DEVELOPMENT AND EVALUATION OF FRACTURE MECHANICS TEST METHODS FOR SANDWICH COMPOSITES

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FAA Sponsored Project Information

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- FAA Technical Monitor
  - Curt Davies

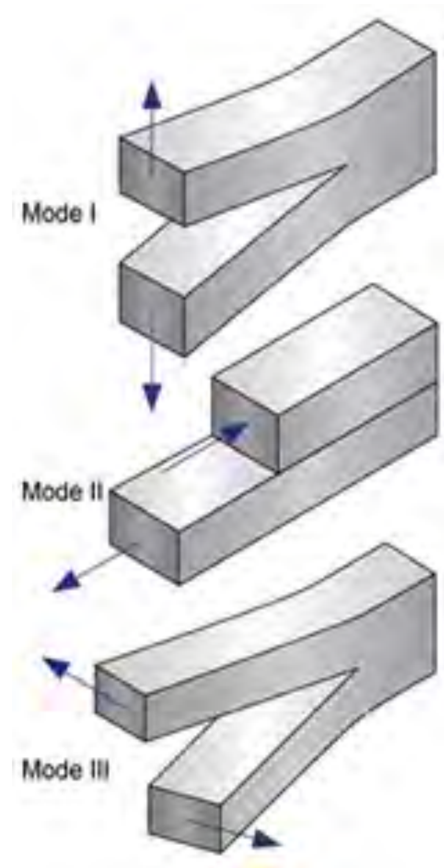
BACKGROUND:
FRACTURE MECHANICS TEST METHODS FOR SANDICH COMPOSITES

- Fracture mechanics test methods for composites have reached a high level of maturity
- Less attention to sandwich composites
  - Focus on particular sandwich materials
  - Focus on environmental effects
  - No consensus on a suitable test configuration or specimen geometry for Mode I or Mode II fracture toughness testing

RESEARCH OBJECTIVE

Develop fracture mechanics test methods for sandwich composites

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

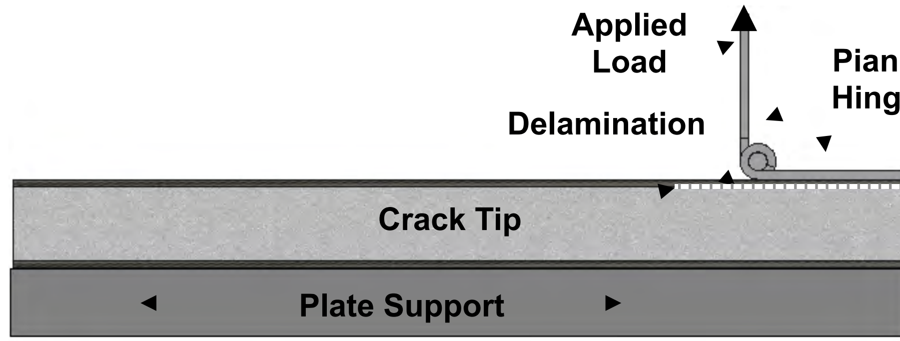


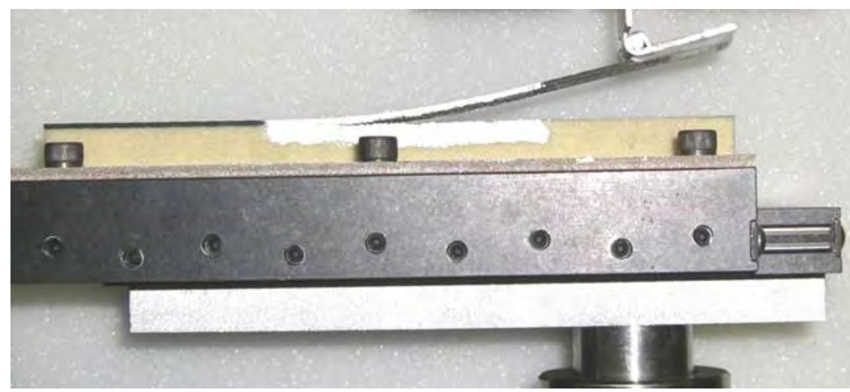
RESEARCH APPROACH:
THREE PHASE PROGRAM

- PHASE I: Identification and initial assessment of candidate test methodologies
- PHASE II: Selection and optimization of best suited Mode I and Mode II test methods
- PHASE III: Identification of acceptable ranges and development of draft ASTM standards

SELECTED MODE I CONFIGURATION: PLATE-SUPPORTED SINGLE CANTILEVER BEAM (SCB)

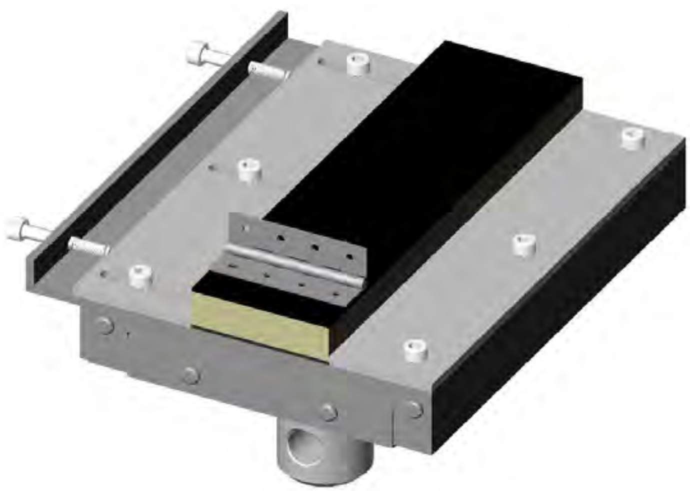
- **Elimination of bending of sandwich specimen**
  - **Minimal Mode II component (less than 5%)**
  - **No significant bending stresses in core**
- **No crack "kinking" observed**
- ***Appears to be suitable for a standard test method***



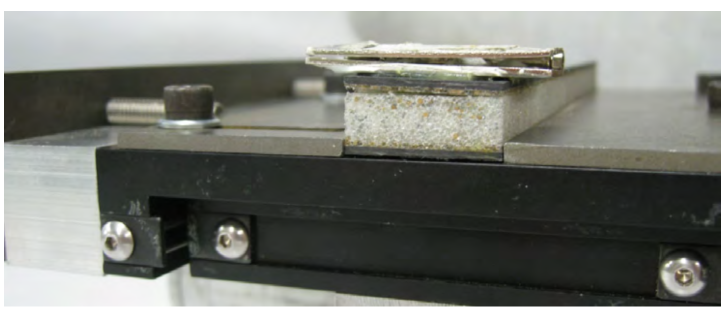


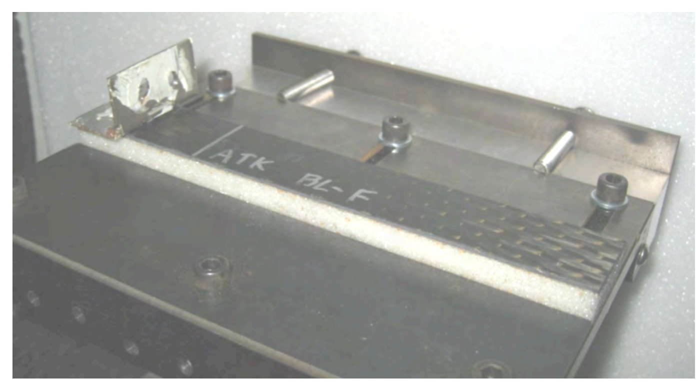
DEVELOPMENT OF TEST FIXTURING:
MODE I TESTING

Single Cantilever Beam (SCB) Test



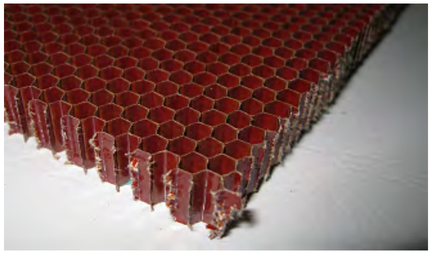
- Ability to test 1 in. to 3 in. wide sandwich specimens
- Edge clamp restraints at base eliminates adhesive bonding
- Translating fixture base maintains vertical loading

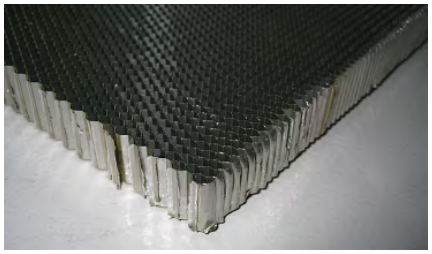




TEST METHOD ASSESSMENT:
ANALYSIS AND TESTING

- **Determination of Acceptable Ranges of Specimen Parameters**
  - **Facesheet parameters**
    - **Thickness, flexural stiffness, flexural strength**
  - **Core parameters**
    - **Thickness, density, stiffness, strength**
  - **Specimen length and width, initial delamination length**
- **Use of four different core materials**
  - **Nomex honeycomb**
  - **Aluminum honeycomb**
  - **Polyurethane foam**
  - **End-grain balsawood**
- **Carbon/epoxy facesheets (woven fabric and prepreg)**

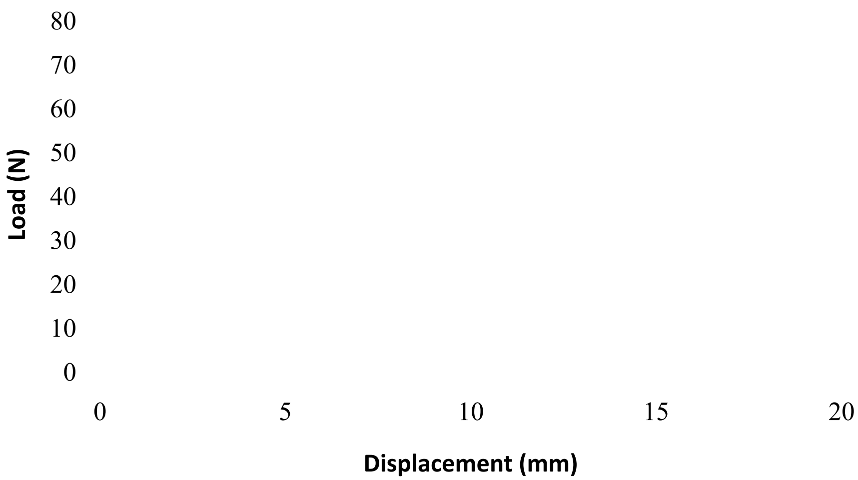


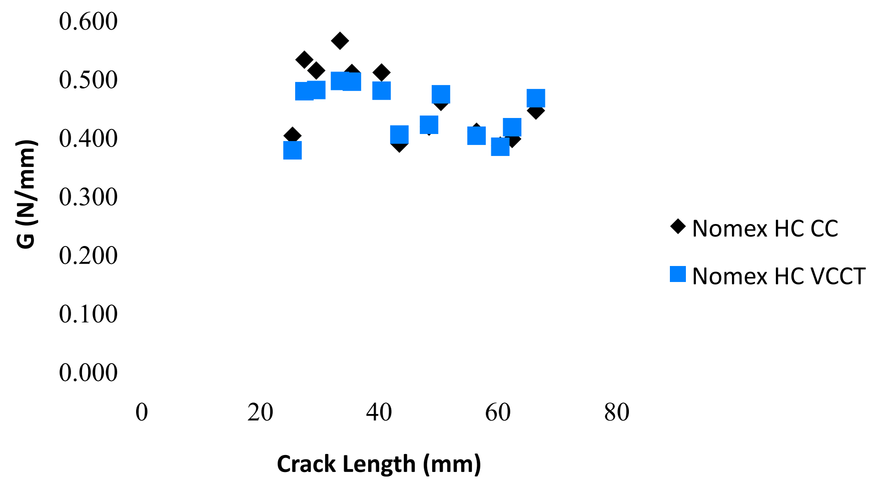


EXAMPLE MODE I RESULTS:
NOMEX HONEYCOMB CORE SANDWICH

- **Stable delamination propagation**
- **No apparent effect of facesheet thickness on G_c**

Typical Load vs. Deflection (6ply)





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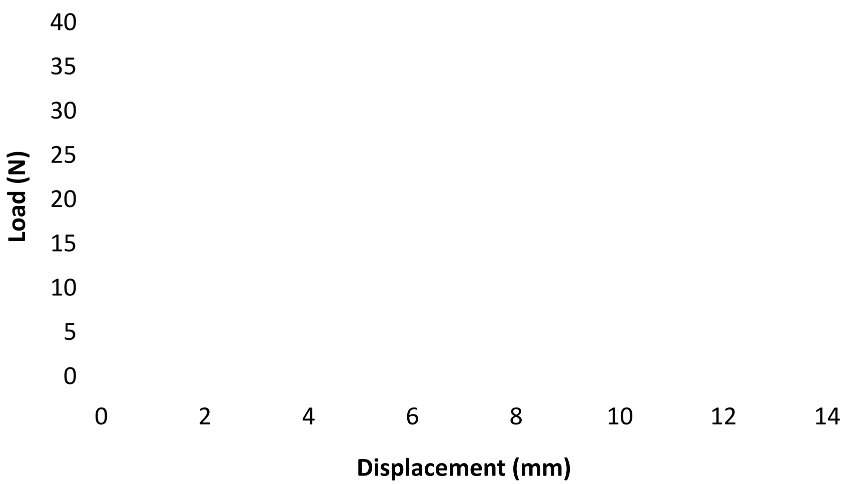
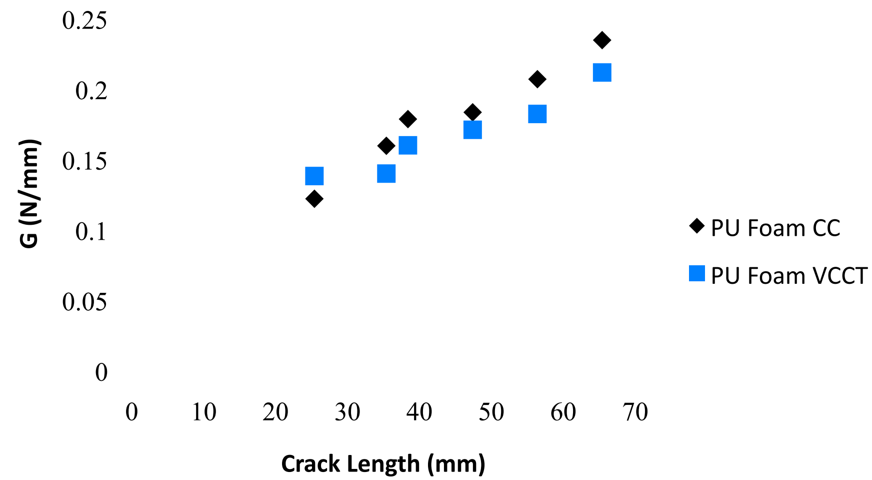
EXAMPLE MODE I RESULTS:
POLYURETHANE FOAM CORE SANDWICH

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

Typical Load vs. Displacement (6 ply)





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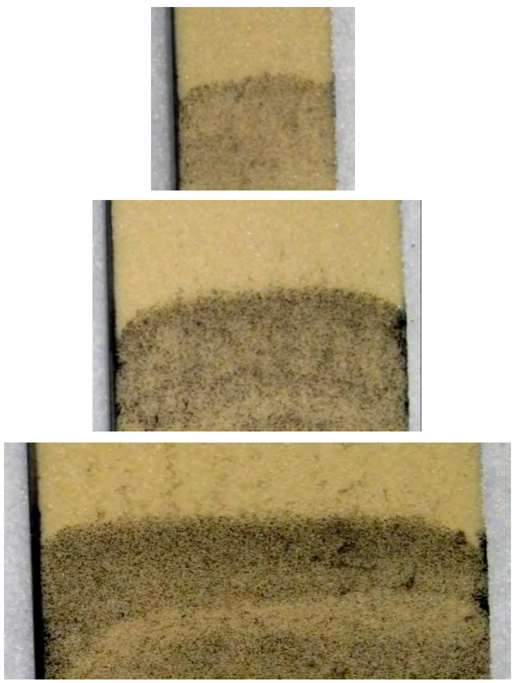
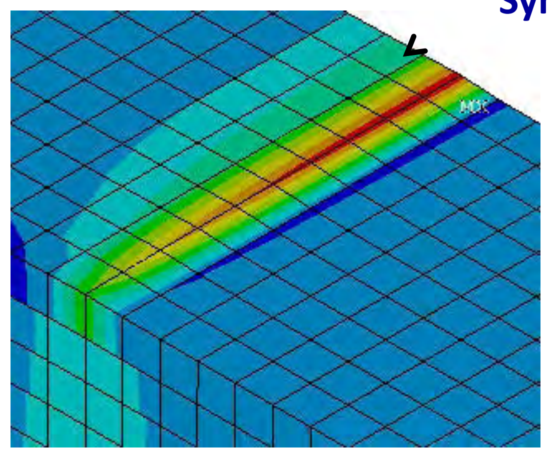
SPECIMEN WIDTH EFFECTS:
ANTICLASTIC BENDING

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



Symmetry BC



Interlaminar normal stress at surface of core (Mode I stress)

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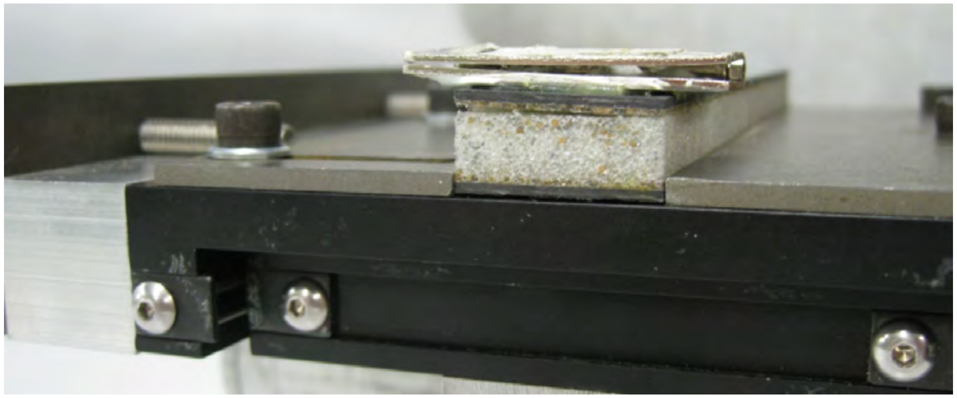
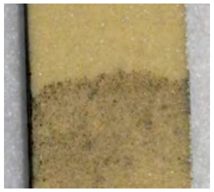
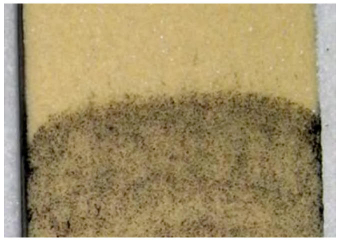
MODE I SENSITIVITY STUDY:
SPECIMEN WIDTH EFFECTS

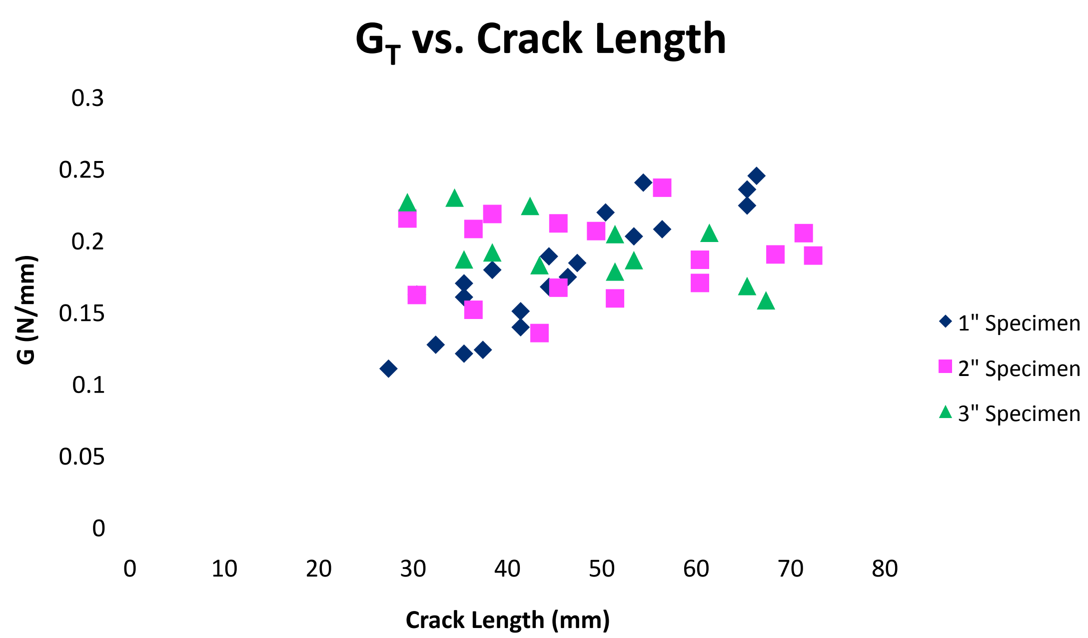
- Testing using 1 in., 2 in., and 3 in. wide specimens
- Crack front during crack growth established using dye penetrant
- Three core materials investigated

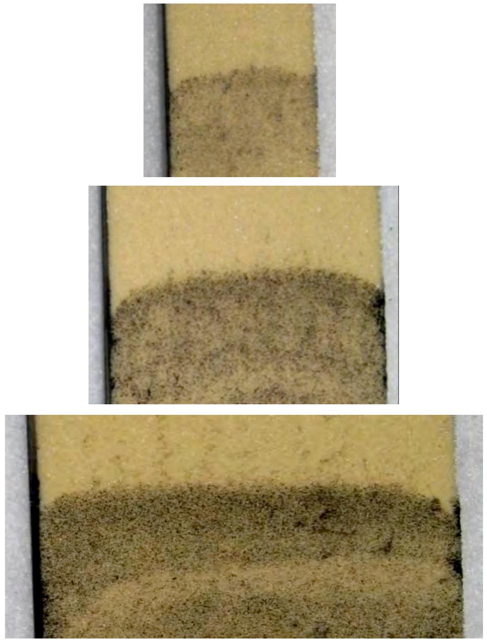






Mode I Width Effects – Polyurethane Foam





Crack front established using dye penetrant

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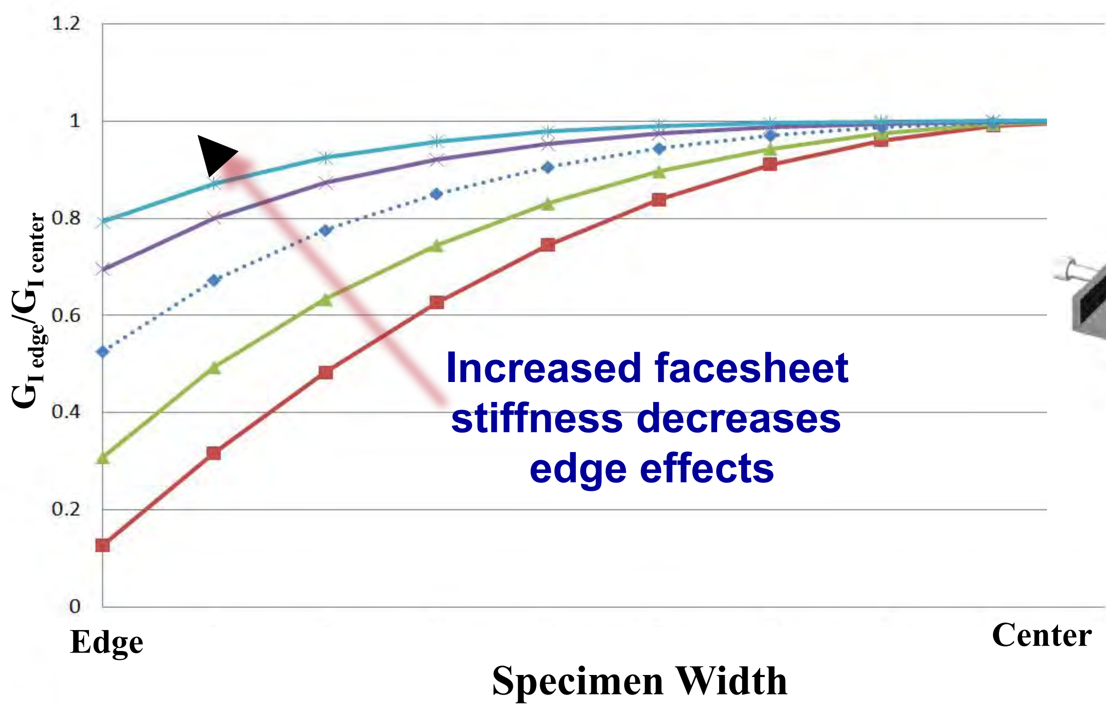
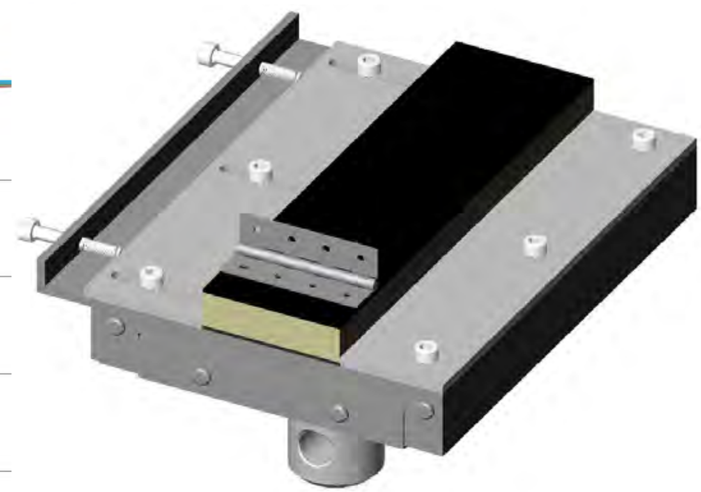
SPECIMEN WIDTH EFFECTS:

METHODS FOR REDUCING VARIATION IN G_I

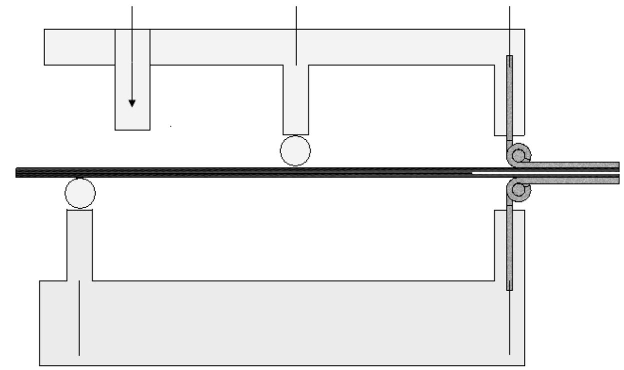
- Increase facesheet bending stiffness, EI
  - Thicker facesheet
  - Addition of doubler (tabbing material)
- Reduce ν_{12} of facesheet
- Increase specimen width



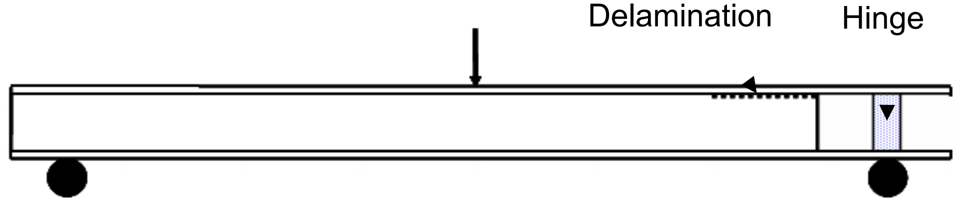


CHALLENGES IN DEVELOPING A SUITABLE MODE II TEST

- **Maintaining Mode II dominated crack growth with increasing crack lengths**
- **Obtaining crack opening during loading**
- **Obtaining stable crack growth along facesheet/core interface**



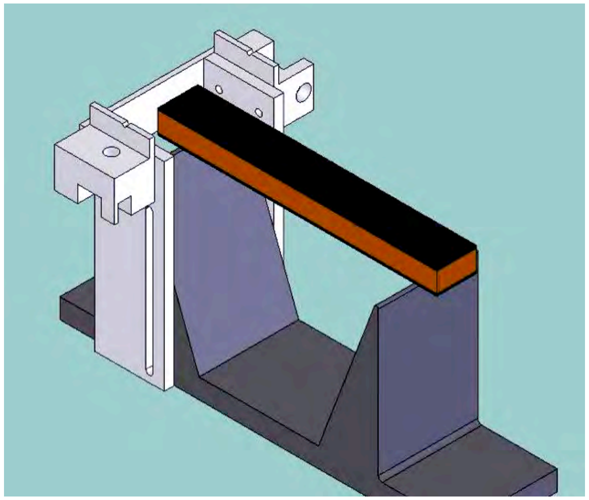
Mixed Mode Bend (MMB) Configuration

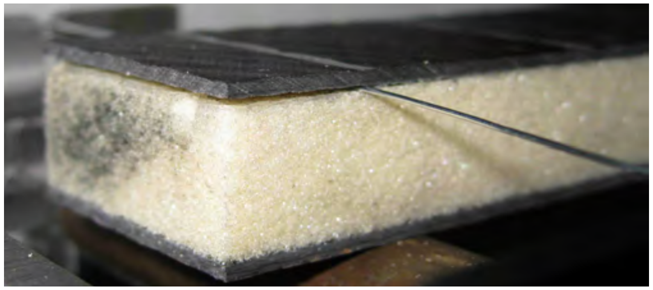


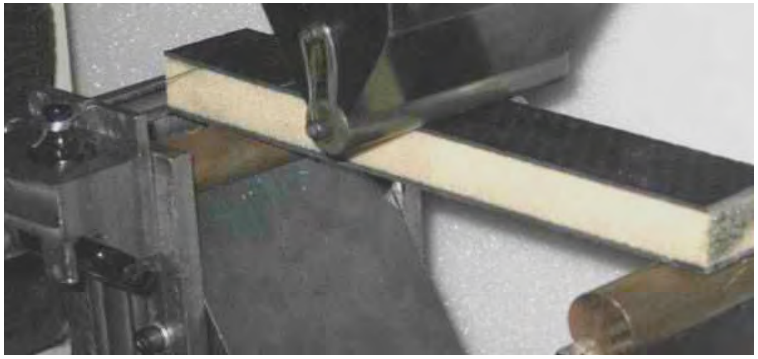
Modified Cracked Sandwich Beam (CSB) with Hinge

SELECTED MODE II CONFIGURATION: END NOTCHED SHEAR (ENS)

- **Modified three-point flexure fixture**
- **High percentage Mode II (>80%) for all materials investigated**
- **Semi-stable crack growth along facesheet/core interface**
- ***Appears to be suitable for a standard Mode II test method***

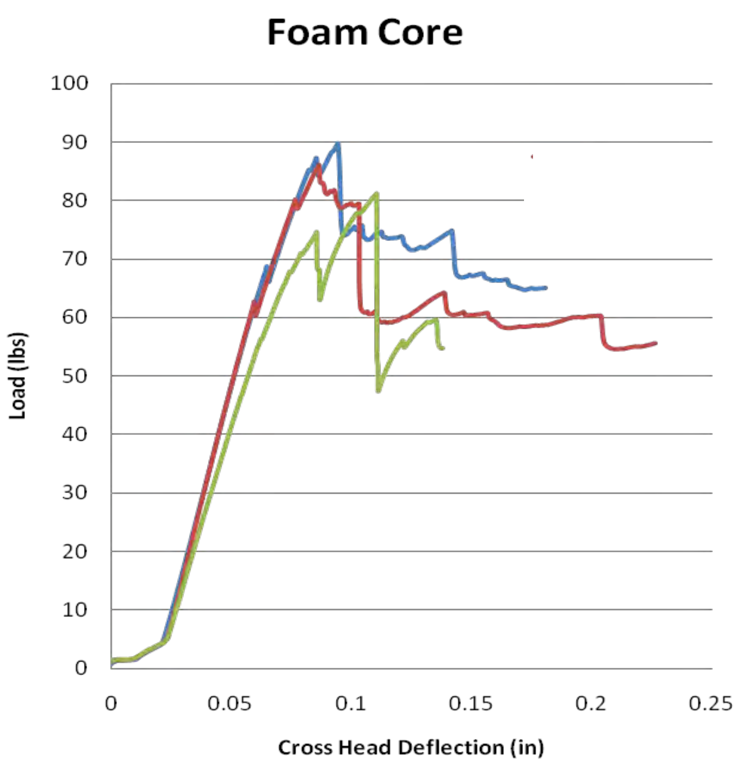


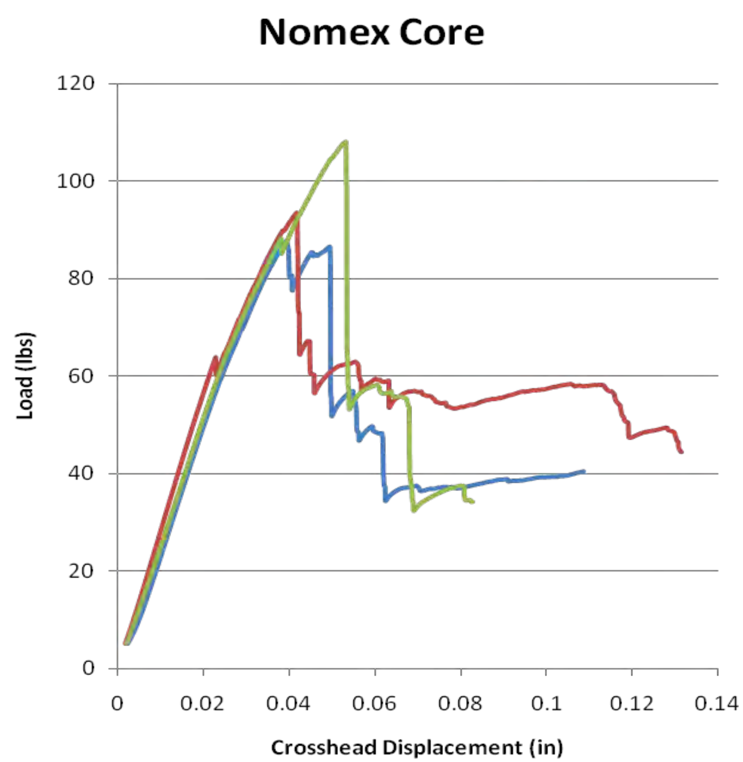




Mode II Test Results:
Foam and Nomex Honeycomb Cores

Semi-stable delamination propagation





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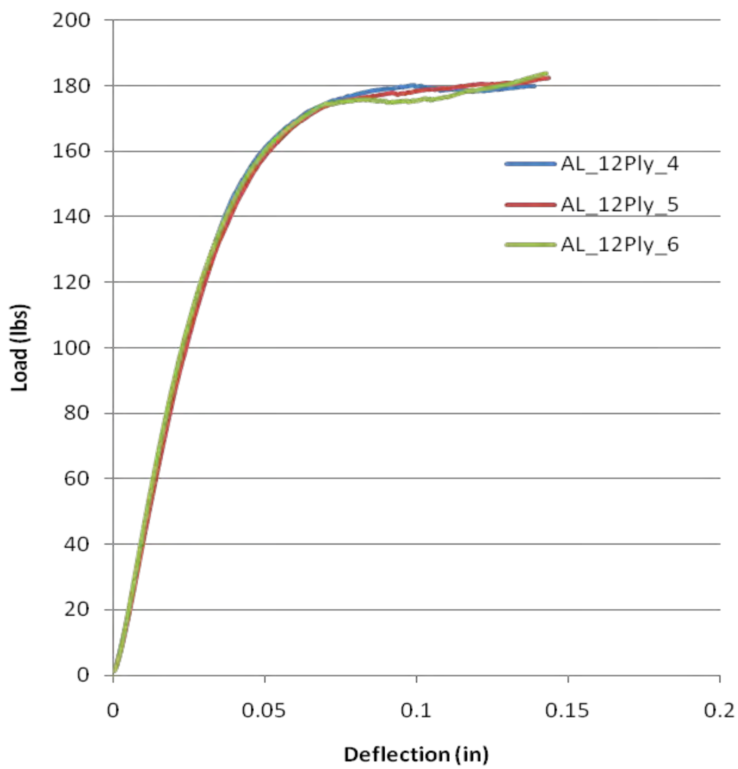
Mode II Test Results: Aluminum Honeycomb Core

Core failure in aluminum honeycomb prior to delamination growth



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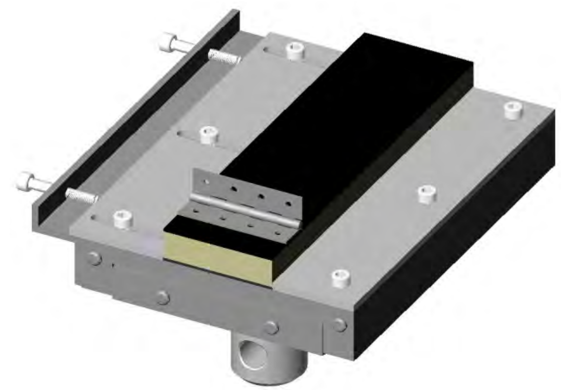
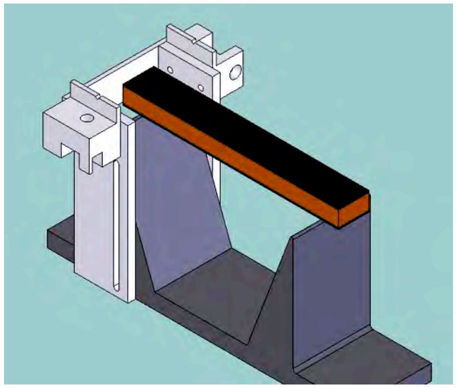
CURRENT FOCUS:

FRACTURE MECHANICS TEST METHODS

- *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*

A LOOK FORWARD

- **Benefit to Aviation**
  - **Standardized fracture mechanics test methods for sandwich composites**
    - **Mode I fracture toughness, G_{IC}**
    - **Mode II fracture toughness, G_{IIC}**
  - **Ability to predict delamination growth in composite sandwich structures**