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Development and Evaluation of Fracture Mechanics Test Methods for Sandwich Composites

2012 Technical Review

Dan Adams, Joe Nelson, Zack Bluth

University of Utah

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FAA Sponsored Project Information

- **Principal Investigator: Dr. Dan Adams**
- **Graduate Student Researchers:**

Joe Nelson	Zack Bluth
Josh Bluth	Brad Kuramoto
Chris Weaver	Andy Gill

- **FAA Technical Monitors**
  - David Westlund & Curt Davies
- **Collaborators:**

NASA Langley	NIAR
Airbus	Boeing
Learjet	Goodrich

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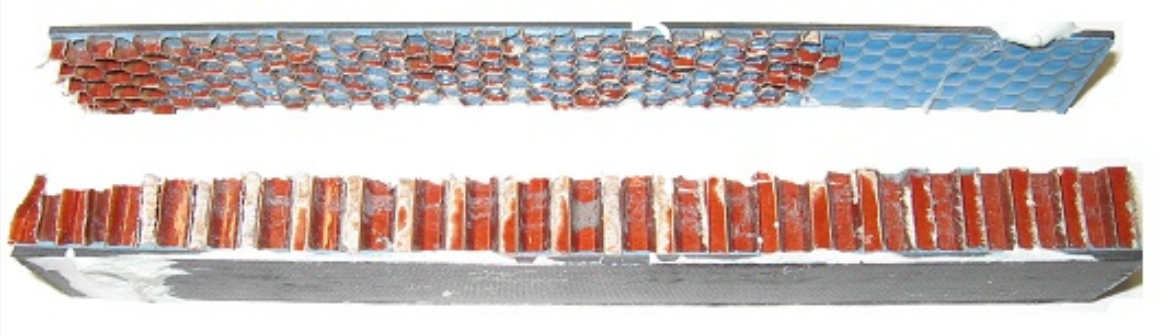
BACKGROUND:

Fracture Mechanics Test Methods for Sandwich 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**



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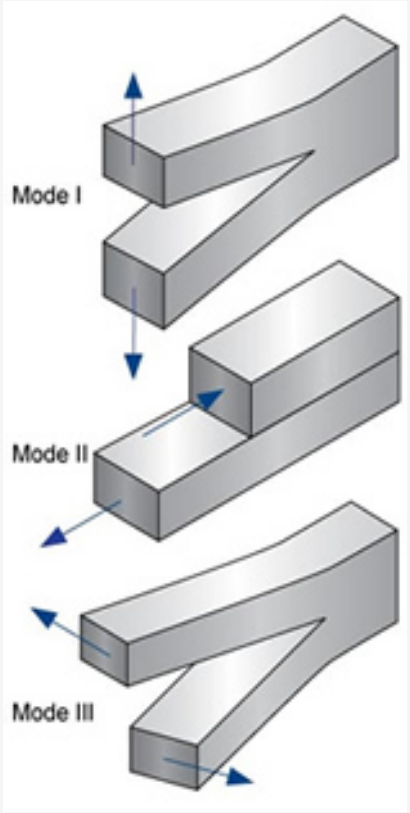
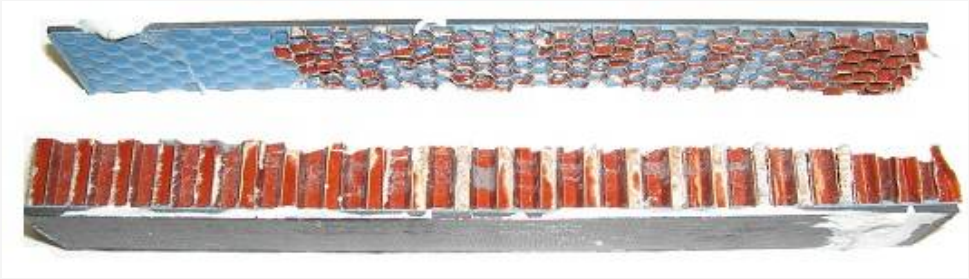
RESEARCH OBJECTIVES:

Fracture Mechanics Test Methods for Sandwich Composites

- Focus on facesheet-core delamination
- 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





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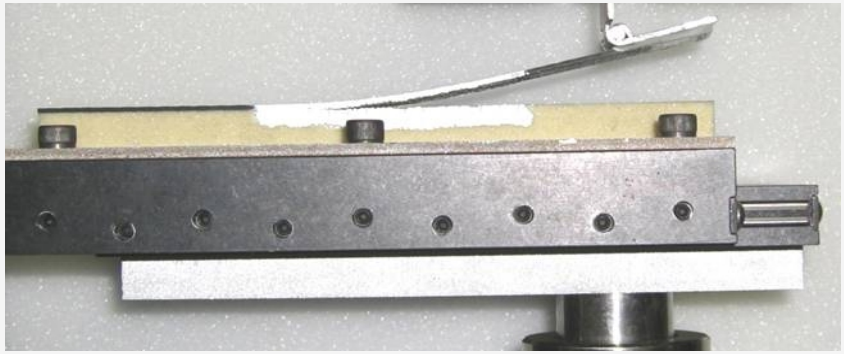
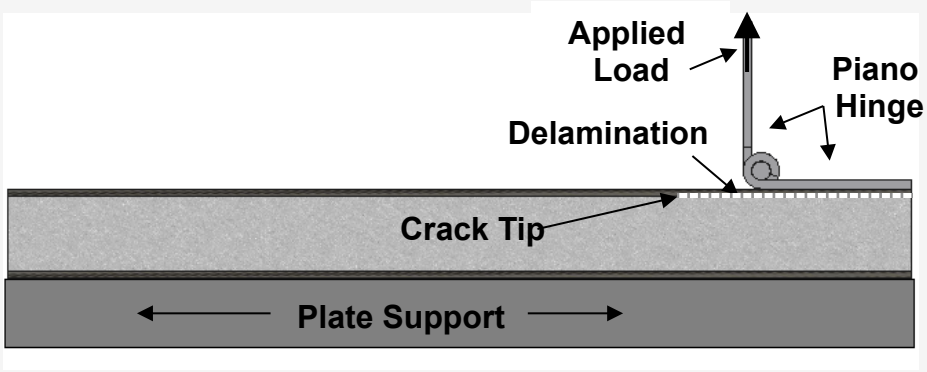
SELECTED MODE I CONFIGURATION:

Single Cantilever Beam (SCB)

- Elimination of bending of sandwich specimen
- Minimal Mode II component
- No significant bending stresses in core
- No crack “kinking” observed
- *Appears to be suitable for a standard test method*

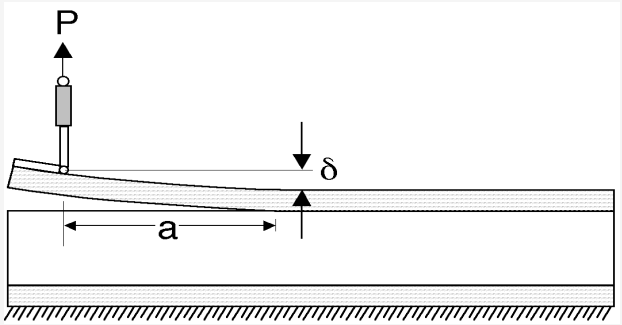


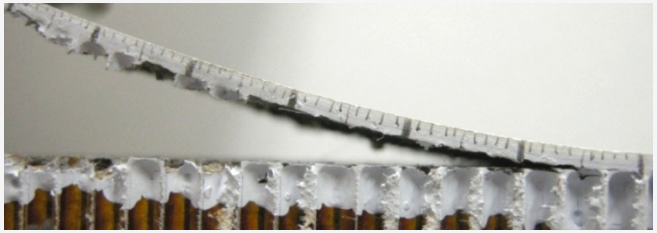


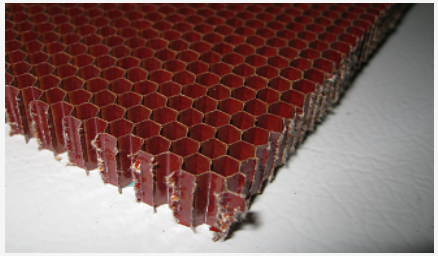
PARAMETERS INVESTIGATED:

Single Cantilever Beam (SCB) Test

- **Specimen geometry**
  - Length
  - Width
  - Initial delamination length
- **Facesheet properties**
  - Thickness
  - Flexural stiffness
  - Flexural strength
- **Core properties**
  - Thickness
  - Density
  - Stiffness
  - Strength







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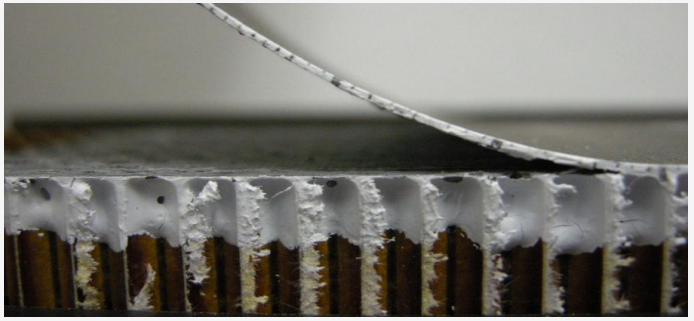
RECENT EFFORTS:

Single Cantilever Beam Test for Sandwich Composites

- **Establishment of recommended specimen width**
  - **Anticlastic curvature and curved crack fronts**
  - **Minimum number of honeycomb cells**
- **Effects of thru-thickness placement of starter crack**
- **Procedures for testing sandwich configurations with "thin" facesheets**
  - **Excessive facesheet rotation**
  - **Problems with using compliance calibration method**
  - **Use of doublers**



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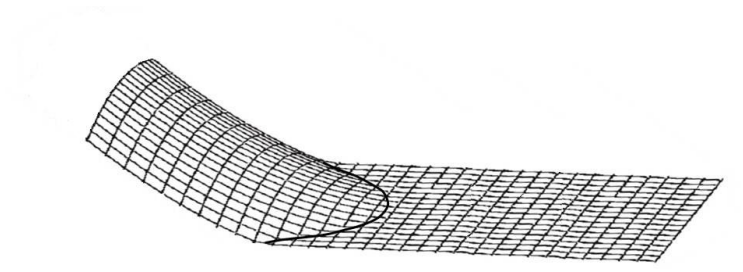
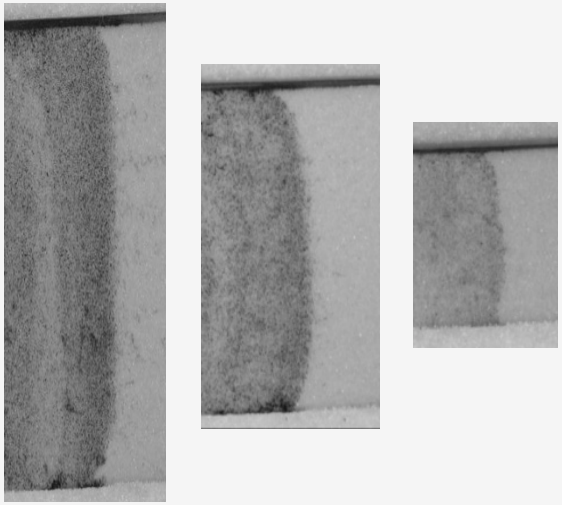
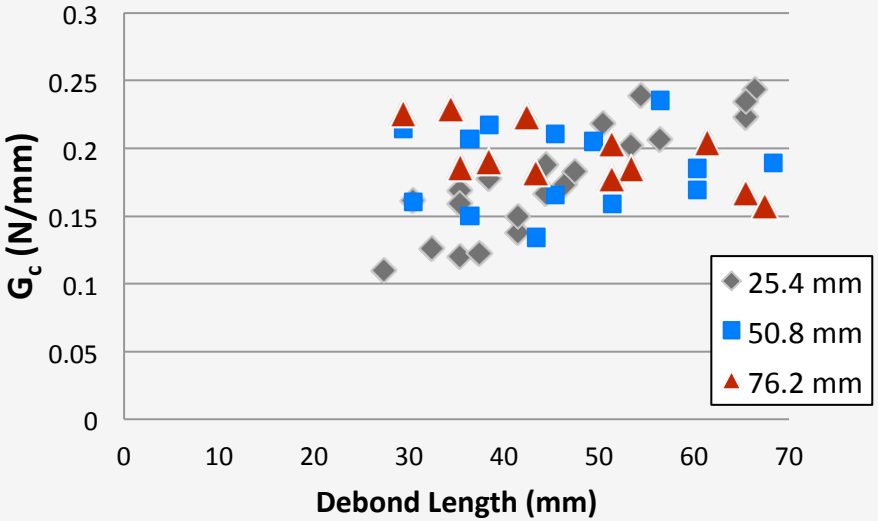
RECOMMENDED SPECIMEN WIDTH:

Anticlastic Curvature and Curved Crack Fronts

Foam Core Sandwich Specimens with Quasi-Isotropic Facesheets





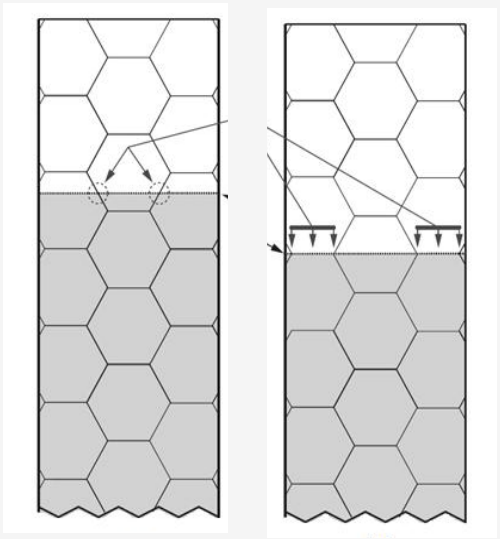


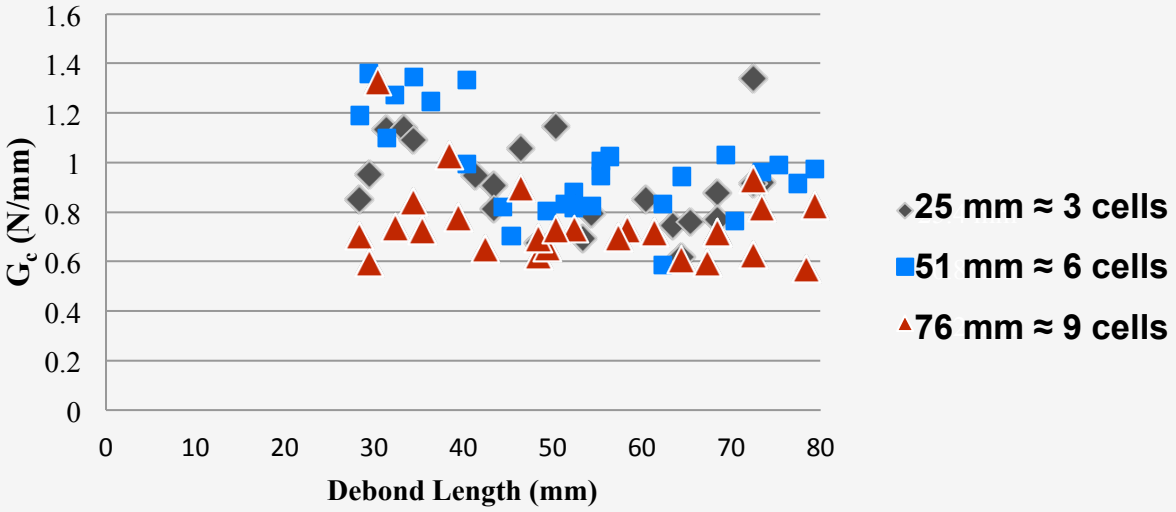
51 mm (2 in.) selected as recommended specimen width

RECOMMENDED SPECIMEN WIDTH:

Minimum Number of Honeycomb Cells

Nomex Honeycomb Core, 51 mm (2 in.) Wide Specimens





Recommend a minimum of 6 honeycomb cells across specimen width

- Most honeycomb cores will have at least 6 cells across 2 in. width
- Width can be increased for larger-celled honeycomb cores

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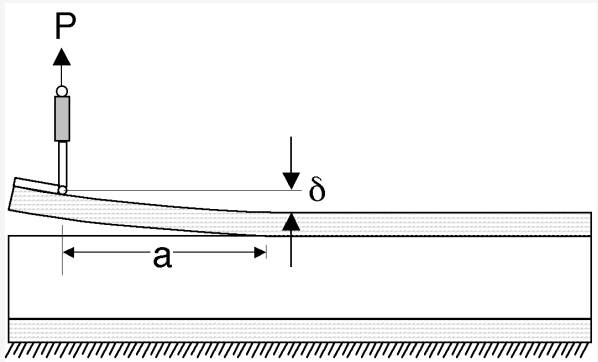
SCB FACESHEET THICKNESS EFFECTS:

Thin Facesheets

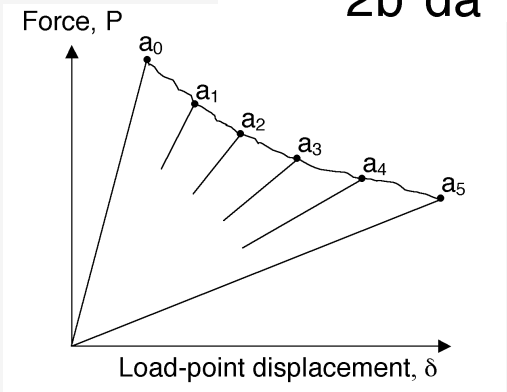
Thin facesheets create inaccuracies when using conventional compliance calibration method

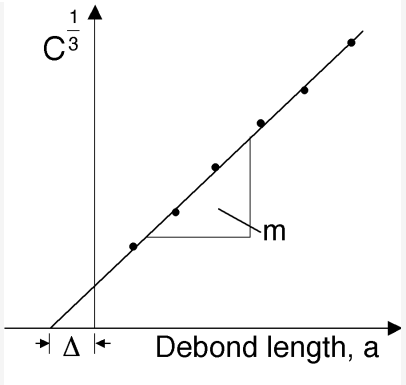
$$C_{SCB} = \frac{\delta}{P} = \frac{4\lambda}{k}\left[\frac{\lambda^2 a^3}{3} + \lambda^2 a^2 F_1 + \lambda a F_2 + \frac{3ak}{10\lambda G_{xz,f} t_f b} + \frac{F_3}{2}\right]$$

Ratcliffe J. and Reeder, J., "Sizing A Single Cantilever Beam Specimen for Characterizing Facesheet/Core Peel Debonding in Sandwich Structure," *Journal of Composite Materials*, Vol. 45 no. 25 2669-2684, 2011



$$G_c = \frac{P_c^2}{2b}\frac{dC}{da} \qquad C = m\left[a + \Delta\right]^3$$

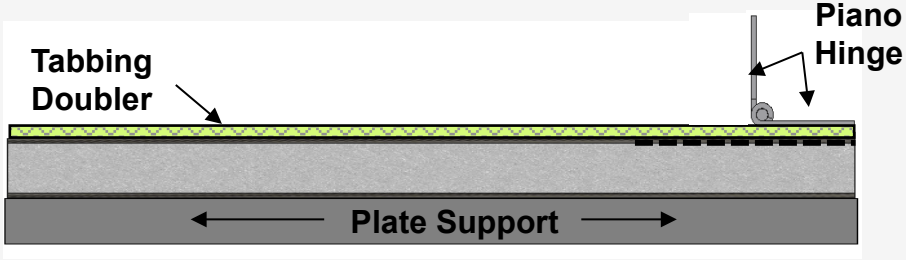


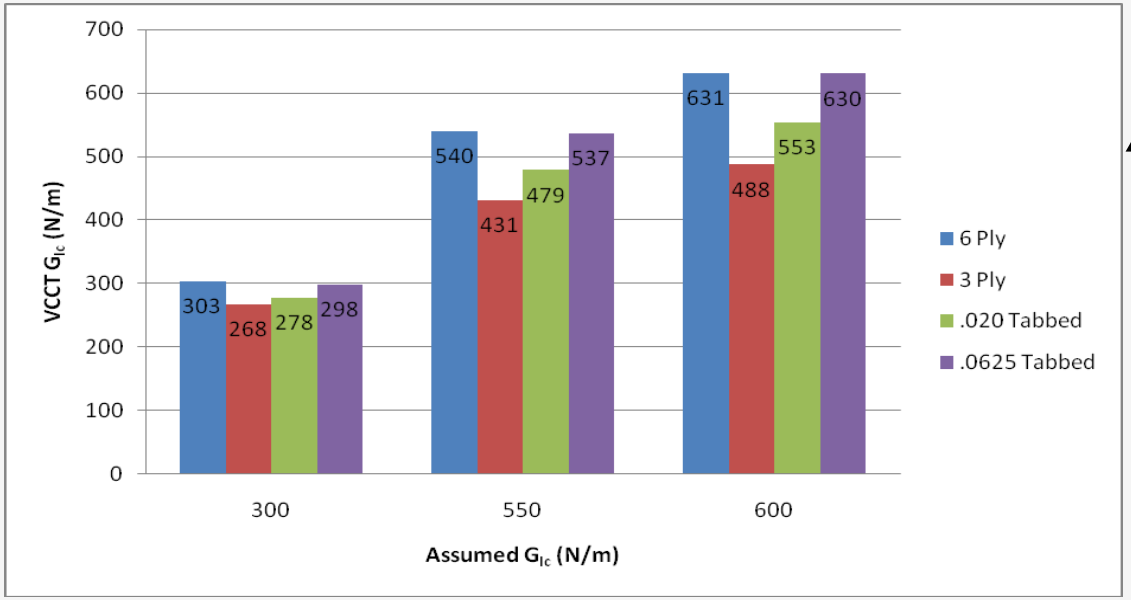


SCB FACESHEET THICKNESS EFFECTS:

Adding Tabbing "Doublers" to Thin Facesheets

Geometrically nonlinear FE simulation of compliance calibration method





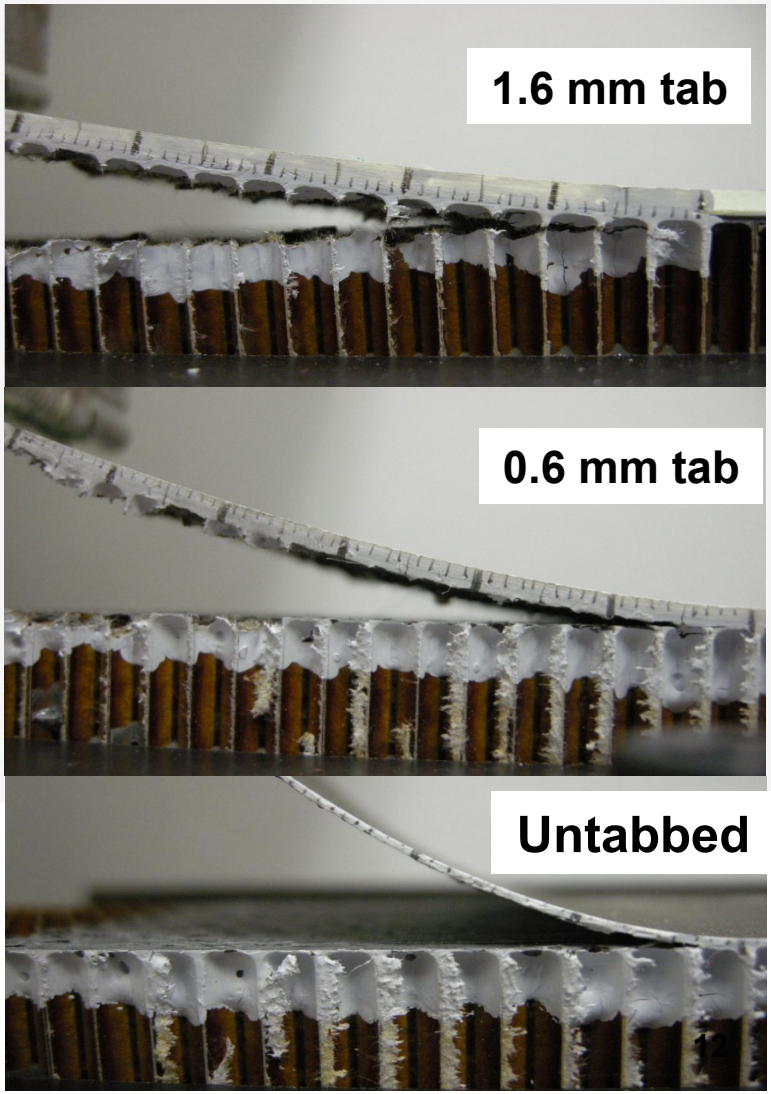
Adding tabbing doublers to upper facesheet predicted to increase accuracy of G_{IC} calculation

USE OF FACESHEET DOUBLER:

Preliminary Test Results

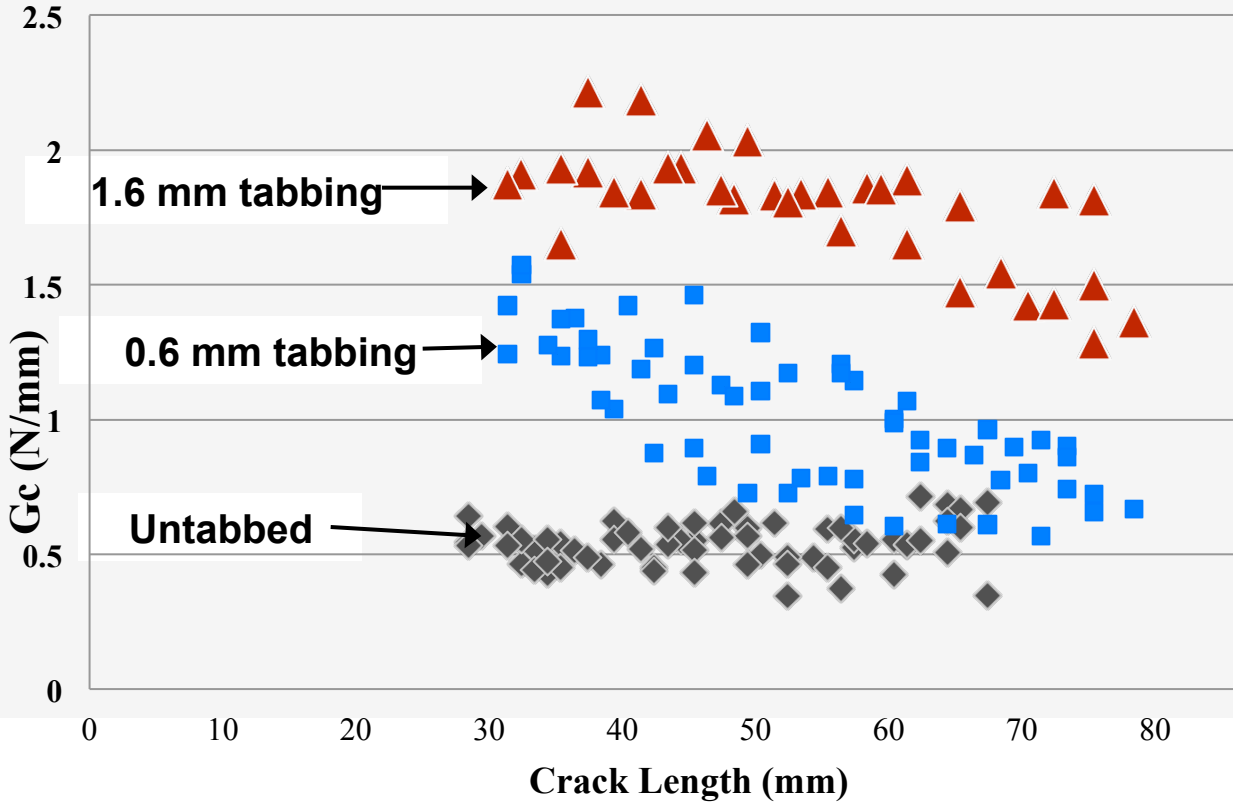
Different crack locations:

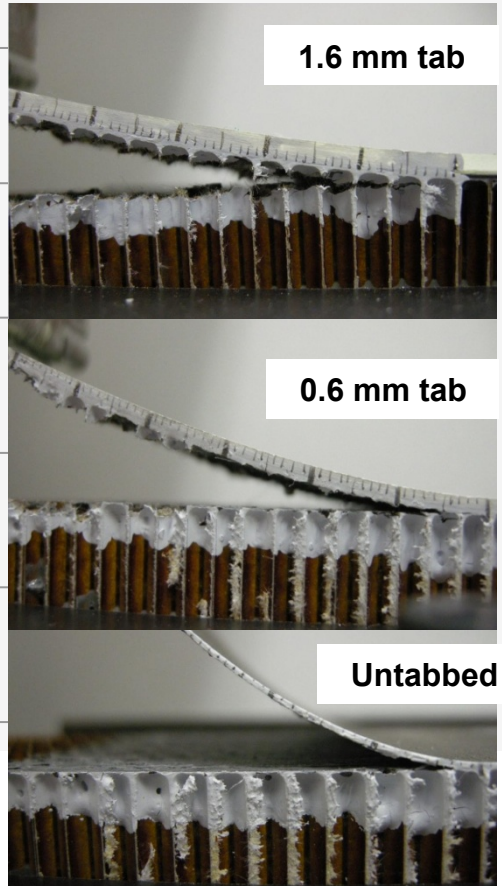
- Thick-tabbed: crack growth in core at the base of adhesive fillets
- Thin-tabbed: crack growth in in vicinity of adhesive/core interface
- Untabbed: crack growth in film adhesive



EFFECTS OF FACESHEET DOUBLER:

Different failure locations produces different G_c values

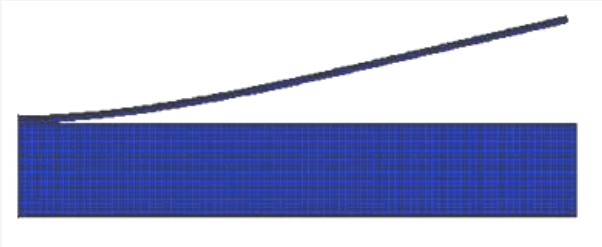


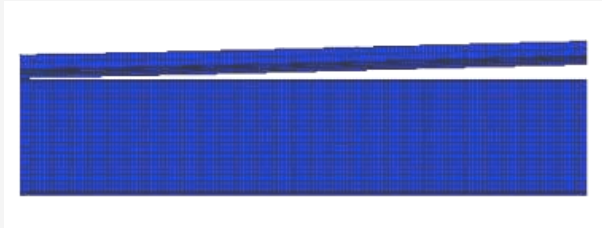


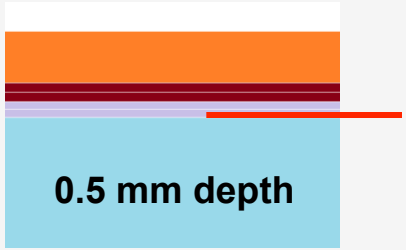
NUMERICAL INVESTIGATION

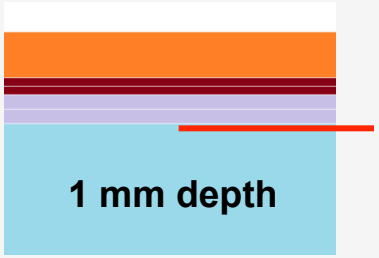
Effects of Facesheet Doubler

- 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









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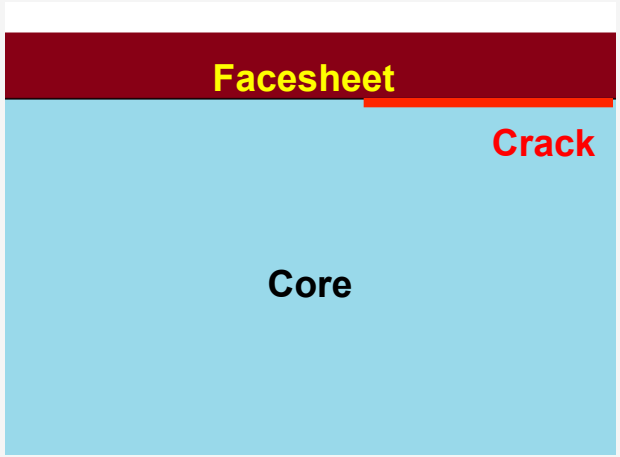
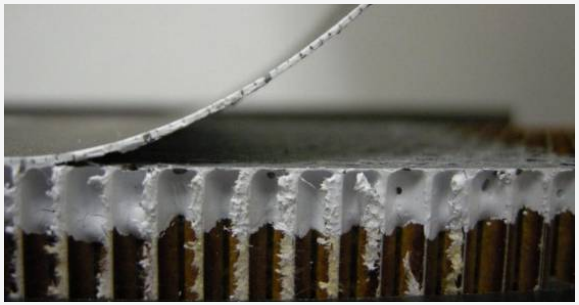
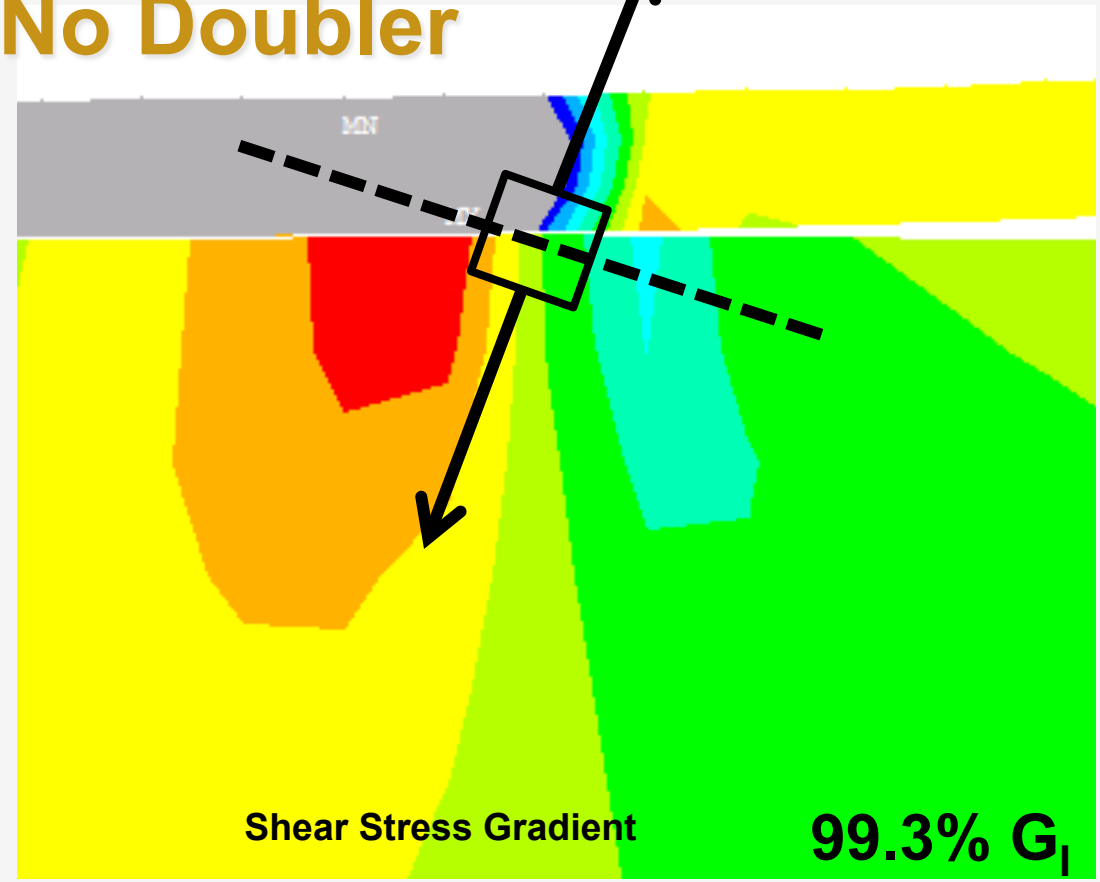
FACESHEET DOUBLER EFFECTS:

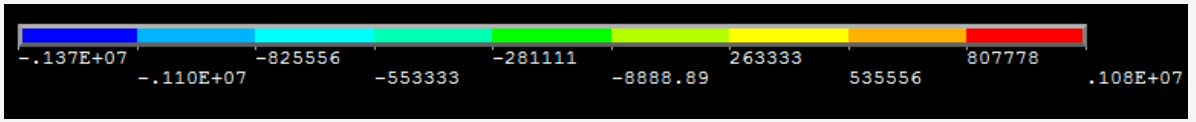


Crack at interface



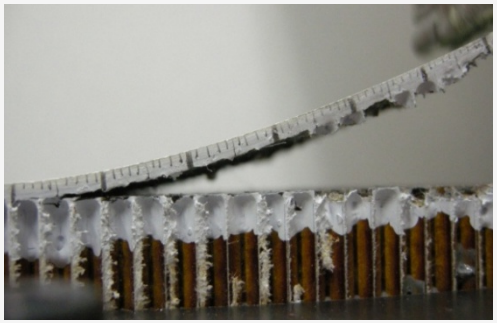
No Doubler

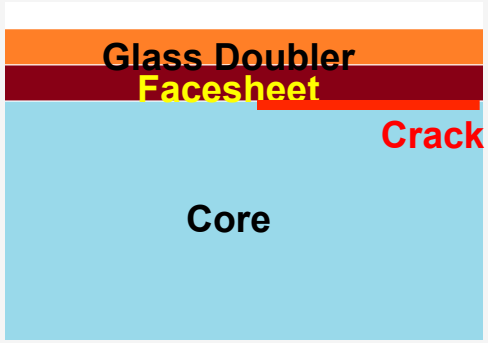




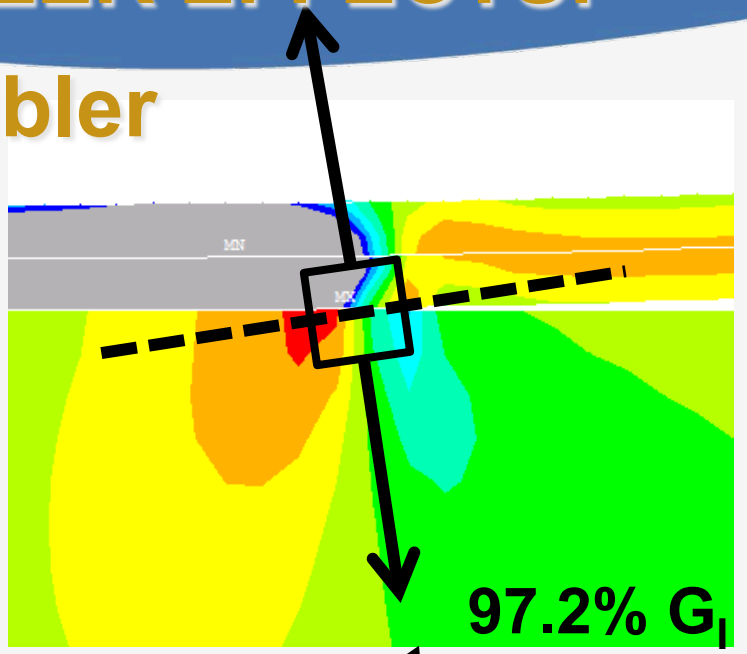
FACESHEET DOUBLER EFFECTS:

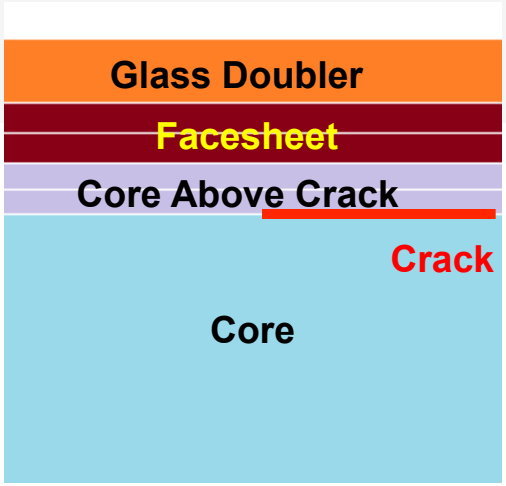
Thin Doubler



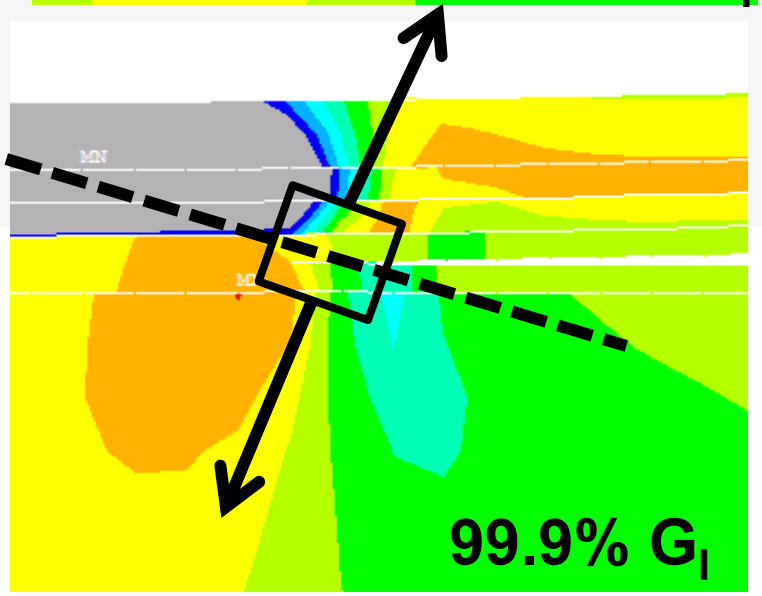


At interface



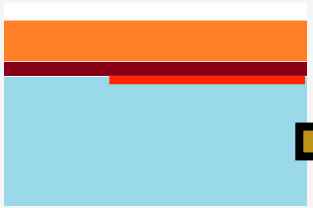


.5 mm depth

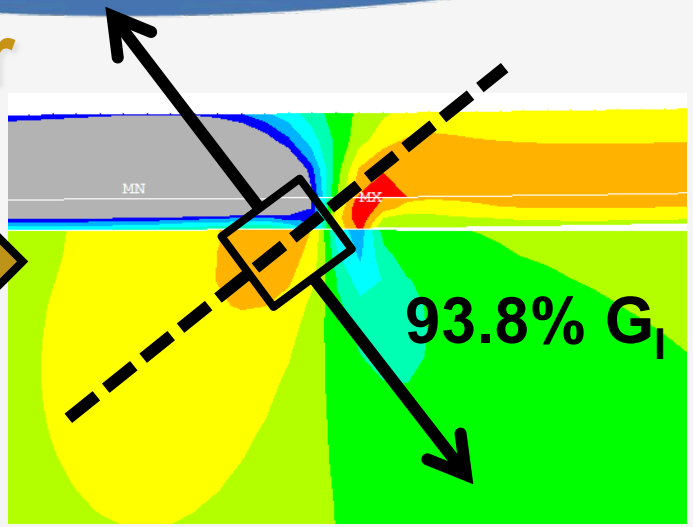


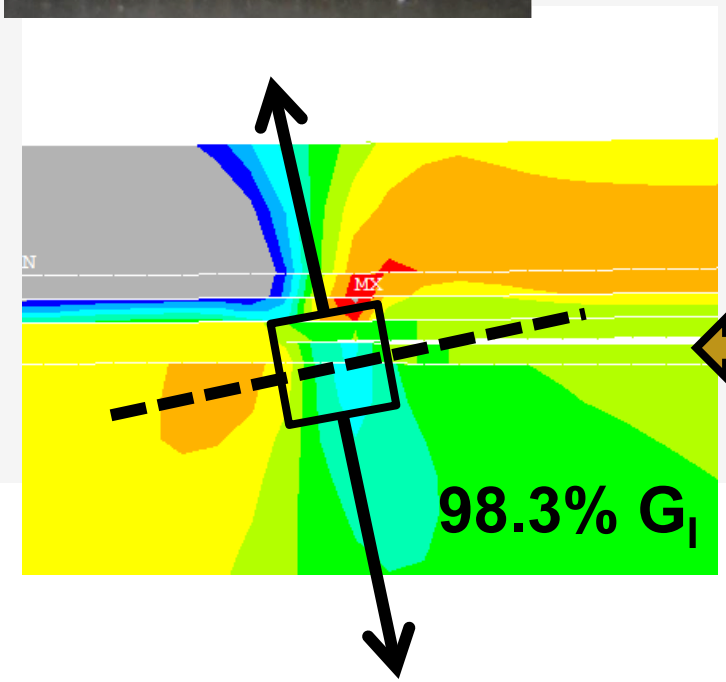
FACESHEET DOUBLER EFFECTS:

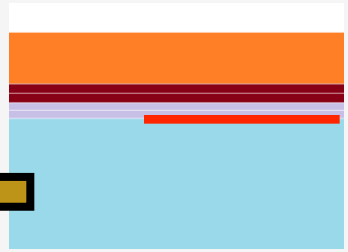
Thick Doubler



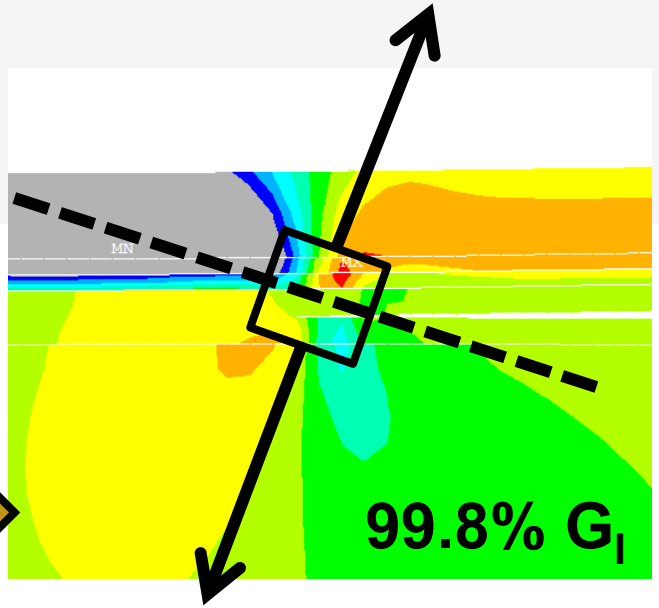
At interface

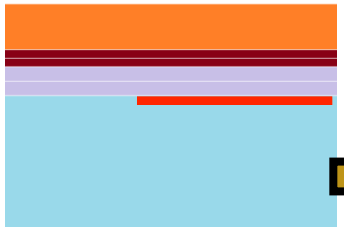






0.5 mm depth



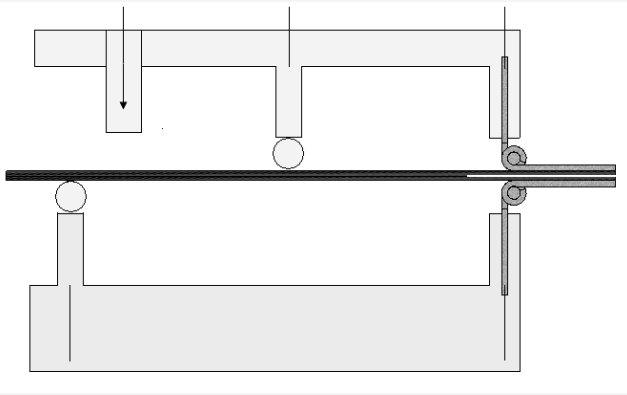


1 mm depth

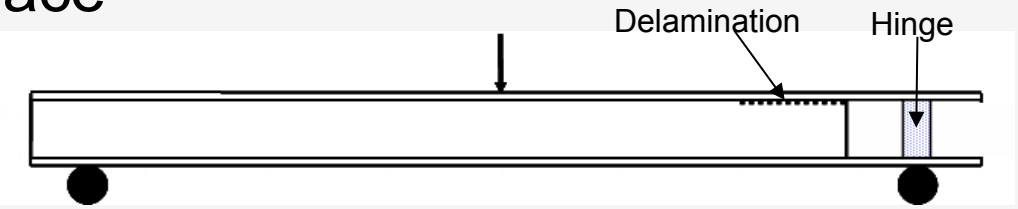
MODE II TEST METHOD DEVELOPMENT

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

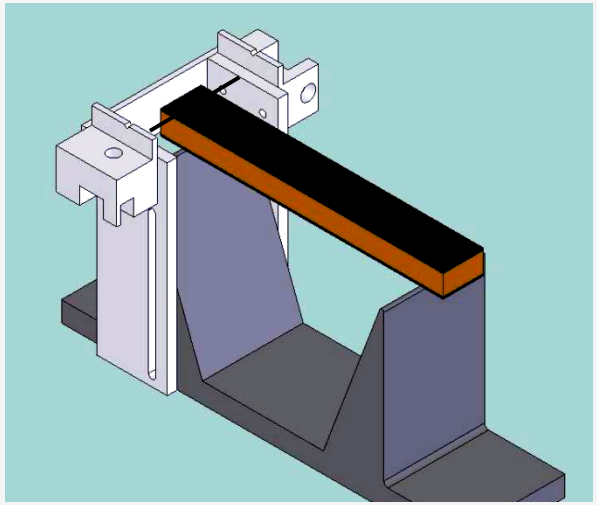


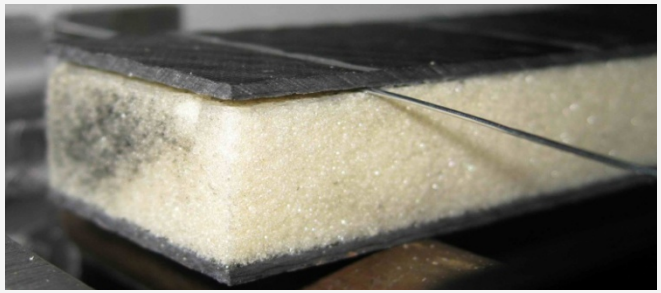
Modified Cracked Sandwich Beam (CSB) with Hinge

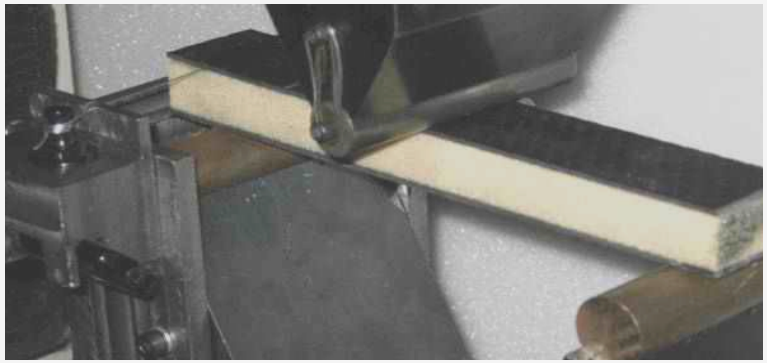
SELECTED MODE II CONFIGURATION:

End Notched Sandwich (ENS) TEST

- 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*







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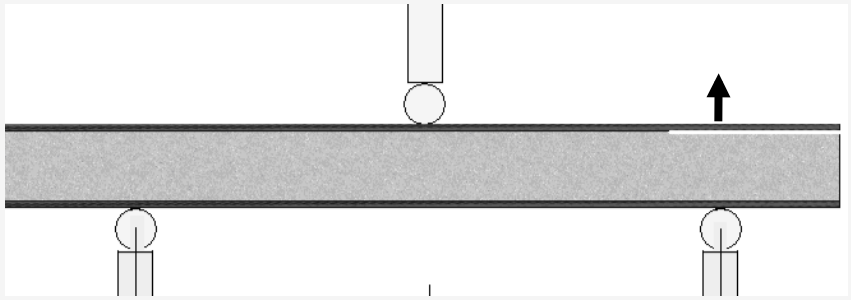
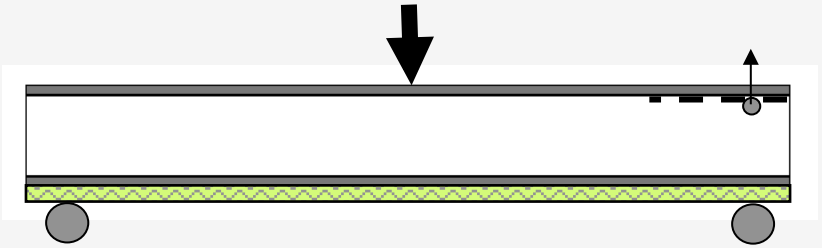
MODE II END NOTCHED SANDWICH TEST

Numerical Investigations Performed

- Mode mixity of crack growth (% G_{II})
- Specimen width effects
- Facesheet thickness effects
  - Adding doubler to lower facesheet
- Crack growth stability
  - Specimen length effects
  - Precrack length effects

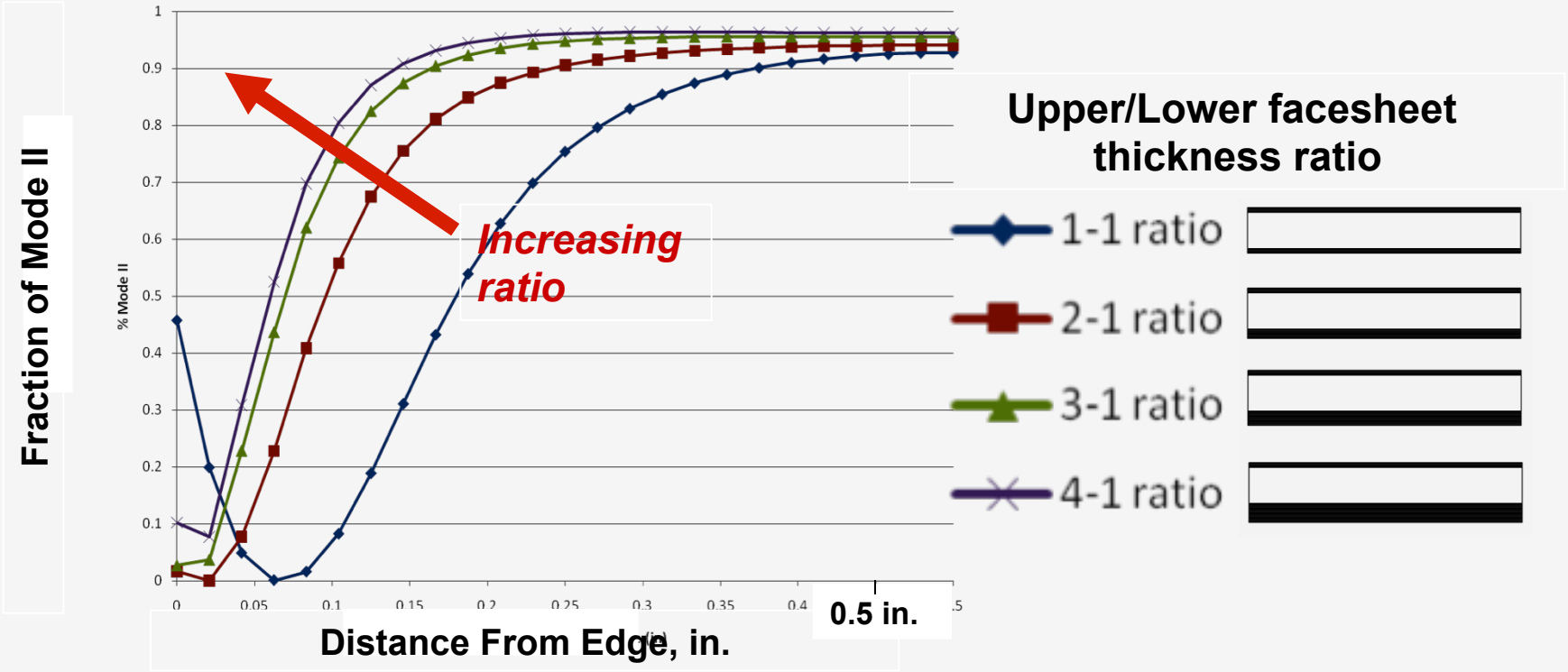




Addressing Mode Mixity/Width Variations

Adding Flexural Stiffness to Bottom Facesheet

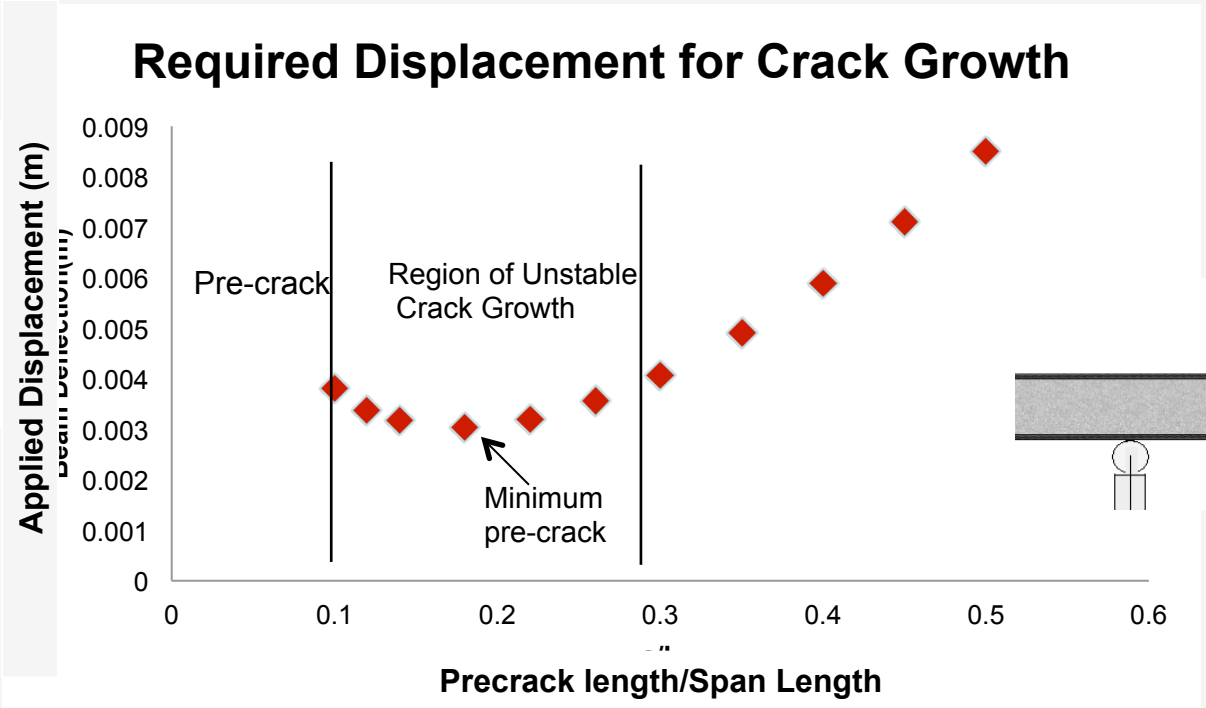
Increasing flexural stiffness (EI) of lower portion of delaminated specimen reduces specimen width effect

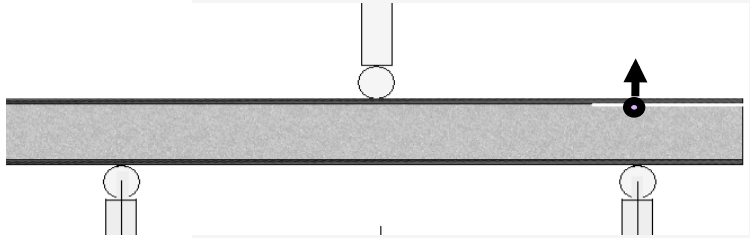


ADDRESSING CRACK GROWTH STABILITY:

Specimen Span Length and Precrack Length

- **Selection of proper precrack length/span length expected to produce stable crack growth**
- **Experimental results have shown this effect**





TOWARDS STANDARDIZATION…

Presentation and discussion at ASTM Committee D30 on Composites every six months

- **Next presentation: April 18, 2012 in Phoenix, AZ**

Overview presentations at CMH-17 Testing Working Group

- **Next presentation: August 22, 2012 (Location TBD)**

Performing SCB testing at the University of Utah for interested parties

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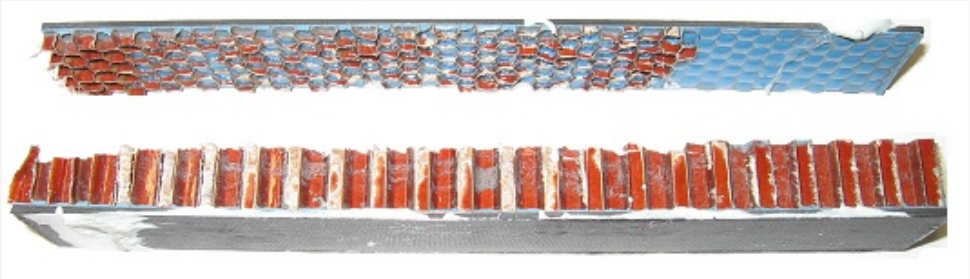
SUMMARY

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 delamination growth in composite sandwich structures



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Thank you for your attention!

Questions?