DEVELOPMENT AND EVALUATION OF FRACTURE MECHANICS TEST METHODS FOR SANDWICH COMPOSITES

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FAA Sponsored Project Information

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RESEARCH OBJECTIVES:
Fracture Mechanics Test Methods for Sandwich Composites

• Focus on facesheet-core debonding
• Mode I and Mode II
  – 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
MODE I TEST CONFIGURATION:
Single Cantilever Beam (SCB)

- Elimination of bending of sandwich specimen
- Minimal crack “kinking” observed
- Mode I dominant - independent of crack length
- Appears to be suitable for standardization
PARAMETERS INVESTIGATED:
Single Cantilever Beam (SCB) Test

- Specimen geometry
  - Length
  - Width
  - Initial crack length

- Facesheet properties
  - Thickness
  - Flexural stiffness
  - Flexural strength

- Core properties
  - Thickness
  - Density
  - Stiffness
  - Strength

- Mode mixity
  - Variations across specimen width
  - Variations with crack length

- Data reduction methods
  - Thru-thickness crack placement
  - Anticlastic curvature & curved crack front

- Large rotations of facesheet
- Use of facesheet doublers
- Facesheet curvature effects
SCB TEST METHOD DEVELOPMENT: Sandwich Configurations with Thin Facesheets

Concern: Excessive facesheet rotation

• Not representative of disbond in actual sandwich structures
• Geometric nonlinearity causes errors when using conventional data reduction method

Possible Solution: Use of facesheet doublers

• Reduce facesheet rotation required for disbonding
• Allow use of compliance calibration method of data reduction
EFFECTS OF FACESHEET DOUBLER:
Different Doubler Thicknesses Produce Different $G_c$ Values…

…and different thru-thickness fracture locations!

![Graph showing the effects of different doubler thicknesses on $G_c$ values and fracture locations.](image)
NUMERICAL INVESTIGATION
Effects of Thin Facesheets & Facesheet Doublers

• Load applied in each model to produce same $G_T$ value
  – No doubler, “thin” doubler, “thick” doubler
• Consider crack growth at three through-the-thickness locations
• Investigate mode mixity ($\% G_i$)
• Investigate orientation of max. principal stress for expected crack growth direction
FACESHEET DOUBLER EFFECTS: No Doubler

Crack at interface

Shear Stress Gradient 99.3% $G_I$
FACESHEET DOUBLER EFFECTS:
Thin Doubler

At interface

Glass Doubler
Facesheet
Crack
Core

0.5 mm depth

97.2% G

99.9% G

Core Above Crack
FACESHEET DOUBLER EFFECTS:
Thick Doubler

At interface

93.8% GI

0.5 mm depth

98.3% GI

1 mm depth

99.8% GI
SUMMARY OF FINDINGS:
Numerical Investigation

- SCB test appears to be Mode I dominant for all cases considered
- Mode II component produced by shear stresses in vicinity of crack tip
- Sign of shear stresses change as a function of:
  - Thickness of facesheet
  - Crack location in core
- Crack predicted to propagate closer to facesheet/core interface for thinner facesheets
- Use of doublers to reduce facesheet rotation is not recommended
EFFECTS OF FACESHEET CURVATURE:
Use of Climbing Drum Peel (CDP) Test

- Facesheet curvature during SCB testing is dependent on facesheet thickness
- High curvature produced with thin facesheets not representative of that seen in sandwich structures with disbonds
- Use of Climbing Drum Peel test permits testing with prescribed facesheet curvature
DETERMINATION OF ENERGY RELEASE RATE, $G_C$: Climbing Drum Peel (CDP) Test

Energy Release Rate, $G_{IC}$:

$$G_{IC} = \frac{(P_2 - P_1)(r_2 - r_1)}{w \cdot r_1}$$

- $r_2 = $ flange radius
- $r_1 = $ drum radius + facesheet thickness
- $w = $ specimen width

Single Cantilever Beam (SCB) Versus Climbing Drum Peel (CDP)

9 Ply ("Thick") Facesheet

![Graph showing crack length vs. Gc with data points for SCB Test w/ CC, SCB Test w/ MBT, and CDP Test]
Single Cantilever Beam (SCB) Versus Climbing Drum Peel (CDP)

6 Ply (“Medium”) Facesheet
Single Cantilever Beam (SCB) Versus Climbing Drum Peel (CDP)

3 Ply (“Thin”) Facesheet

![Graph showing crack length vs. energy release rate for SCB and CDP tests with different labels for test conditions.]
Effect of Facesheet Thickness:
Single Cantilever Beam (SCB) Specimens

3 Ply Facesheet  6 Ply Facesheet  9 Ply Facesheet
Effect of Facesheet Thickness: Climbing Drum Peel (CDP) Specimens

3 Ply Facesheet

6 Ply Facesheet

9 Ply Facesheet

Untested Tested Portion Precrack
SUMMARY OF PRELIMINARY FINDINGS: Climbing Drum Peel Testing

- $G_C$ measurements from Climbing Drum Peel and Single Cantilever Beam tests in agreement for thicker facesheets
- $G_C$ measurements from Single Cantilever Beam tests are reduced for thin facesheets
- Slight through-thickness difference in fracture location with facesheet thickness for both test methods
CURRENT FOCUS:
Effects of Facesheet Curvature on Apparent $G_c$

Preliminary design of a large radius Climbing Drum Peel fixture
MODE II TEST CONFIGURATION:
Edge-Notched Sandwich Configurations

Monolithic Composites:
3 Point End Notch Flexure (3ENF)
(Currently proposed for ASTM standardization)

Sandwich Composites:
End Notch Cantilever (ENC)
MODE II END NOTCHED CANTILEVER TEST: Symmetrical Bending Version of 3-ENF

End Notched Flexure
(Unsymmetric bending)

End Notched Cantilever
(Symmetric bending)
PROPOSED MODE II CONFIGURATION
End Notched Cantilever (ENC) Test

- Cantilever beam configuration
- Can be loaded upward (tension) or downward (compression)
- Predicted performance meets or exceeds that of 3-ENF configuration for all sandwich configurations considered to date

Improved crack growth stability
- Appears to be suitable for a standard Mode II test method
SUMMARY

Benefits to Aviation

– Standardized fracture mechanics test methods for sandwich composites
  • Mode I fracture toughness, $G_{IC}$
  • Mode II fracture toughness, $G_{IIC}$

– Test results used to predict disbond growth in composite sandwich structures