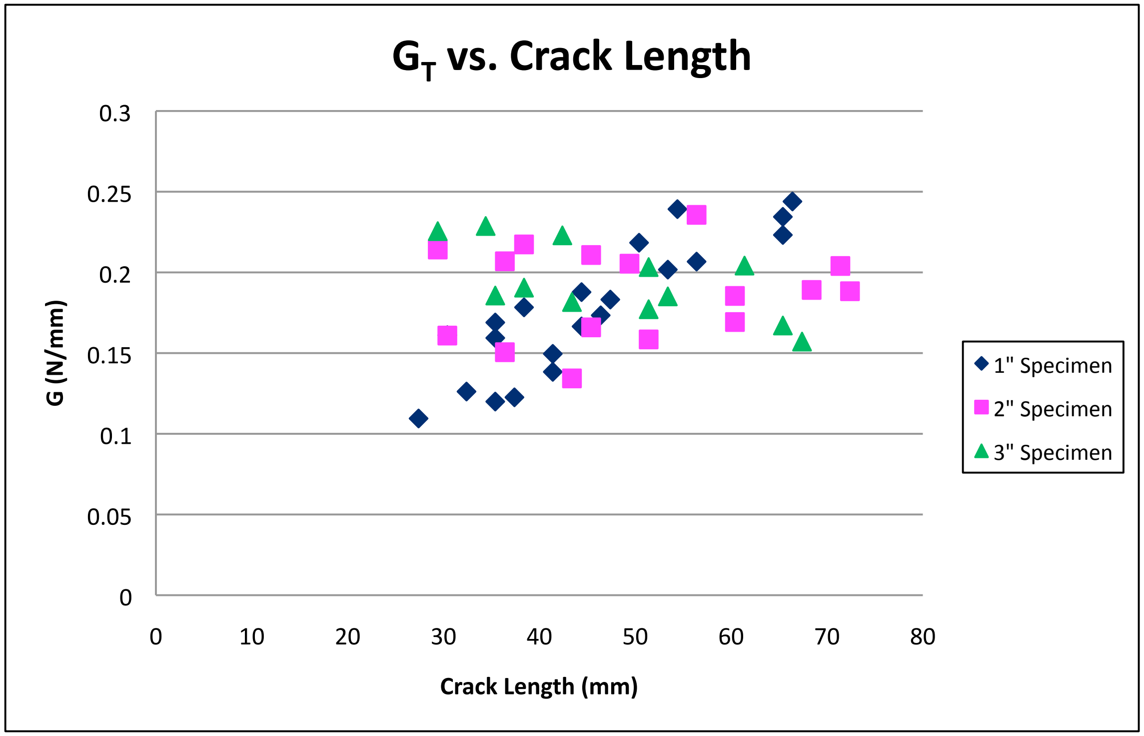
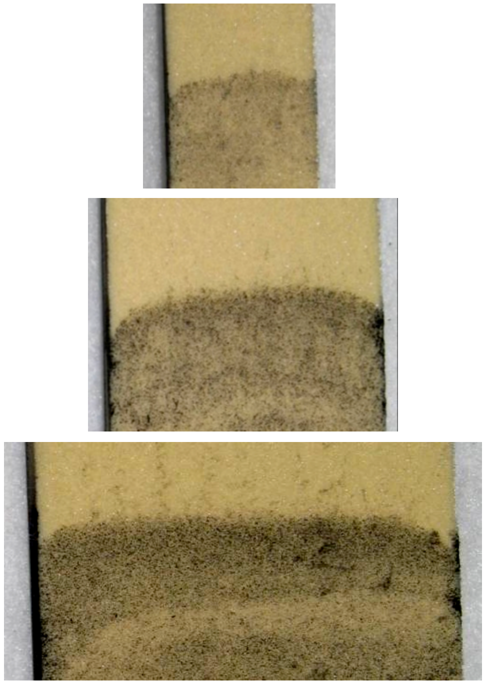
Mode I Single Cantilever Beam (SCB) Test: Width Effects With Polyurethane Foam Core

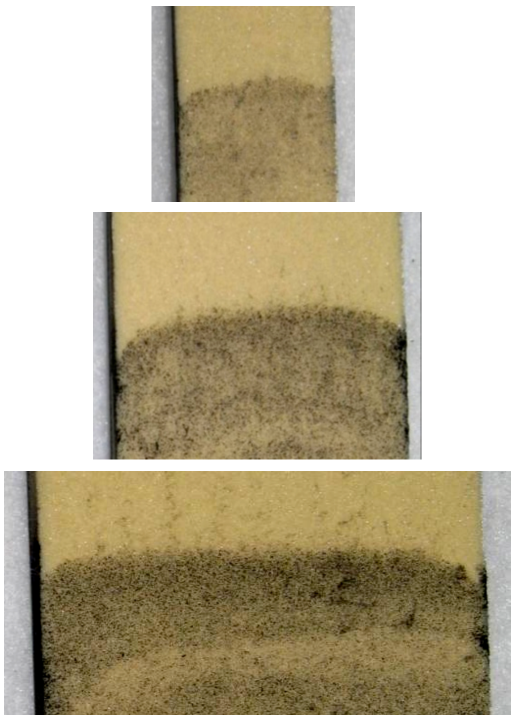


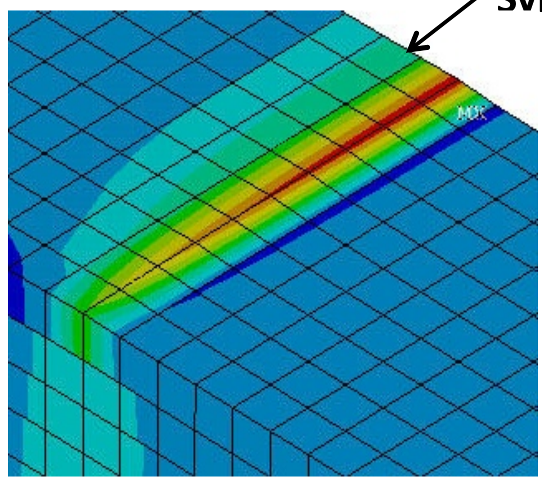


Crack front established using dye penetrant

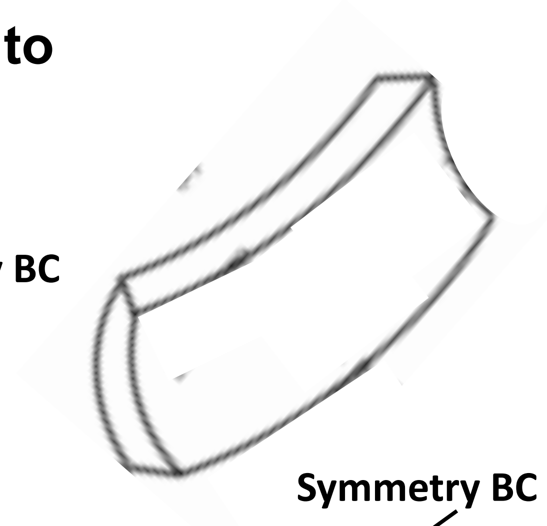
Specimen Width Effects:
Anticlastic Curvature Due To Bending

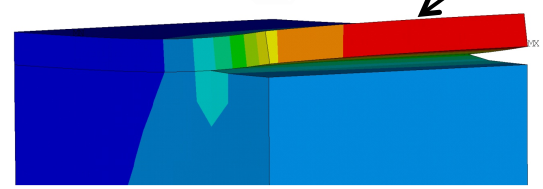
- **Crack front lagging on the free edges due to anticlastic bending of facesheet**
- **Anticlastic curvature highly dependent on v_{12} of facesheets**





Interlaminar normal stress at top surface of core





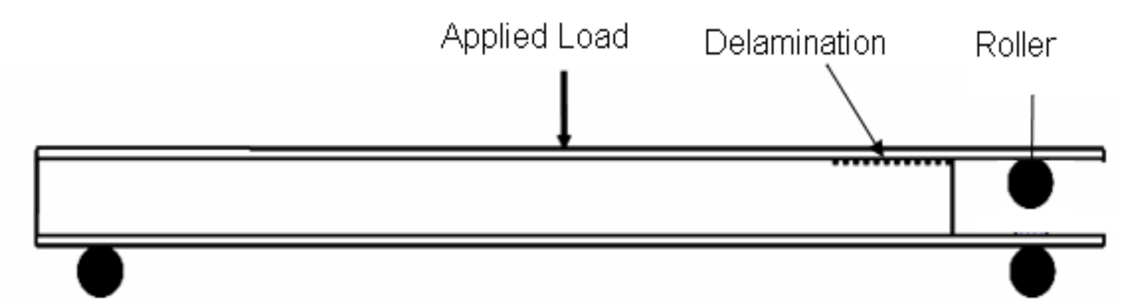
Vertical displacement of delaminated facesheet

Current Status:
Mode I Single Cantilever Beam (SCB) Test

- Appears well-suited for common sandwich configurations
  - High percentage Mode I
  - Delamination propagation along facesheet/core interface
  - Stable or semi-stable crack growth
- Width effect present due to anticlastic curvature
- Completing parametric study to identify recommended specimen geometries
- Composing a draft ASTM standard

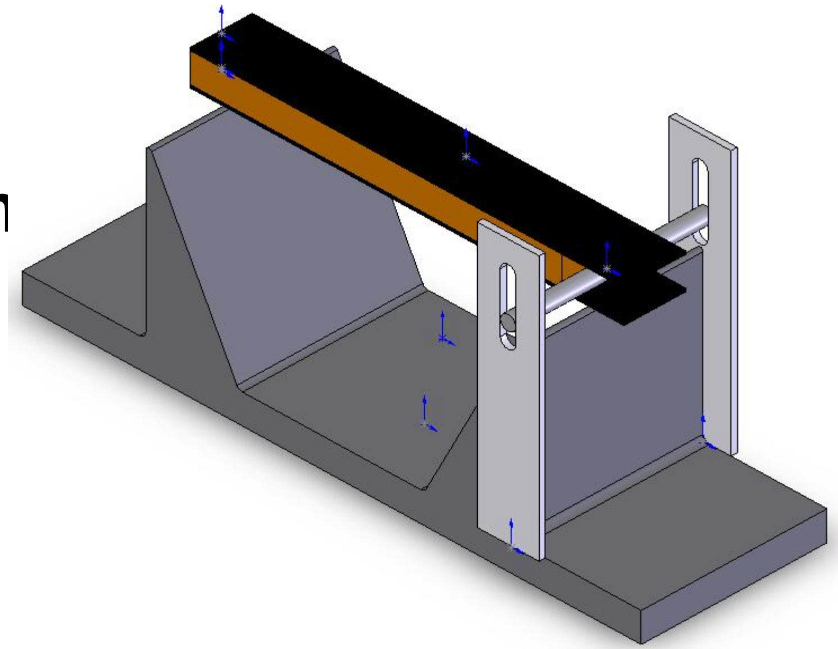
SELECTED MODE II CONFIGURATION: *Hinged* Cracked Sandwich Beam (CSB)

- **Three-point flexure loading**
- **Additional support provided at delaminated facesheet to create crack opening**
- **Relatively high percentages (>80%) of Mode II energy release rate produced**
- ***Appears to be a suitable Mode II test method***

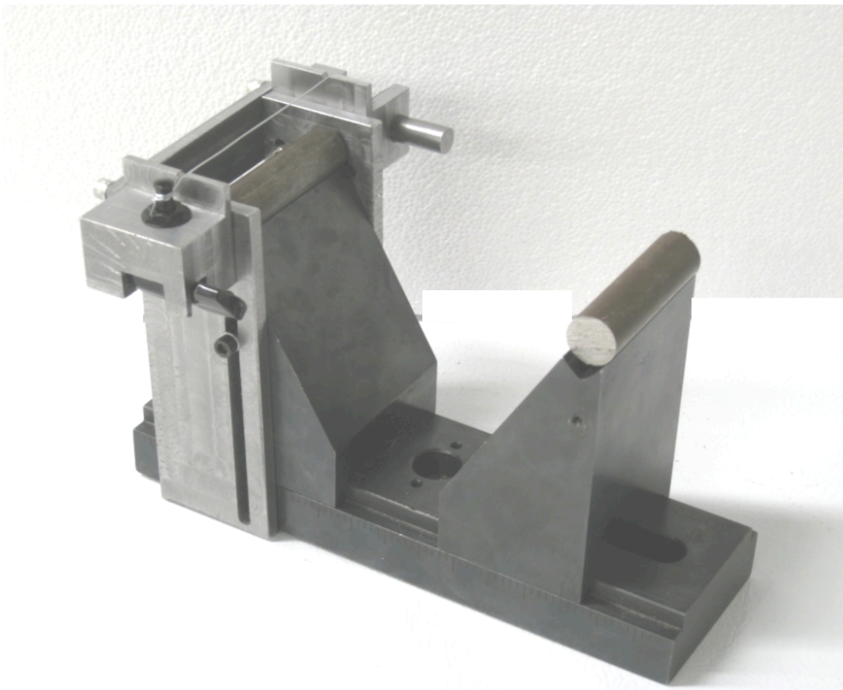


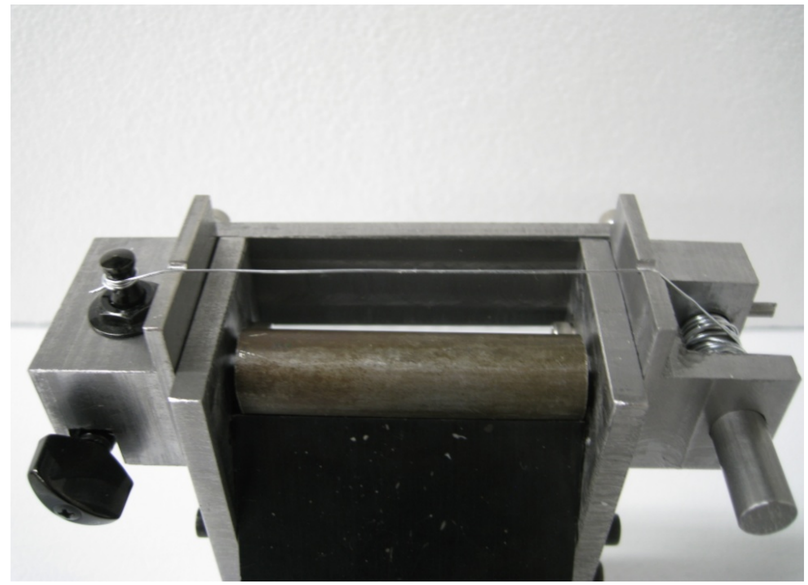
Original Mode II Test Fixture

- **Modified three-point flexure fixture**
- **Roller used to prevent facesheet/core interaction**
- **Required removal of core to place roller**



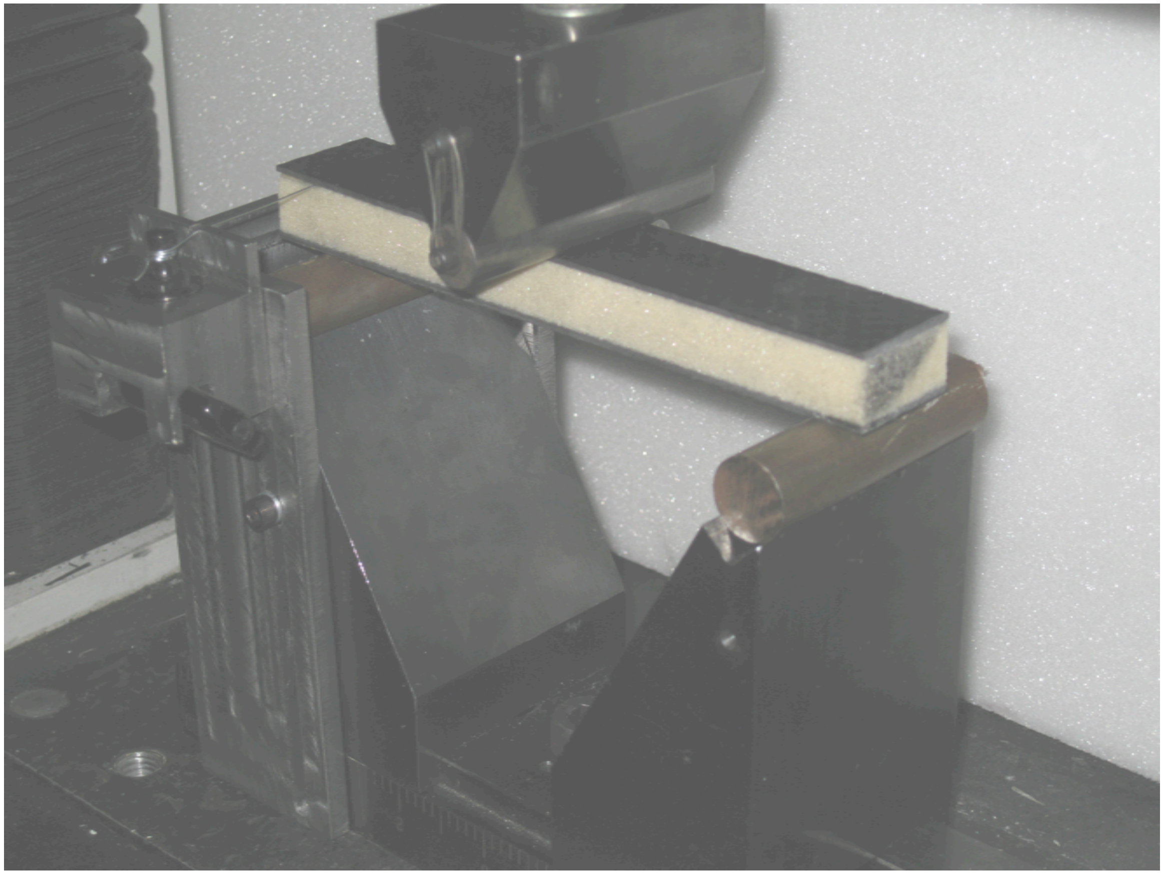
Further Test Fixture Development:
Mode II Testing





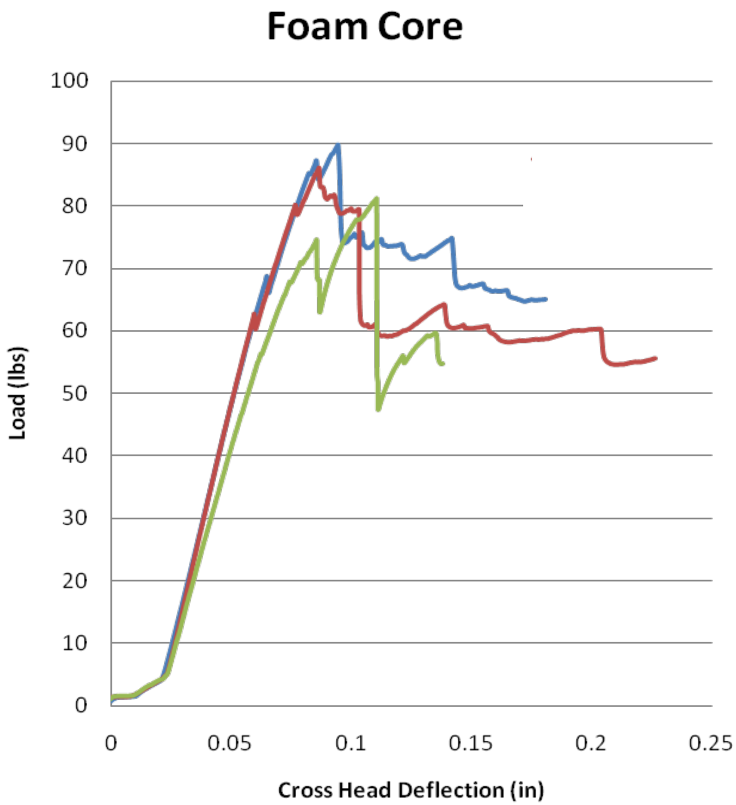
- **Spool assembly allows tensioning of wire**
- **Adjustable height of wire**

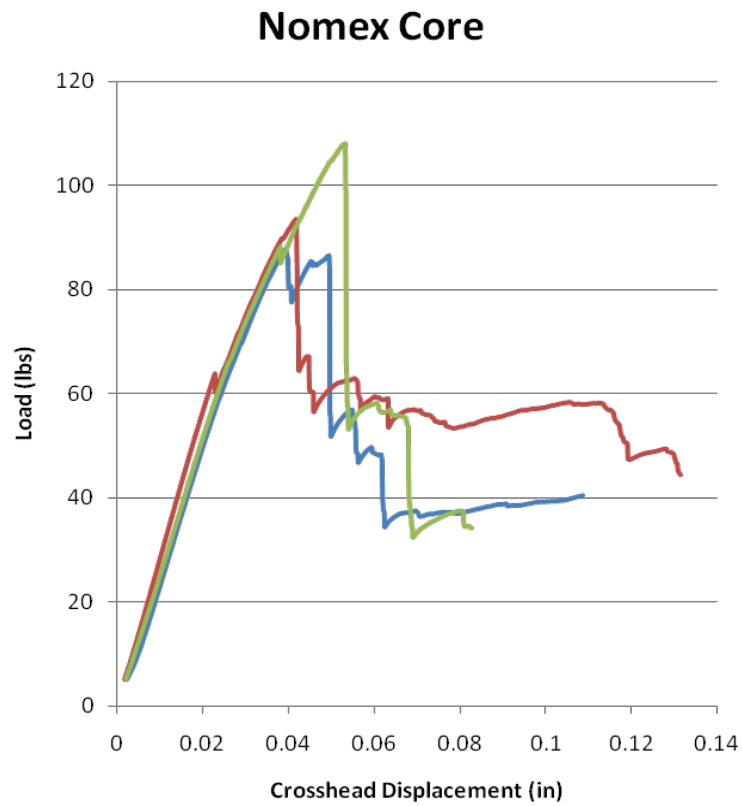
Prototype Mode II Test Fixture:
Hinged Cracked Sandwich Beam (CSB)



Mode II Test Results:
Foam and Nomex Honeycomb Cores

Semi-stable delamination propagation





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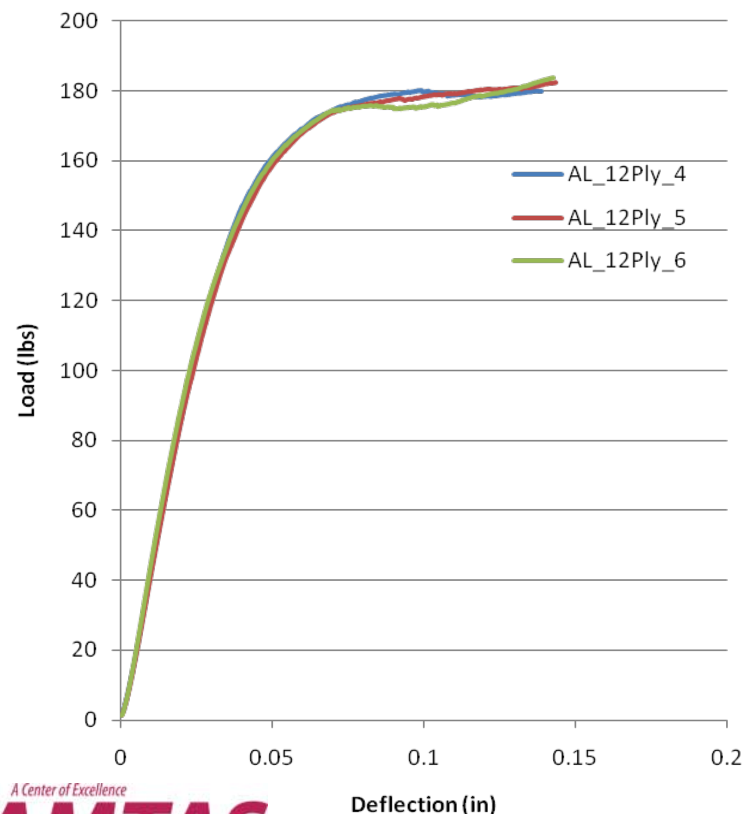
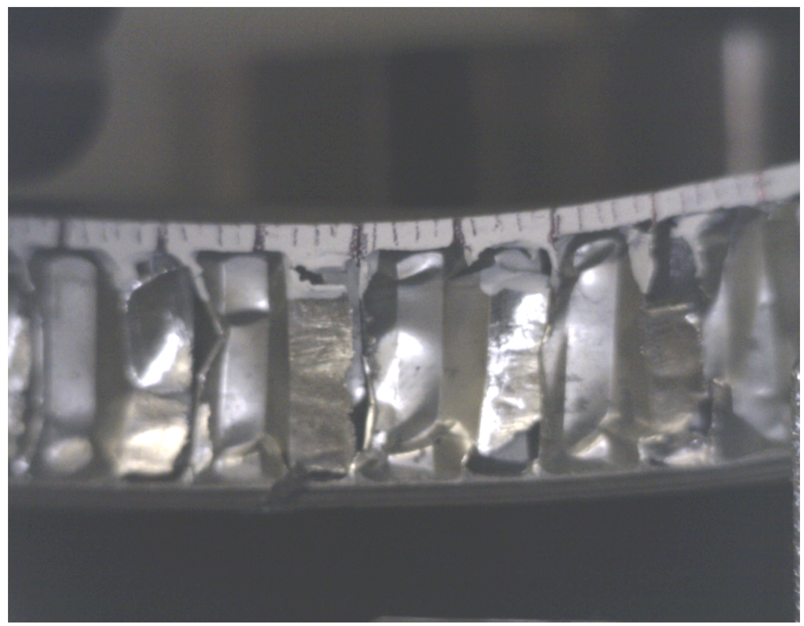
Mode II Test Results:
Aluminum Honeycomb Core

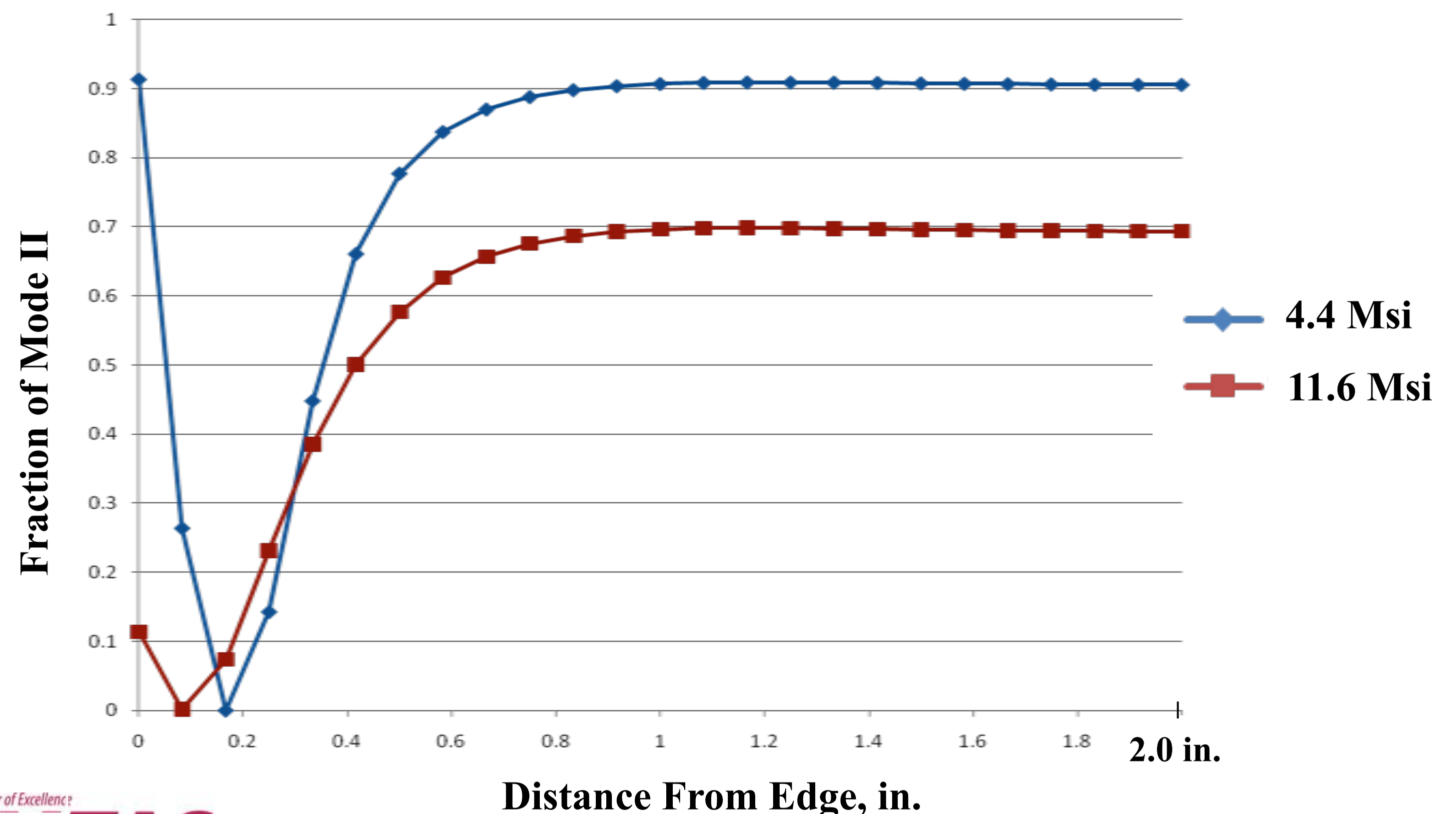
Core failure in aluminum honeycomb prior to delamination growth





Facesheet Stiffness Effects:
Mode Mixity Variations Across Specimen Width

- 3D finite element analysis of 4 in. wide specimen
- Two facesheet moduli values analyzed: 4.4 Msi and 11.6 Msi



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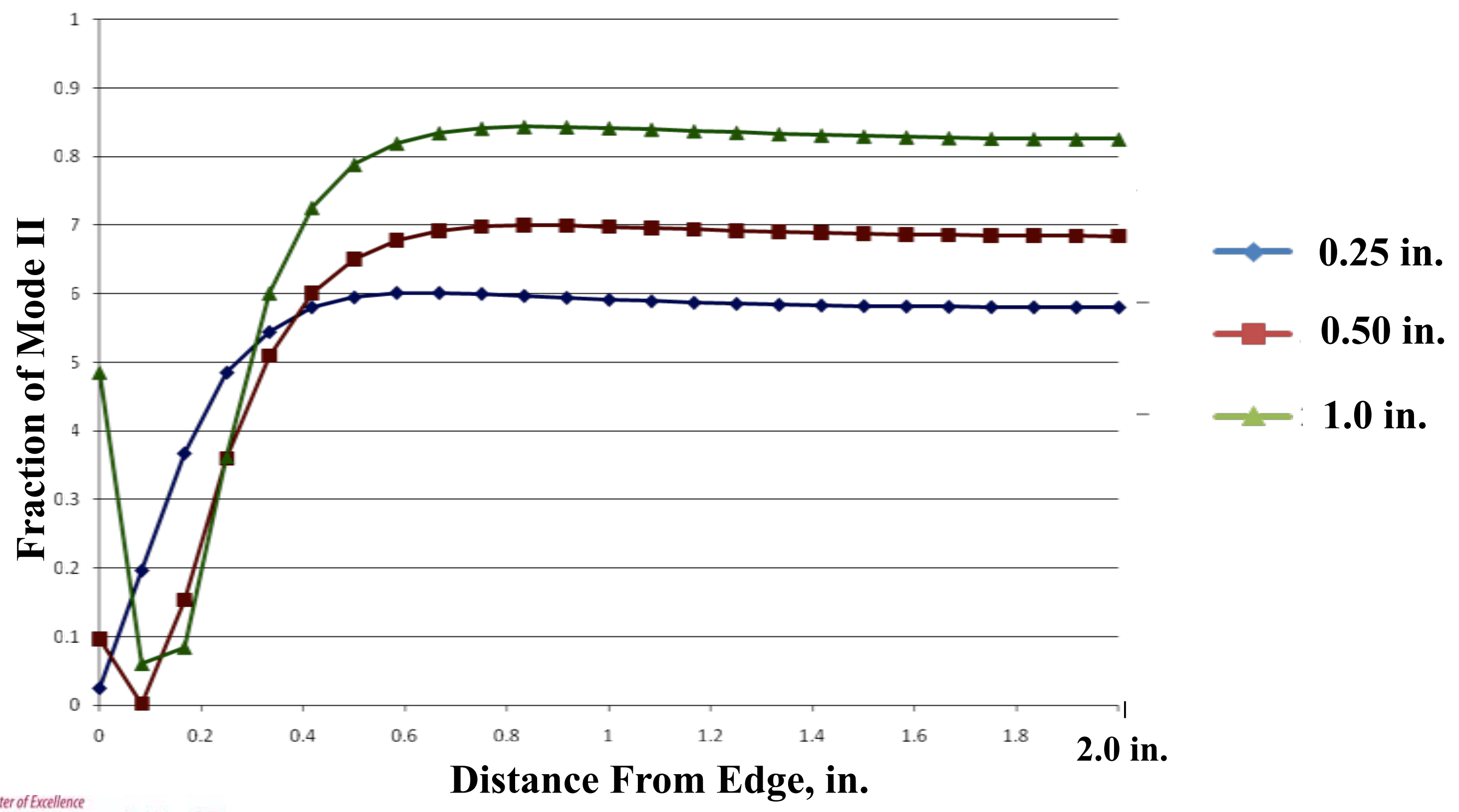
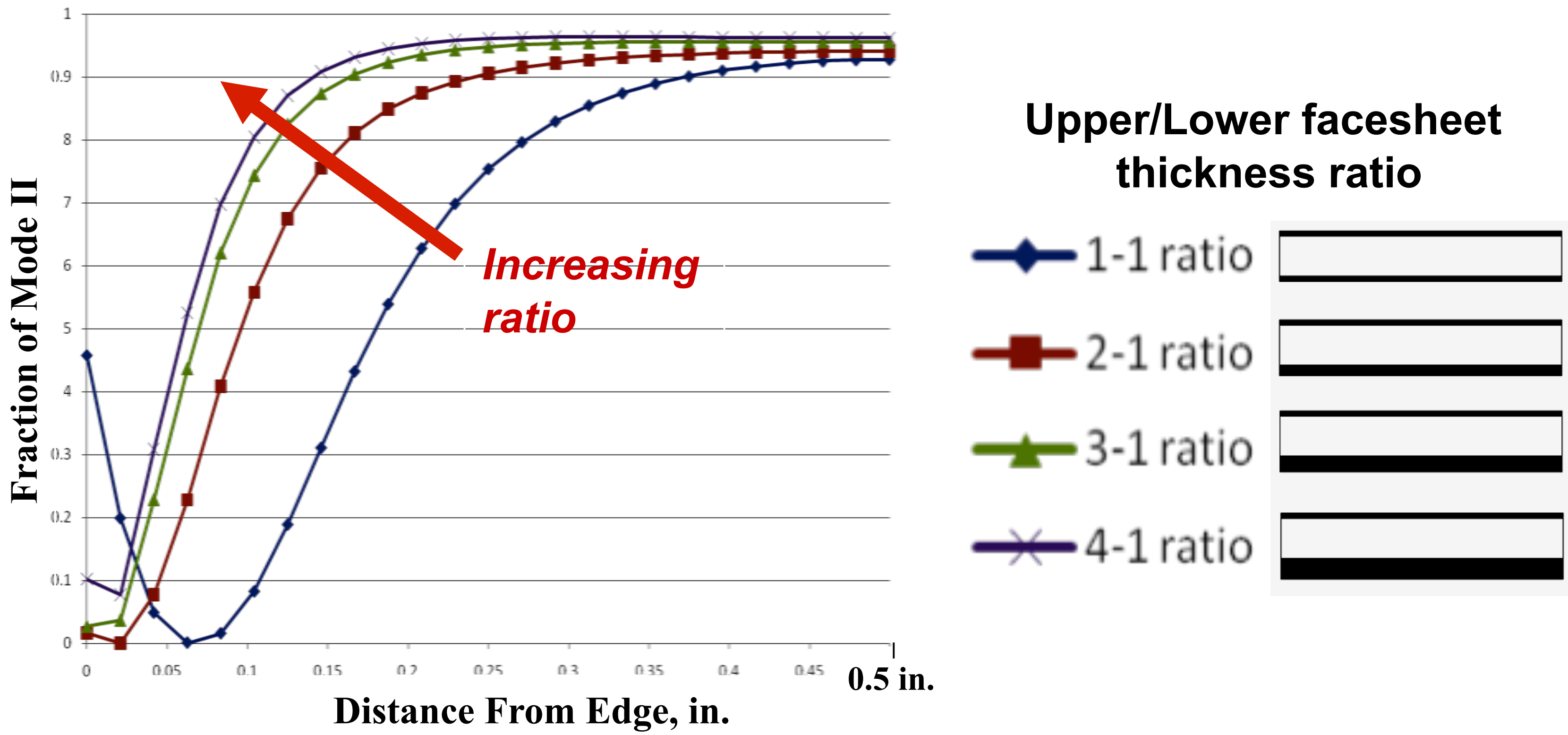
Core Thickness Effects:
Mode Mixity Variations Across Specimen Width

- 3D finite element analysis of 4 in. wide specimen
- Three core thicknesses investigated

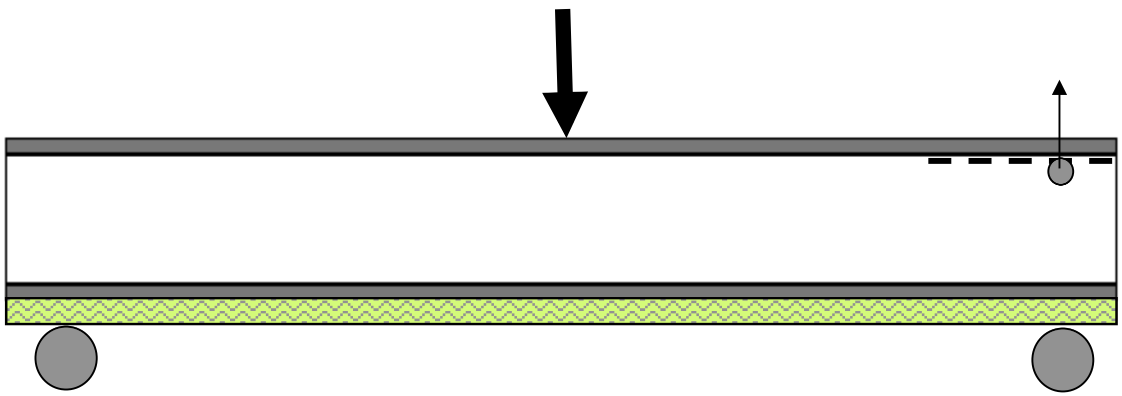


Addressing Mode Mixity/Width Variation:
Adding Flexural Stiffness to Bottom Facesheet

Increasing flexural stiffness (EI) of lower portion of delaminated specimen reduces specimen width effect



Increasing Flexural Stiffness to Bottom Facesheet: Asymmetric Tabbing of Sandwich Composite



Tabbing of bottom of sandwich with conventional tabbing material G10 glass-epoxy expected to produce acceptable flexural stiffness ratio

CURRENT FOCUS:
Sensitivity Studies on Specimen Parameters

- *Determination of Acceptable Ranges of Sandwich Configurations*
  - **Facesheet parameters**
    - **Thickness, flexural stiffness, flexural strength**
  - **Core parameters**
    - **Thickness, stiffness, strength**
  - **Specimen and delamination geometry**

- *Composing draft ASTM standards*