DEVELOPMENT AND EVALUATION OF FRACTURE MECHANICS TEST METHODS FOR SANDWICH COMPOSITES

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FAA Sponsored Project Information

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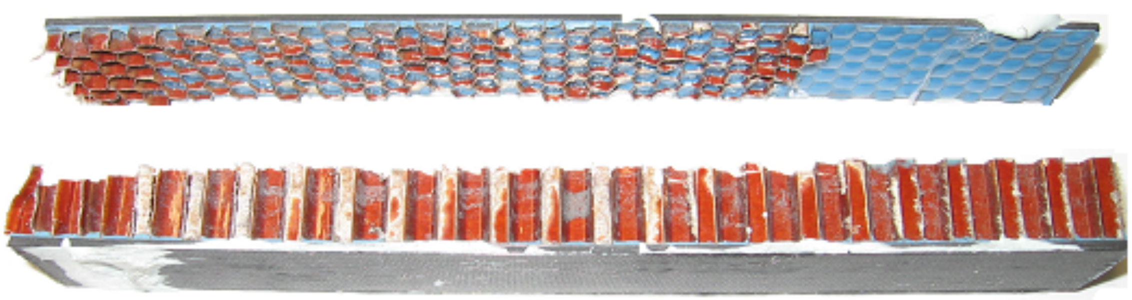
  - Josh Bluth
- FAA Technical Monitor
  - Curt Davies

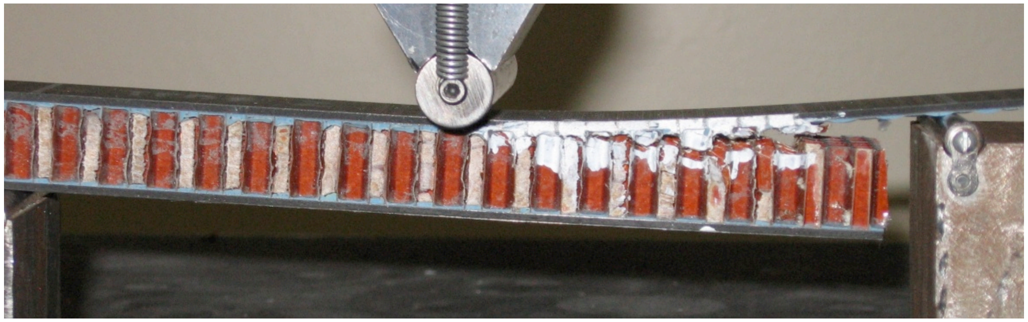
BACKGROUND:
FRACTURE MECHANICS TEST METHODS FOR SANDICH COMPOSITES

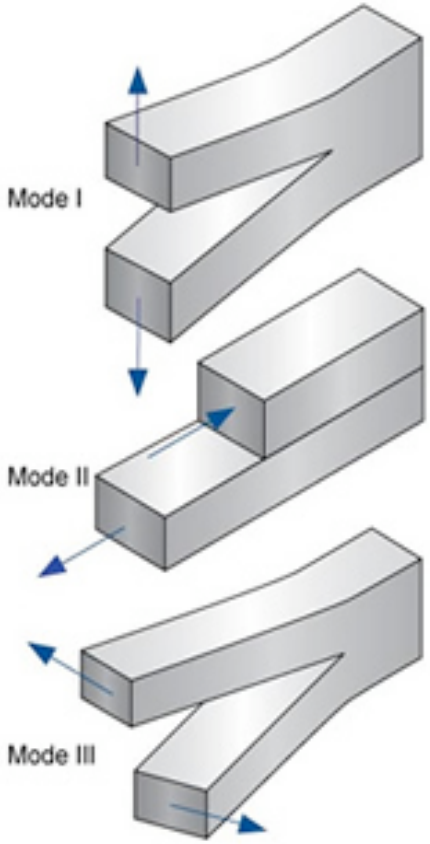
- **Fracture mechanics test methods for composites have reached a high level of maturity**
- **Less attention to sandwich composites**
  - **Focus on particular sandwich materials**
  - **Focus on environmental effects**
  - **No consensus on a suitable test configuration or specimen geometry for Mode 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: Development of draft ASTM standards**

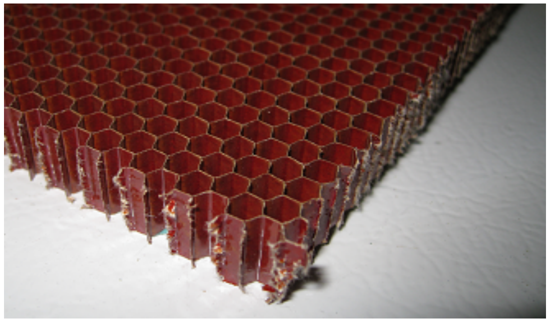
PHASE I (REVIEW):
Identification and initial assessment of candidate test methodologies

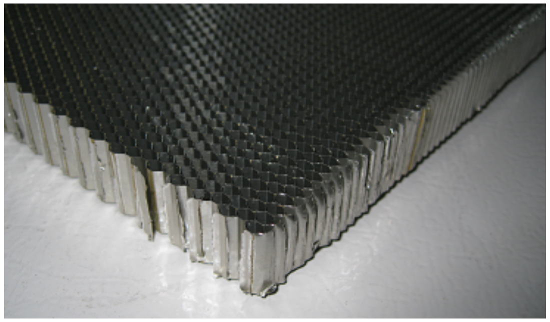
- Identify candidate Mode I and Mode II test methodologies
  - Literature review- Lead to five Mode I and eight Mode II configurations
  - Modifications from adhesive and composite laminate tests
  - Original concepts were also created
- Identification of materials and geometries currently in use for structural sandwich composites
- Assessment of candidate test configurations using finite element analysis
- Select promising configurations for mechanical testing

PHASE I CONTINUED

Identification and initial assessment of candidate test methodologies

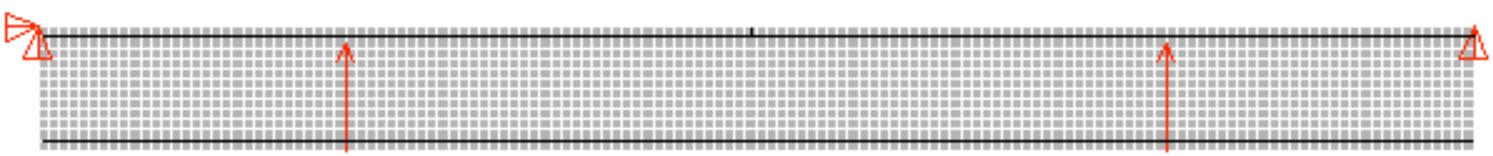
- Three core materials (12-14 mm thickness)
  - Polyurethane foam core with density of 160 kg/m^3 (10 lb/ft^3)
  - Nomex honeycomb core
  - Aluminum honeycomb core
- Two facesheet materials (1.3-1.5 mm thickness each)
  - Woven carbon/epoxy, VARTM processed
  - Unidirectional carbon/epoxy, secondary bonding





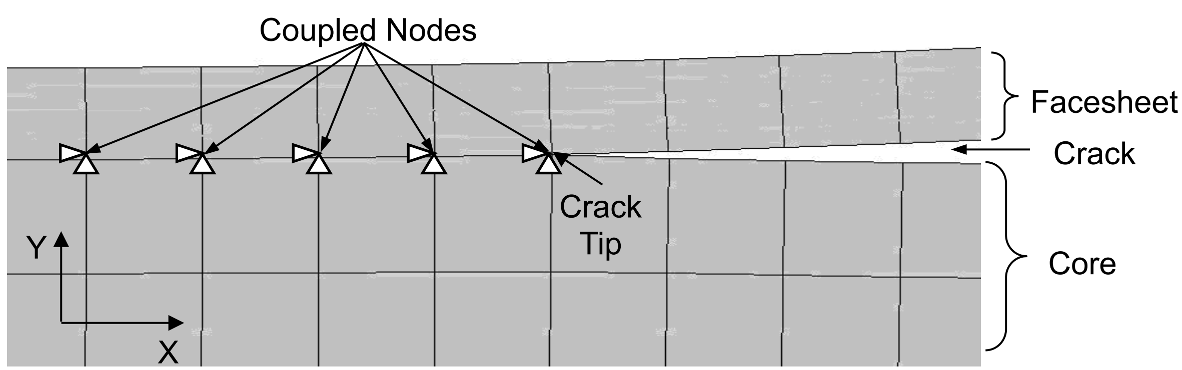
PHASE I CONTINUED:

- Finite element analysis of initial test configurations
  - Evaluate fracture mode mixity (i.e. Mode I vs. Mode II)
  - Analyze stress state within specimen
  - Monitor crack opening after load application (Mode II)
  - Determine suitable loading geometries
  - Select promising Mode I and Mode II test configurations for mechanical testing



PHASE I CONTINUED:

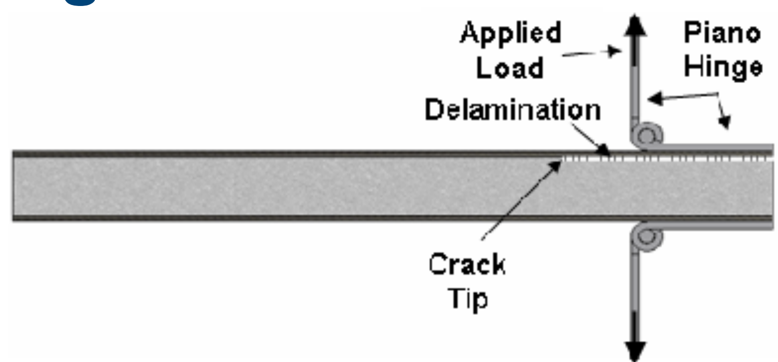
- Finite element modeling
  - ANSYS 8.0 software
  - Two-dimensional, plane strain, geometrically nonlinear analyses
  - Crack path created with a row of overlapping nodes, coupled beyond crack tip
  - Crack closure method used to calculate energy release rates, G_I and G_{II}



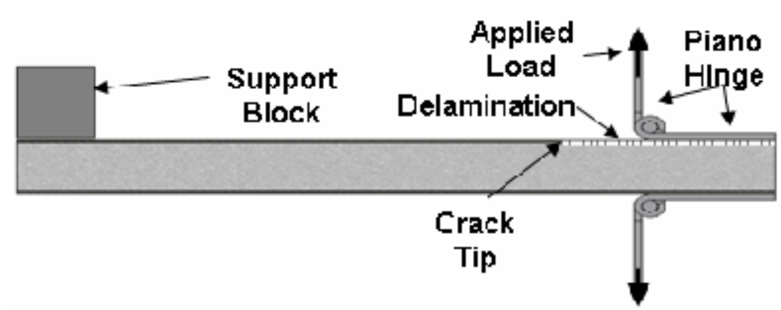
PHASE I MECHANICAL TEST RESULTS:

Mode I Investigation

- Identification of Mode I test configurations
  - Double Cantilever Beam (DCB)
    - Significant Mode II component
    - Significant bending stresses in core
    - Crack “kinking” for Nomex honeycomb core
    - Specimen rotation due to off axis loading
    - Determined to be unsuitable for a standard test method



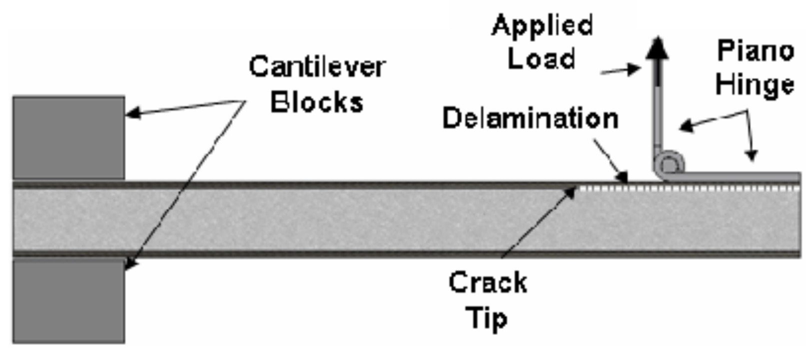
  - Modified DCB (MDCB)
    - Significant Mode II component
    - Crack “kinking” for Nomex honeycomb core
    - Determined to be unsuitable for a standard test method



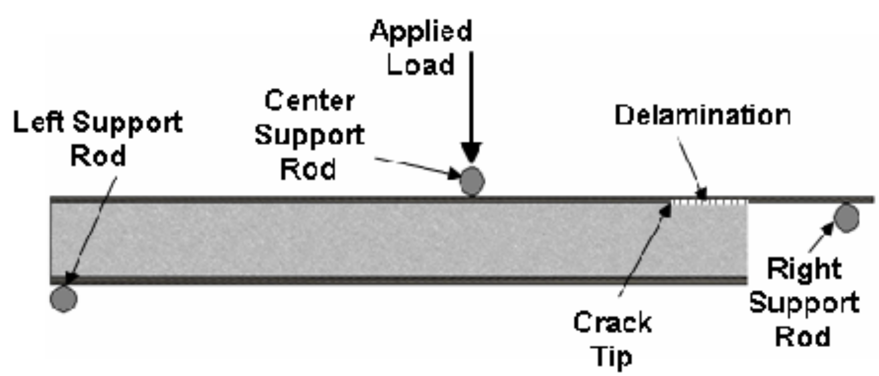
PHASE I MECHANICAL TEST RESULTS:

Mode I Investigation

- Single Cantilever Beam (SCB) with cantilever beam support
  - Significant Mode II component
  - Crack "kinking" for Nomex honeycomb core
  - Determined to be unsuitable for a standard test method



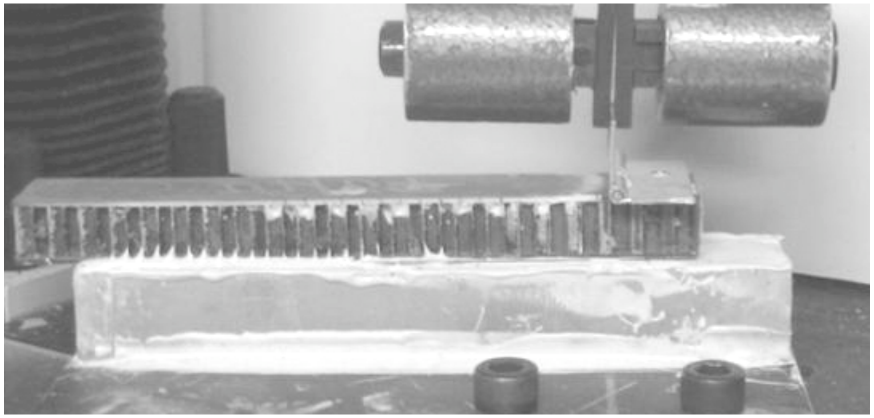
- Three Point Flexure (TPF)
  - Significant bending stresses in core
  - Extra machining operations required for specimen
  - Determined to be unsuitable for a standard test method

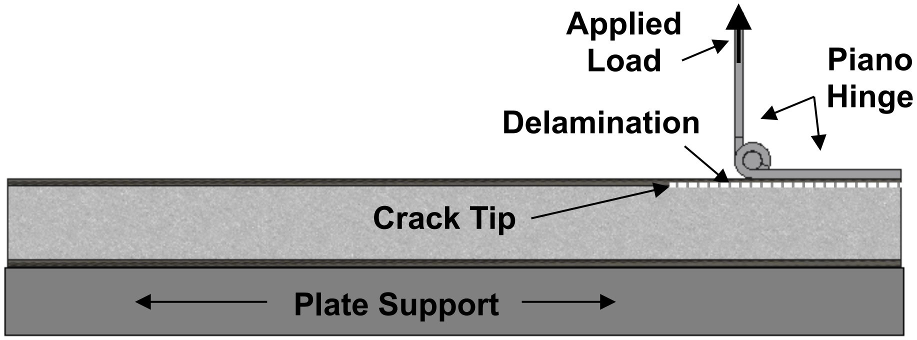


PHASE I MECHANICAL TEST RESULTS:

Mode I Investigation

- Plate-Supported SCB (MSCB)
  - 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*

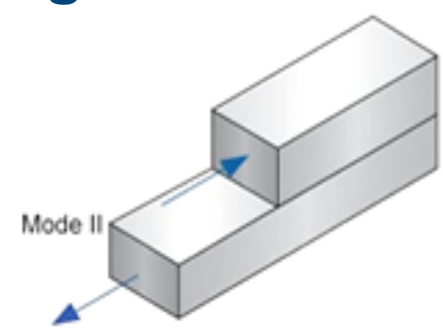




PHASE I RESULTS:

Mode II Investigation

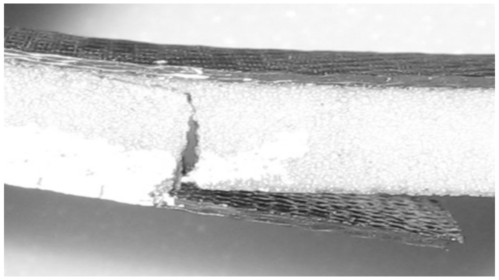
- Identification of Mode II test configuration
  - Three-point End Notch Flexure (3ENF)
  - Mixed Mode Bending (MMB)
  - End Load Split (ELS)
  - Four-point delamination test
  - Cracked Sandwich Beam (CSB) with hinge
  - Modified CSB
  - Facesheet delamination test
  - DCB with uneven bending moments
  - Three-point cantilever
  - Double sandwich test



PHASE I RESULTS:

Mode II Investigation

- 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
  - Only two of the ten investigated test configurations produced any form of interlaminar stable crack growth
    - Modified CSB (MCSB)
    - Mixed Mode Bending (MMB)
  - Seven test configurations experienced crack "kinking", the other unstable

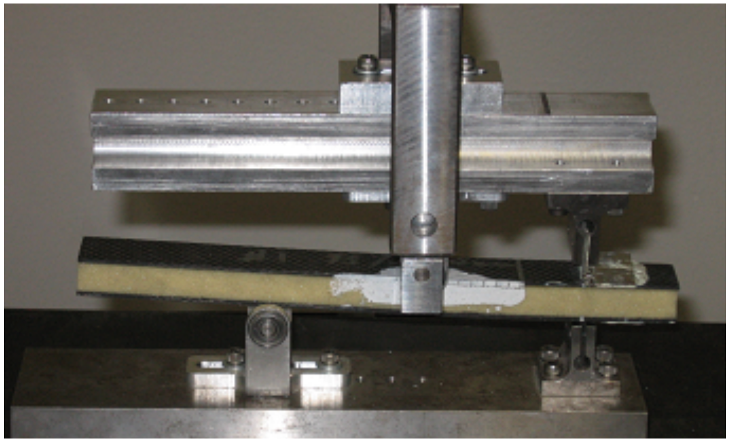


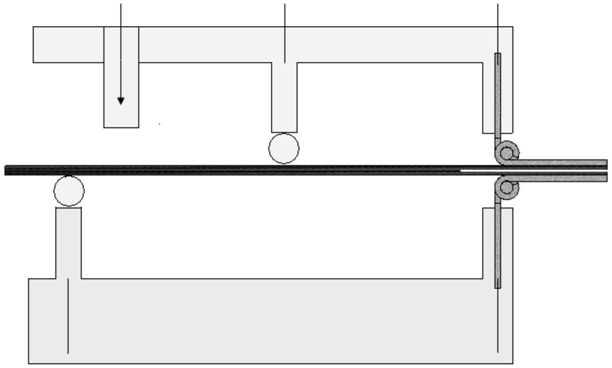
PHASE I MECHANICAL TEST RESULTS:

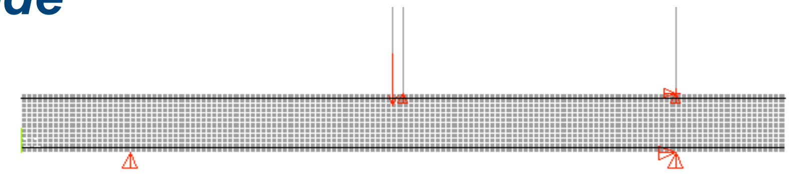
Mode II Investigation

- Mixed Mode Bending (MMB)
  - Crack opening as delamination propagates for foam core
  - Possible to achieve high percentage Mode II (>90%) using short lever arm lengths
  - Semi-stable crack growth for foam core
  - Crack "kinking" for Nomex honeycomb core
  - Core crushing for aluminum honeycomb core

Not well suited for a standard Mode II test method





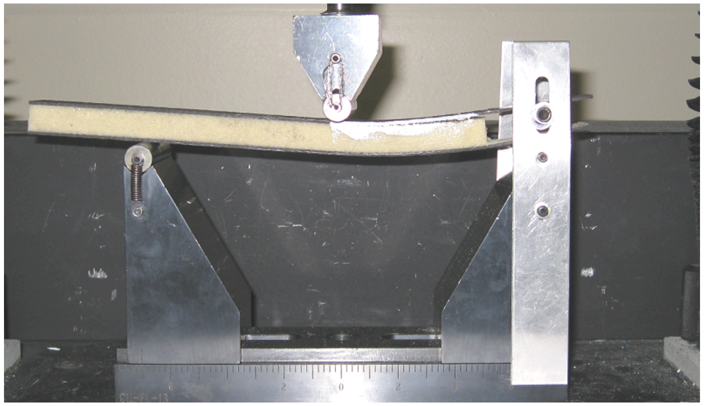


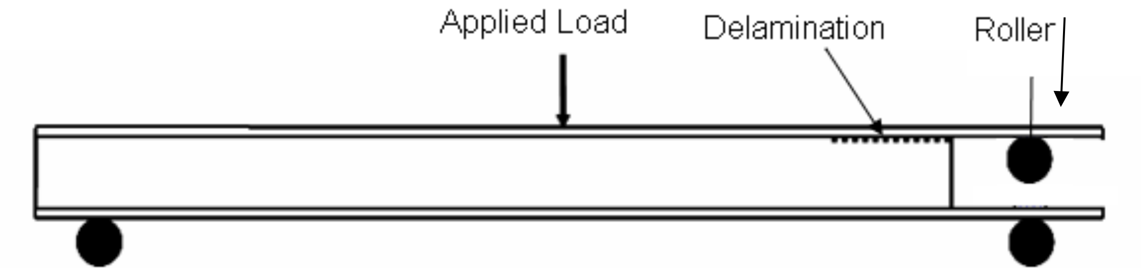
PHASE I MECHANICAL TEST RESULTS:

Mode I Investigation

- **Modified Cracked Sandwich Beam with Hinge**
  - Creates crack opening as delamination propagates
  - High percentage Mode II (>80%) for all materials investigated
  - Semi-stable crack growth along facesheet/core interface

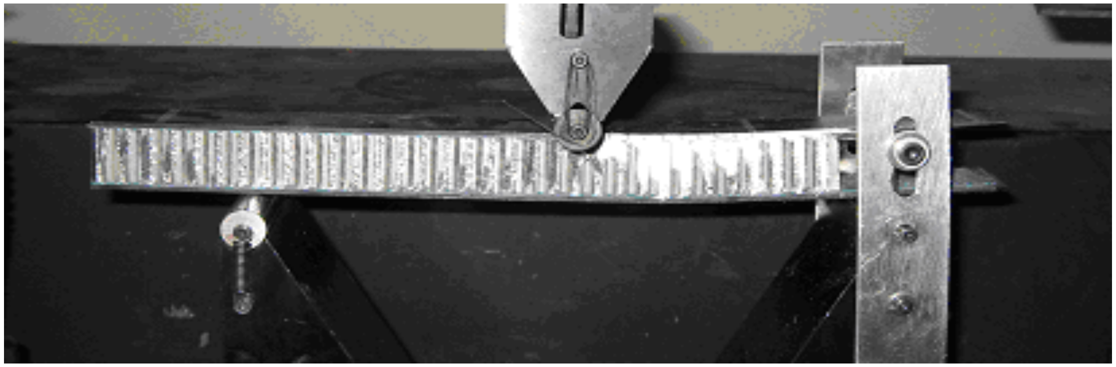
Appears to be suitable for a standard Mode II test method





PHASE II ACTIVITIES:
Further Development of Mode I and Mode II Test Methods

- Sensitivity study – determination of acceptable range of specimen parameters
- Development of suitable test fixturing
- Development of suitable test procedures
- Development of suitable data analysis methods

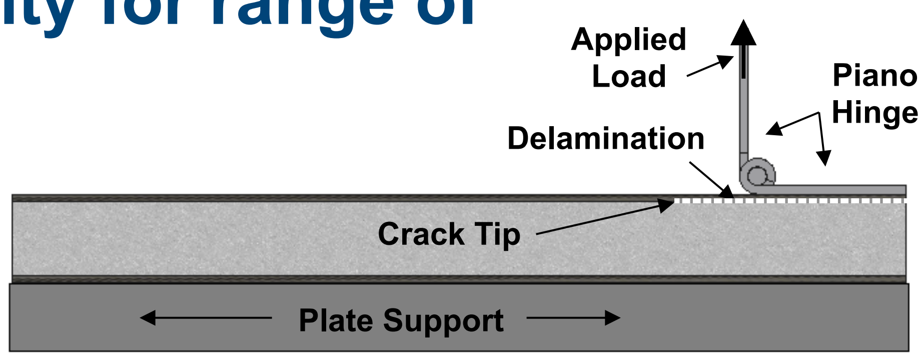


SENSITIVITY STUDIES: Determination of Acceptable Ranges of Specimen Parameters

- Facesheet parameters
  - Thickness, flexural stiffness, flexural strength
- Core parameters
  - Thickness, density, stiffness, strength
- Specimen and delamination geometry

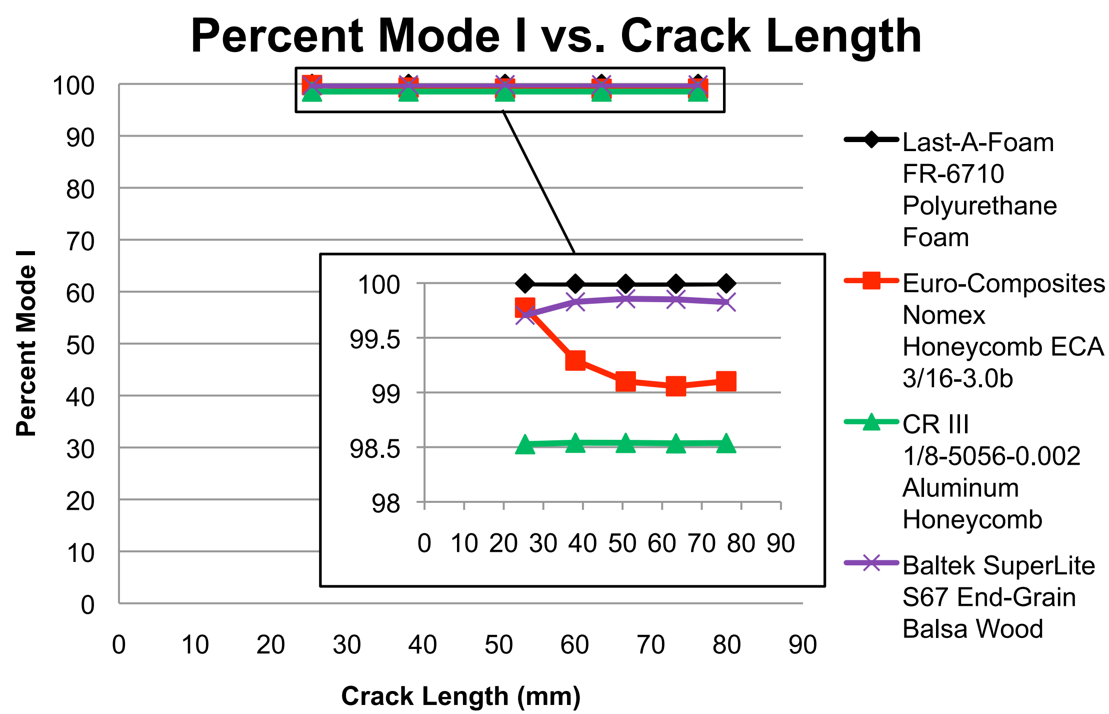
CURRENT FOCUS: Mode I Sensitivity Study

- Use of plate-supported Single Cantilever Beam (SCB) test
- Focus on two parameters of concern
  - Sandwich core material
  - Facesheet thickness
- Investigate mode mixity for range of delamination lengths



MODE I SENSITIVITY STUDY:
Effect of Core Material on %Mode I

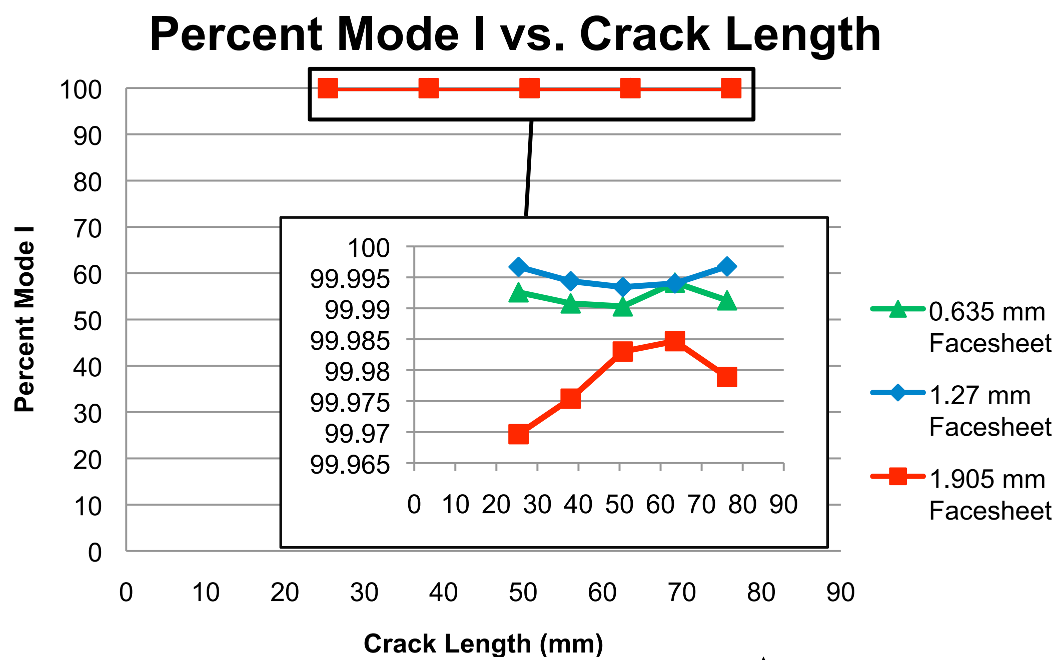
- Mode I dominant over range of cores considered
- Minimal variability among materials and crack lengths
- Test appears suitable for a wide range of common core materials

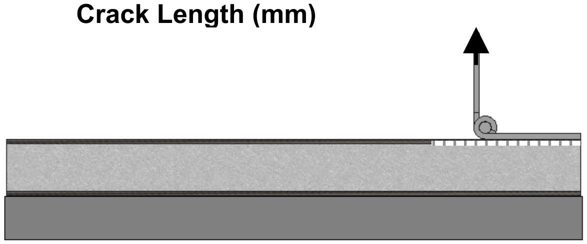


MODE I SENSITIVITY STUDY: Effect of Facesheet Thickness

Woven carbon/epoxy facesheets, polyurethane foam core

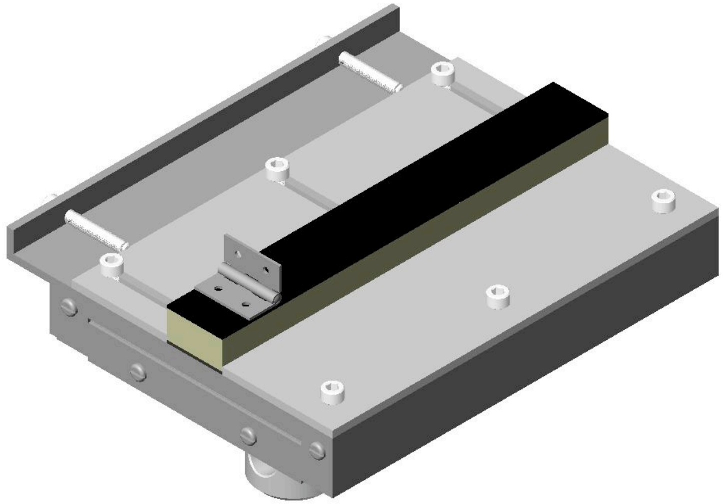
- **Mode I dominant over range of facesheet thicknesses considered**

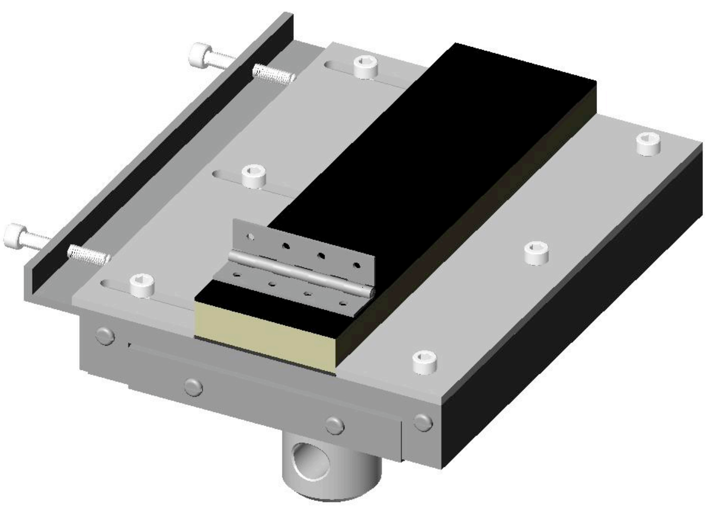


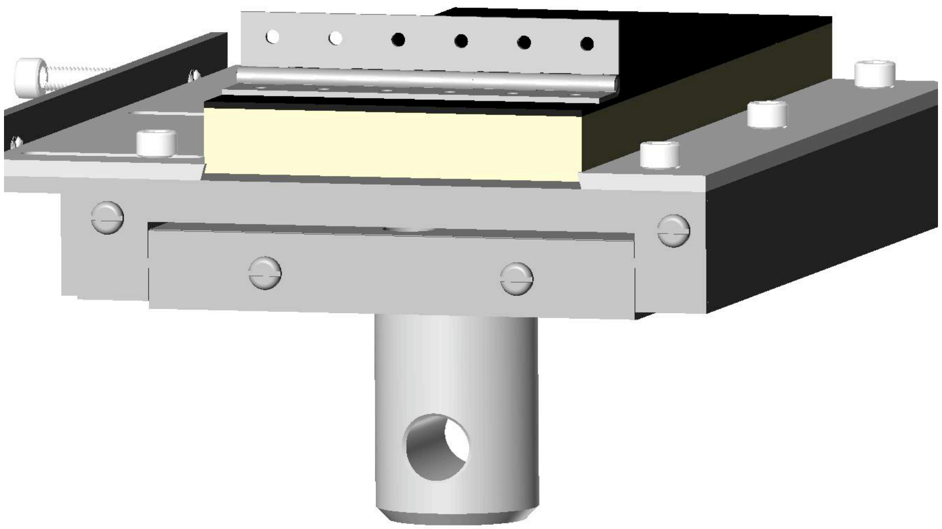


CURRENT FOCUS:
Mode I Test Fixture Development

- Ability to test 1 in. to 3 in. wide sandwich specimens
- Edge clamp restraints to lower panel support
- Translating fixture base

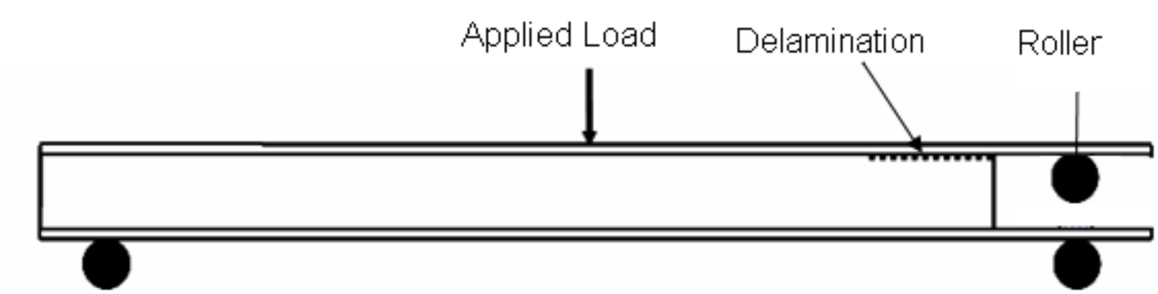






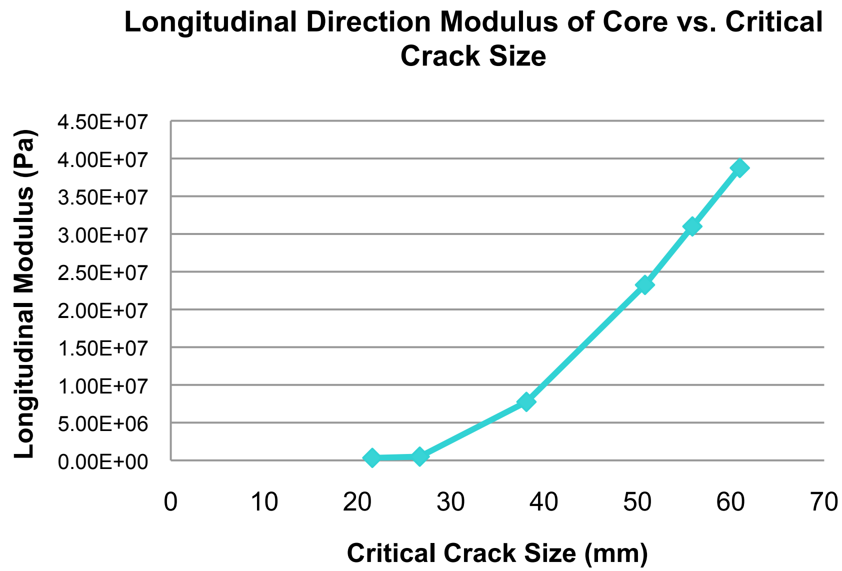
CURRENT FOCUS: Mode II Sensitivity Study

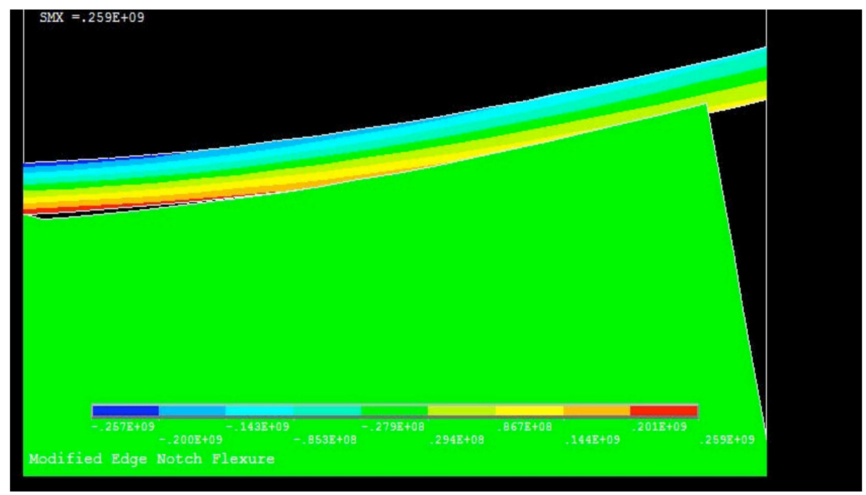
- Use of Modified Cracked Sandwich Beam
- Determination of acceptable range of specimen parameters
  - Core thickness, stiffness
  - Facesheet flexural stiffness
- Investigate mode mixity and crack opening for range of delamination lengths



MODE II SENSITIVITY STUDY: Effect of Core Material

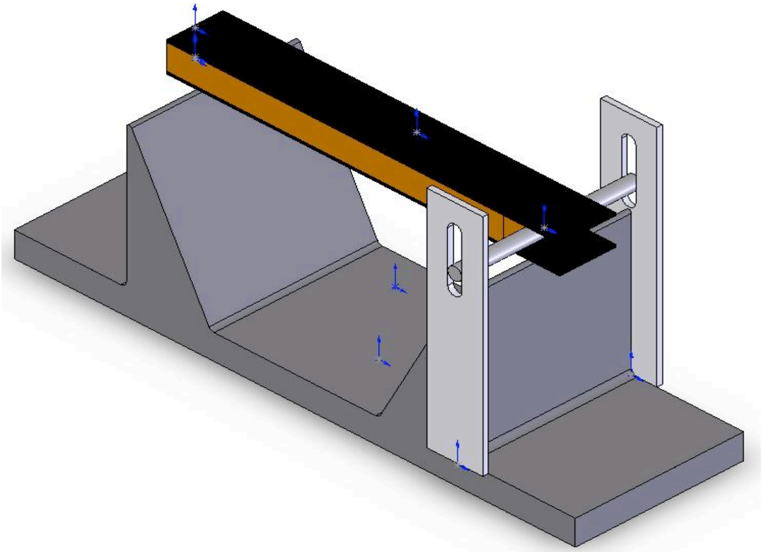
- **Varying the cores in plane modulus has little affect on % Mode II**
  - **Foam, Nomex, and aluminum honeycomb all remained above 90%**
- **Failure of test decided when there is core/face-sheet interaction**
- **In plane modulus of core affects crack length at which interaction begins**
- **Use trend line to develop MCSB core material test limits**





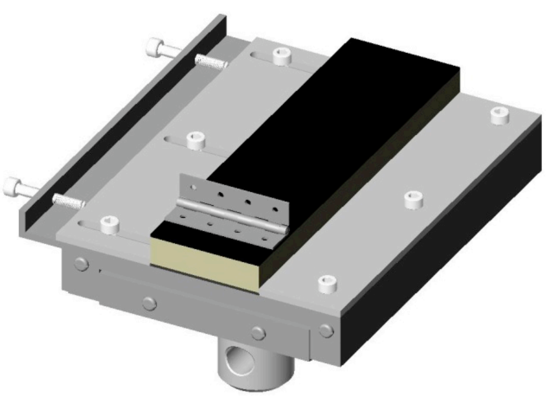
CURRENT FOCUS: Mode II Test Fixture Development

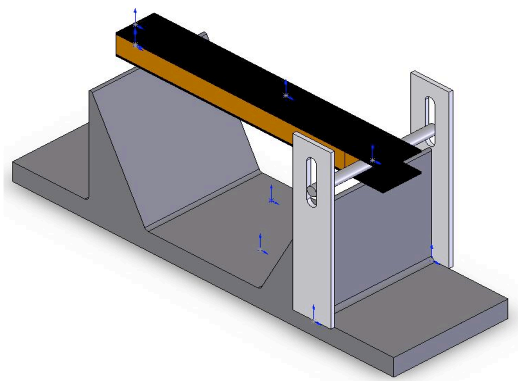
- Modified three-point flexure configuration
- Emphasis on minimizing specialized specimen preparation-core removal
- Proposed design would support top face sheet without need of core removal



UPCOMING ACTIVITIES:
Further Development of Mode I and Mode II Test Methods

- Sensitivity study – determination of acceptable range of specimen parameters
  - Computational simulations to determine limits
  - Experimental validation of limits
- Fabrication and evaluation of test fixturing
- Development of suitable test procedures
- Development of suitable data analysis methods





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