DEVELOPMENT AND EVALUATION OF FRACTURE MECHANICS TEST METHODS FOR SANDWICH COMPOSITES

Dan Adams
Department of Mechanical Engineering
University of Utah
Salt Lake City, UT
The Joint Advanced Materials and Structures Center of Excellence

FAA Sponsored Project Information

• Principal Investigator: Dr. Dan Adams
• Graduate Student Researchers:
  – Chris Weaver
  – Andy Gill
  – Brad Kuramoto
  – Josh Bluth
• FAA Technical Monitor
  – Curt Davies
BACKGROUND:
FRACTURE MECHANICS TEST METHODS FOR SANDICCH 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

• Identification and initial assessment of candidate test methodologies

• Selection and optimization of best suited Mode I and Mode II test methods

• Development of draft ASTM standards
INITIAL FOCUS:
IDENTIFY AND ASSESS CANDIDATE
TEST METHODOLOGIES

• Identification of candidate Mode I and Mode II test methodologies
  – Literature review
  – Modifications from adhesive tests
  – Original concepts
• 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
SANDWICH MATERIAL SELECTION FOR INITIAL ASSESSMENT

• Three core materials (12-14 mm thickness)
  – Polyurethane foam core with density of 160 kg/m³ (10 lb/ft³)
  – 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
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
OVERVIEW:
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, $G_1$ and $G_{II}$
  - Constant applied load (45 Newtons)
  - Variable crack lengths (50 mm of crack growth)
OVERVIEW: INITIAL MECHANICAL TESTING

- 5 kip Instron load frame
- Traveling microscope
- White paint used to enhance visibility of crack growth
- Three replicates per test condition
- Use of finite element analysis to calculate energy release rates
SANDWICH CONFIGURATIONS FOR INITIAL ASSESSMENT

- **Carbon-Epoxy/Polyurethane Foam (CE/PF)**
  - 12.7 mm thick polyurethane foam core
  - 1.3 mm thick quasi-isotropic carbon fabric/epoxy facesheets
  - VARTM processed

- **Carbon-Epoxy/Nomex Honeycomb (CE/NH)**
  - 14 mm thick Nomex honeycomb
  - 1.5 mm thick quasi-isotropic prepreg carbon/epoxy facesheets
  - Secondary bonding using film adhesive
IDENTIFICATION OF MODE I TEST CONFIGURATIONS

- Double Cantilever Beam (DCB)
- Modified DCB (MDCB)
- Single Cantilever Beam (SCB) with cantilever beam support
- Plate-Supported SCB (MSCB)
- Three Point Flexure (TPF)
CANDIDATE MODE I CONFIGURATION: DOUBLE CANTILEVER BEAM (DCB)

- Based on ASTM D 5528 for monolithic composite laminates

- For sandwich composites:
  - Significant Mode II component
  - Significant bending stresses in core
  - Crack “kinking” for Nomex honeycomb core

- Determined to be unsuitable for a standard test method
CANDIDATE MODE I CONFIGURATION: MODIFIED DCB

- Support block prevents specimen rotation

- No significant improvement over DCB configuration:
  - Significant Mode II component
  - Crack “kinking” for Nomex honeycomb core

- Determined to be unsuitable for a standard test method
CANDIDATE MODE I CONFIGURATION: SINGLE CANTILEVER BEAM (SCB) WITH CANTILEVER SUPPORT

- Reduction in bending of sandwich specimen
  - Minimal Mode II component (less than 5%)
  - Reduced bending stresses in core

- Crack “kinking” for Nomex honeycomb core

- Not well suited for a standard test method
CANDIDATE 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
CANDIDATE MODE I CONFIGURATION: THREE-POINT FLEXURE (TPF)

- No crack “kinking” observed
- Significant bending of sandwich specimen
  - Significant bending stresses in core
  - Minimal Mode II component (less than 5%)
- Extra machining operations required for specimen
- Not well suited for a standard test method
SUMMARY:

MODE I TEST CONFIGURATIONS

Plate-Supported Single Cantilever Beam (SCB) test configuration recommended for further investigation

- Identification of suitable specimen geometries
- Development of suitable test fixture
IDENTIFICATION OF MODE II SANDWICH COMPOSITE TEST CONFIGURATIONS

- 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 with hinge
- Facesheet delamination test
- DCB with uneven bending moments
- Three-point cantilever
- Double sandwich test
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 test methods appeared suitable…
CANDIDATE MODE II CONFIGURATION: MIXED-MODE BEND (MMB) TEST

- Crack opening as delamination propagates
- Possible to achieve high percentage Mode II (>90%) using short lever arm lengths
- Semi-stable crack growth
- Crack “kinking” for Nomex honeycomb core
- Core crushing for aluminum honeycomb core
- **Not well suited for a standard Mode II test method**
CANDIDATE MODE II CONFIGURATION: MODIFIED CRACKED SANDWICH BEAM (CSB) WITH HINGE

- 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
CURRENT STATUS

Further evaluation of selected test methods:

- Parametric study to investigate range of applicability
  - Sandwich composite materials
  - Sandwich composite geometries
- Development of improved test fixturing
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