DEVELOPMENT AND EVALUATION OF FRACTURE MECHANICS TEST METHODS FOR SANDWICH COMPOSITES

Dan Adams
Department of Mechanical Engineering
University of Utah
Salt Lake City, UT

AMTAS Autumn 2011 Meeting
Edmonds, WA **November 1, 2011**

A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures
A part of the FAA Joint Advanced Materials & Structures Center of Excellence

THE UNIVERSITY OF UTAH

FAA Sponsored Project Information

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

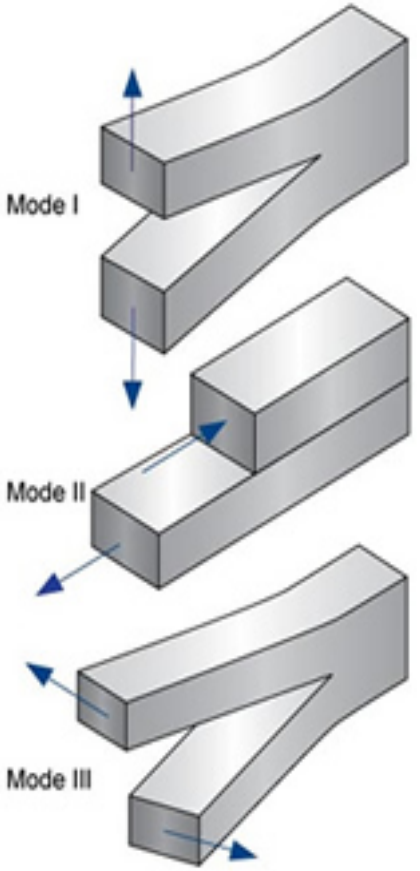
Joe Nelson	**Zack Bluth**
Josh Bluth	**Brad Kuramoto**
Chris Weaver	**Andy Gill**

- **FAA Technical Monitor**
  - **Curt Davies David Westlund**
- **Primary Collaborator:**
  - **NASA Langley Research Center (James Ratcliffe)**

RESEARCH OBJECTIVES:

Fracture Mechanics Test Methods for Sandwich Composites

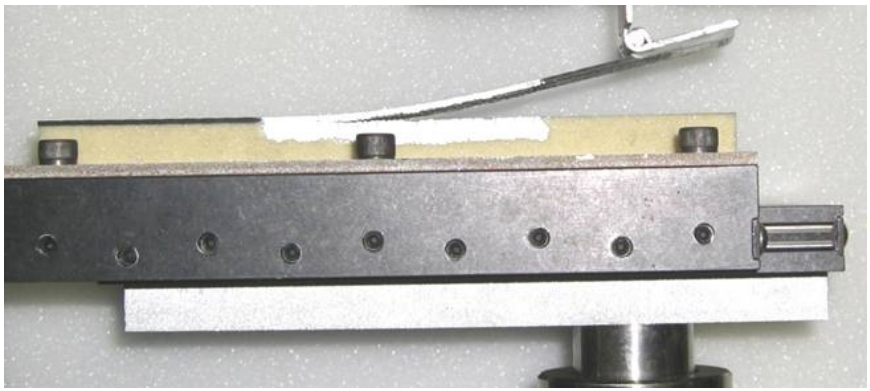
- **Focus on facesheet-core delamination**
- **Mode I and Mode II**
  - Identification and initial assessment of candidate test methodologies
  - Selection and optimization of best suited Mode I and Mode II test methods
  - Development of draft ASTM standards

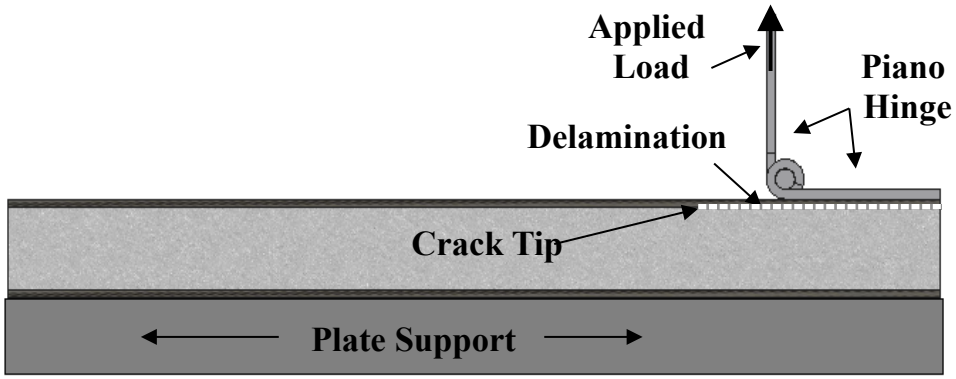


SELECTED MODE I CONFIGURATION:

Single Cantilever Beam (SCB) Test

- **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***

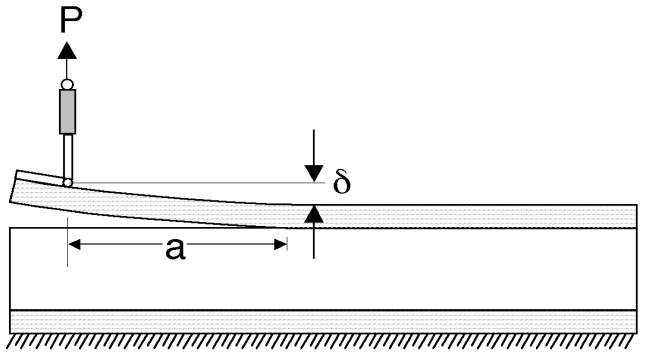


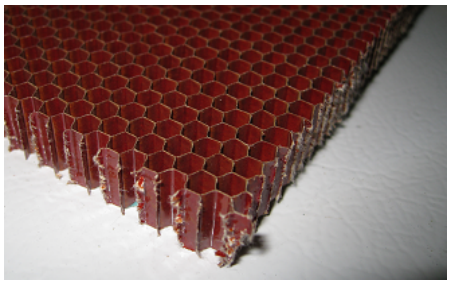


PARAMETERS INVESTIGATED:

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

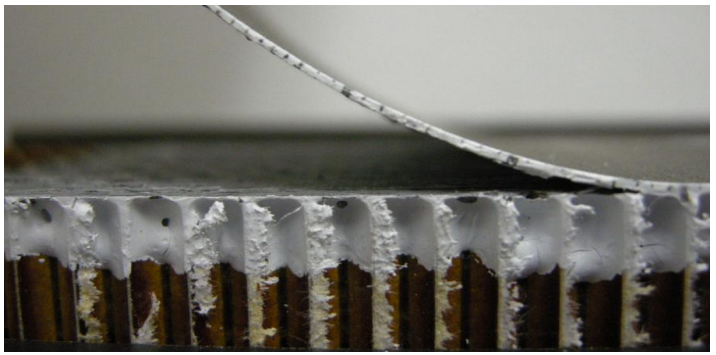




RECENT EFFORTS:

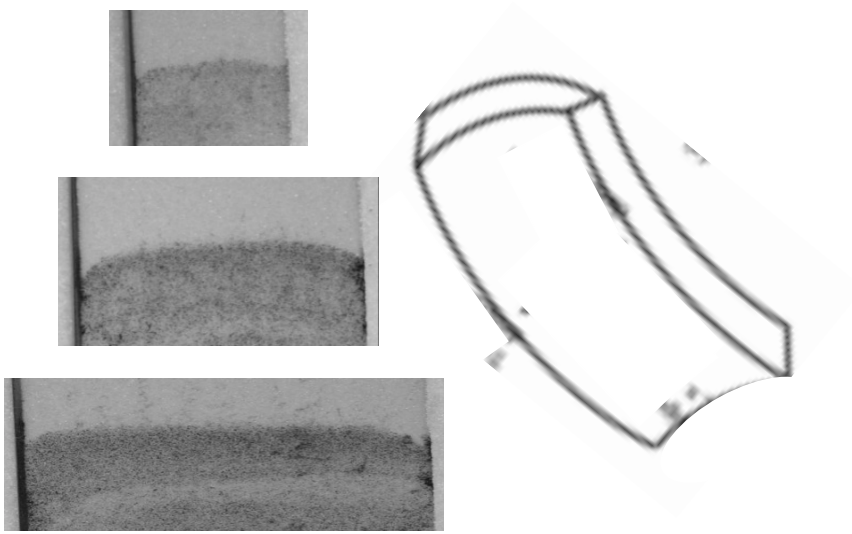
Single Cantilever Beam Test for Sandwich Composites

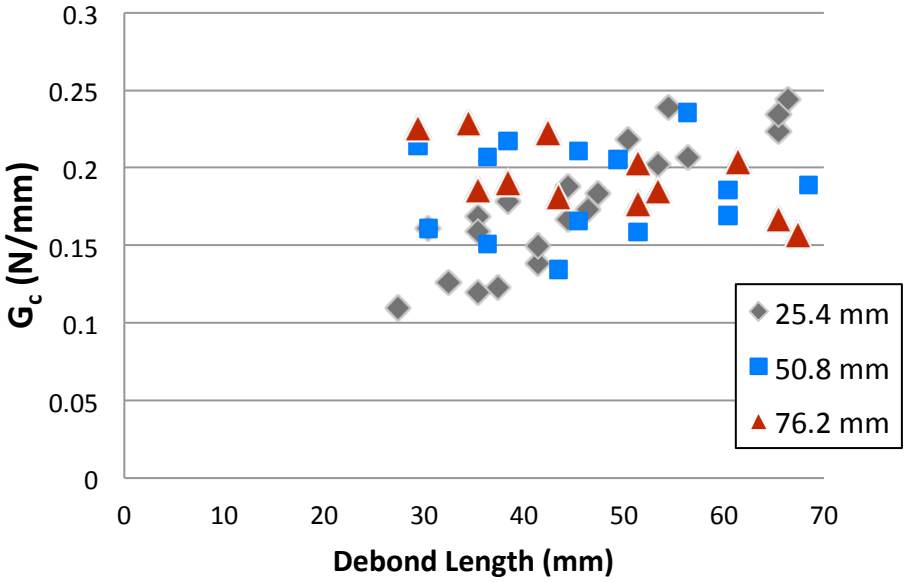
- Establishment of recommended specimen width
  - Anticlastic curvature and curved crack fronts
  - Minimum number of honeycomb cells
- Effects of thru-thickness placement of starter crack
- Procedures for testing sandwich configurations with "thin" facesheets
  - Excessive facesheet rotation
  - Problems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



RECOMMENDED SPECIMEN WIDTH:
Anticlastic Curvature and Curved Crack Fronts

Foam Core Sandwich Specimens with Quasi-Isotropic Facesheets

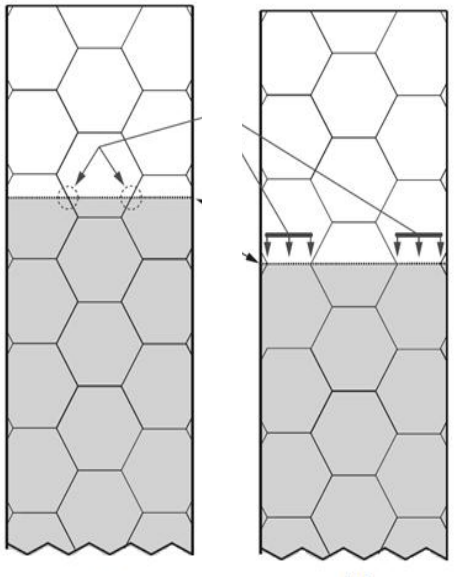


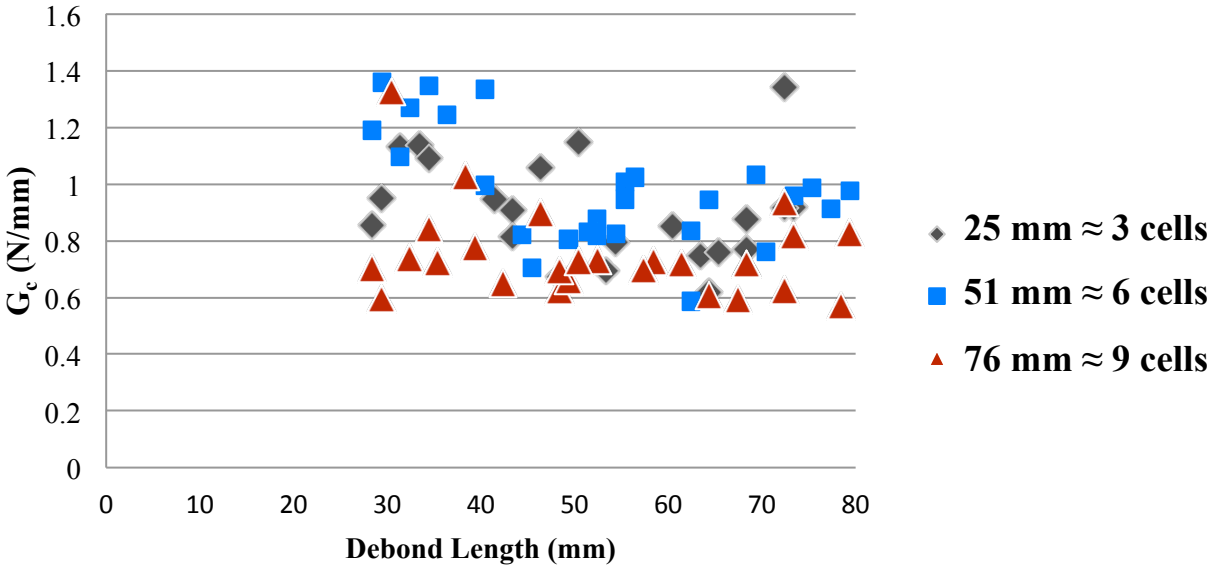


51 mm (2 in) selected as recommended specimen width

RECOMMENDED SPECIMEN WIDTH:
Minimum Number of Honeycomb Cells

Nomex Honeycomb Core, 3/8 in. Honeycomb Cell Size



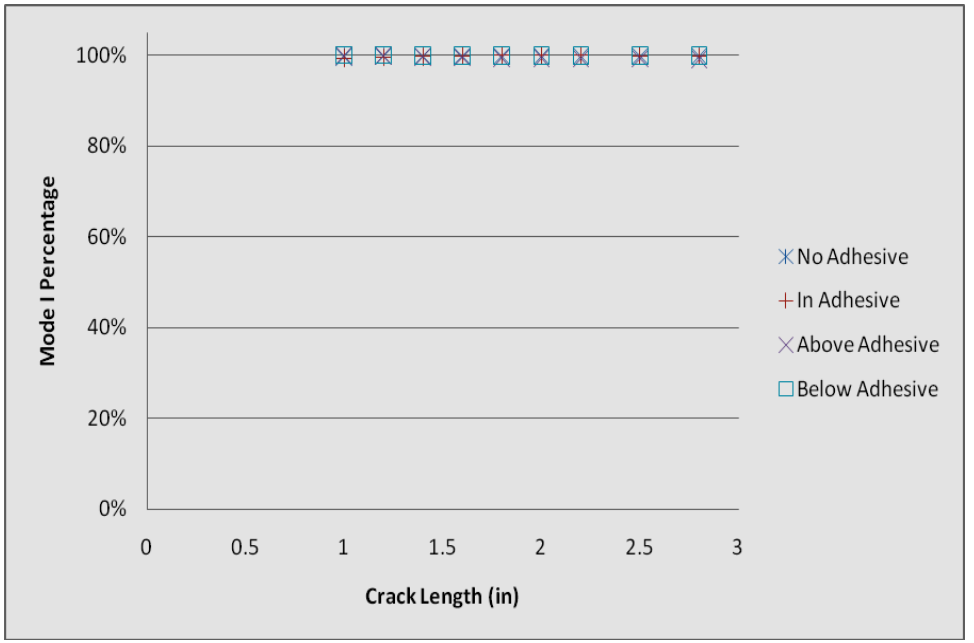


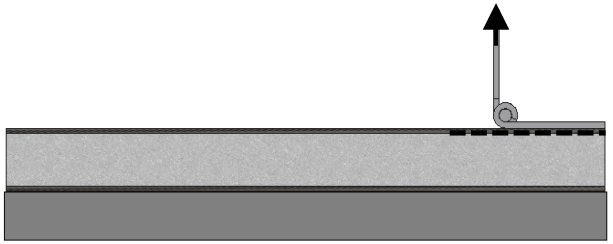
Minimum of 6 honeycomb cells across specimen width

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

EFFECTS OF STARTER CRACK PLACEMENT: Predicted Mode Mixity

- Modeled with and without an adhesive layer
- Four crack locations:
  - Facesheet/core interface (no adhesive)
  - Within adhesive
  - Above adhesive
  - Below adhesive
- Initial results: no effect on mode mixity
- Further investigation underway





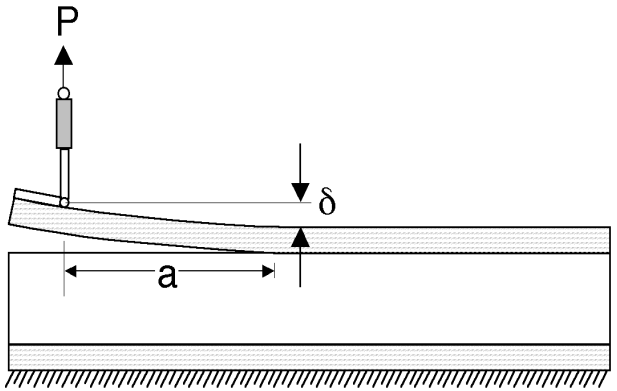
SCB FACESHEET THICKNESS EFFECTS:

Thin Facesheets

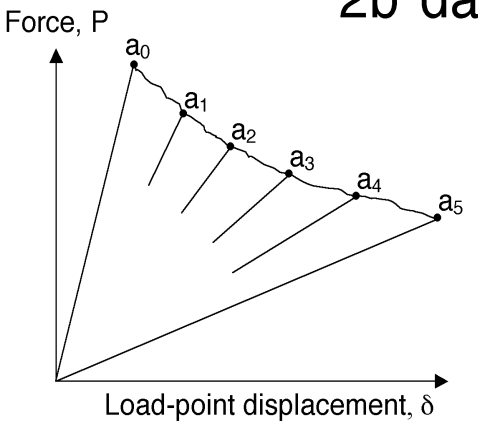
Thin facesheets create inaccuracies when using conventional compliance calibration method

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

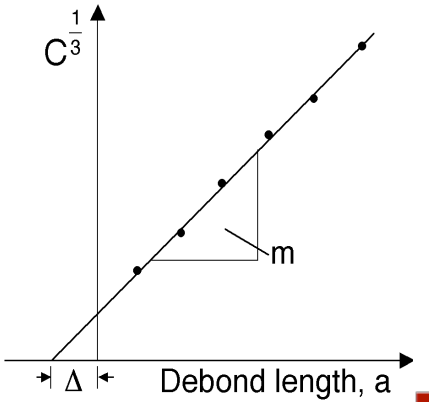
Ratcliffe J. and Reeder, J., "Sizing A Single Cantilever Beam Specimen for Characterizing Facesheet/Core Peel Debonding in Sandwich Structure, to appear in Journal of Composite Materials, 2011.



$$G_c = \frac{P_c^2}{2b}\frac{dC}{da}$$



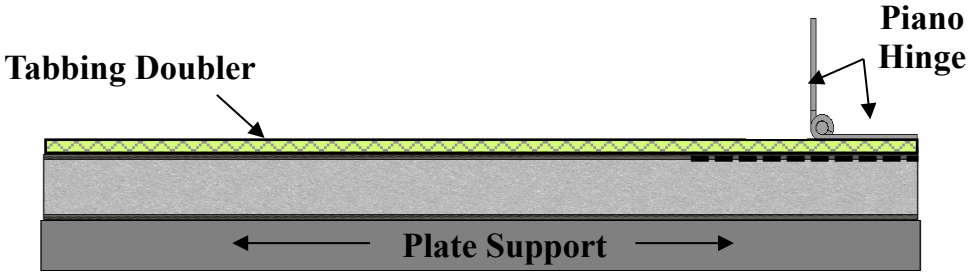
$$C = m\left[a + \Delta\right]^3$$

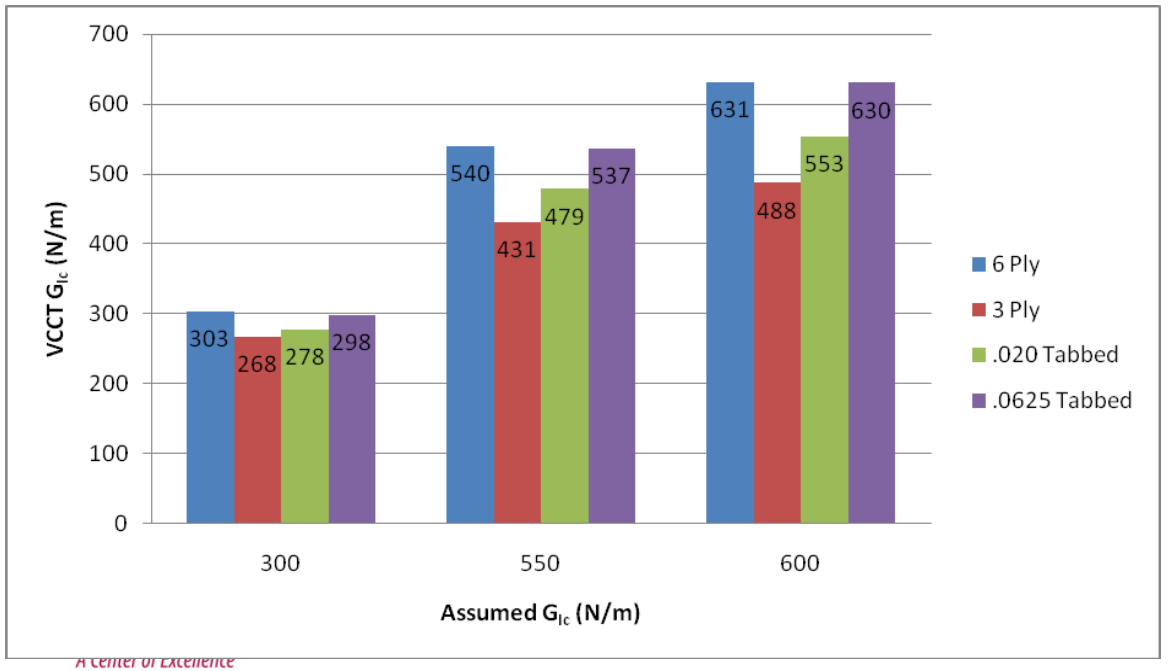


SCB FACESHEET THICKNESS EFFECTS:

Adding Tabbing "Doublers" to Thin Facesheets

Geometrically nonlinear FE simulation of compliance calibration method



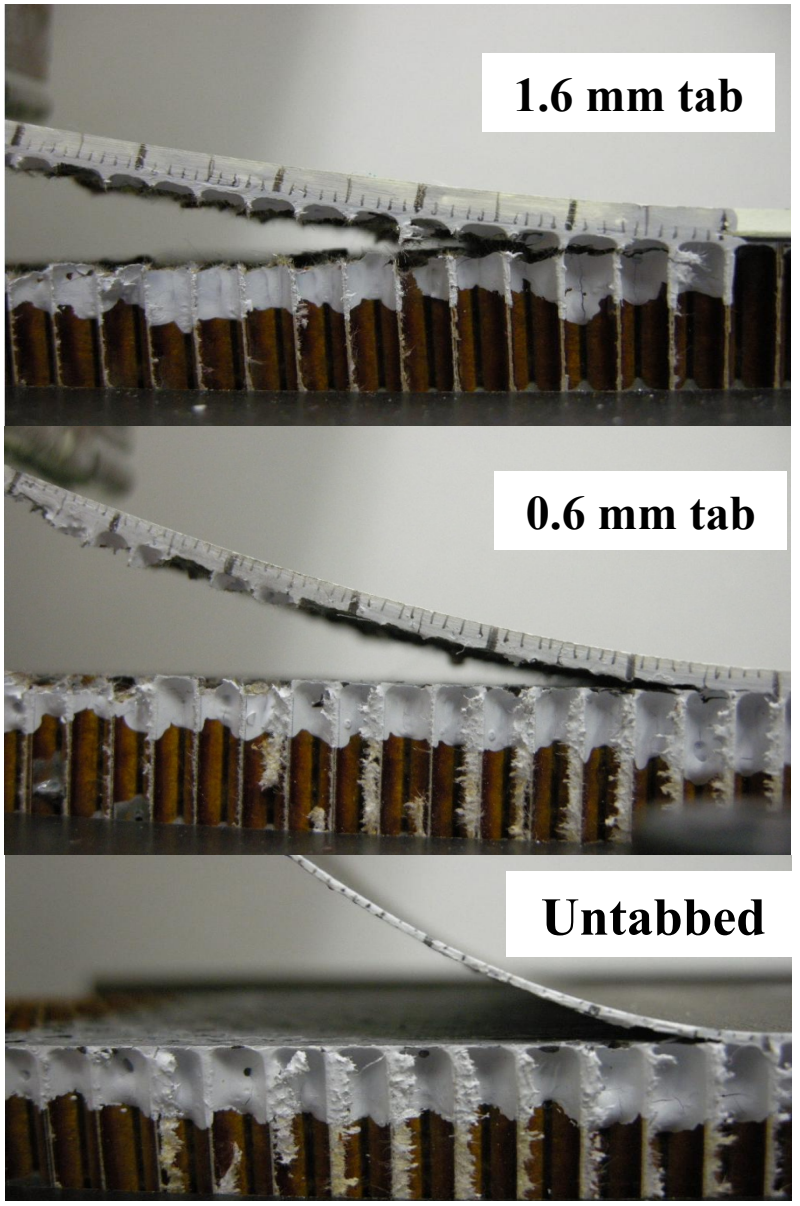


Adding tabbing doublers to upper facesheet predicted to increases accuracy of G_{IC} calculation

USE OF FACESHEET DOUBLER:
Preliminary Test Results

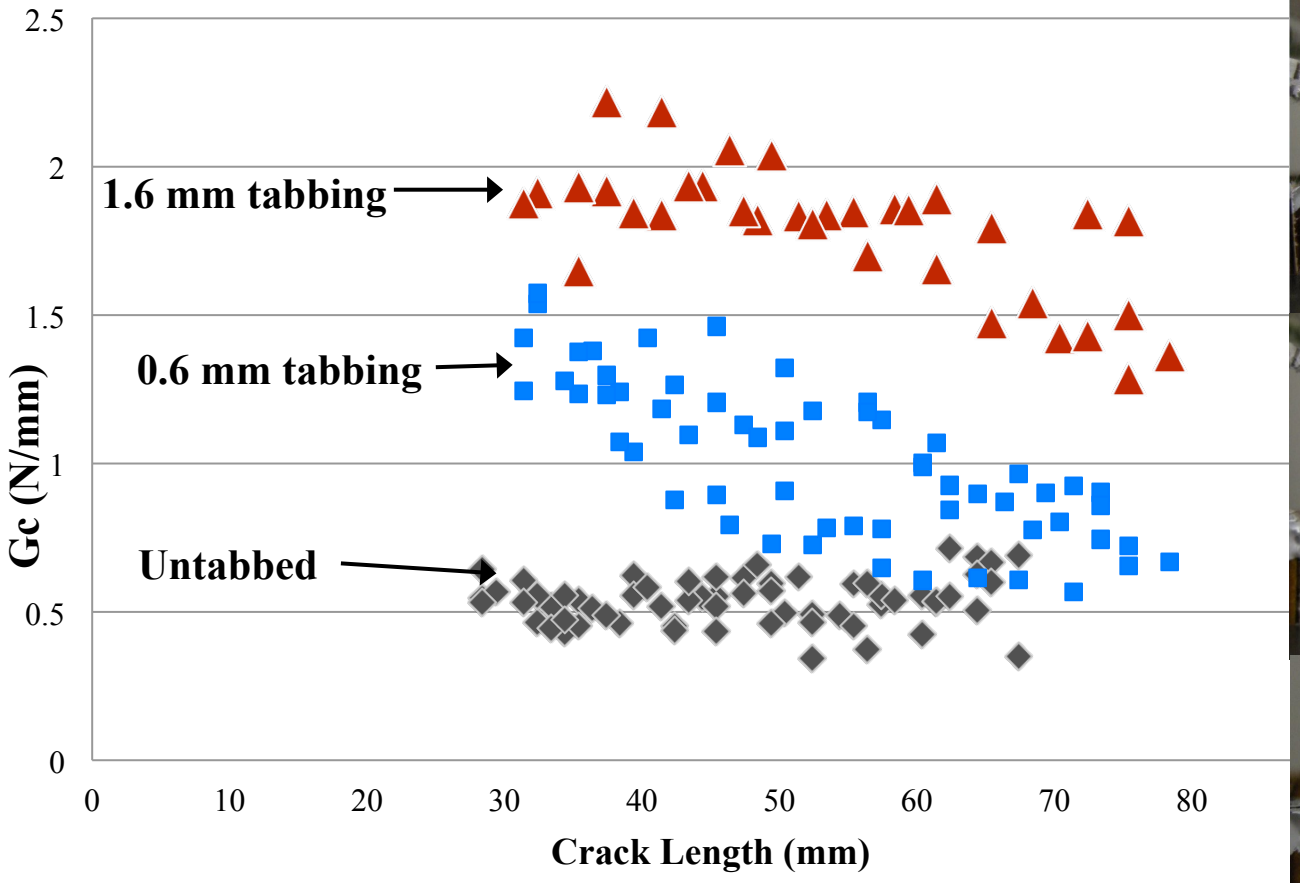
Different crack locations:

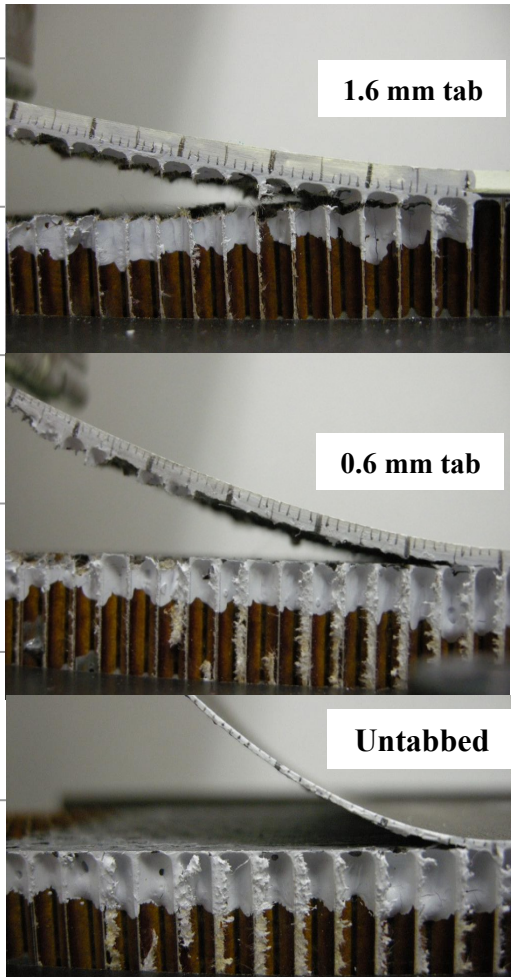
- **Thick-tabbed: crack growth in core at the base of adhesive fillets**
- **Thin-tabbed: crack growth in in vicinity of adhesive/core interface**
- **Untabbed: crack growth in film adhesive**



USE OF FACESHEET DOUBLER:
Preliminary Test Results

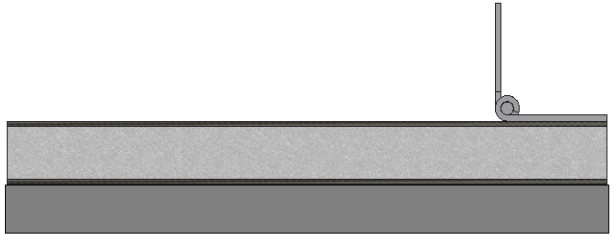
Different failure locations produces different fracture toughness values

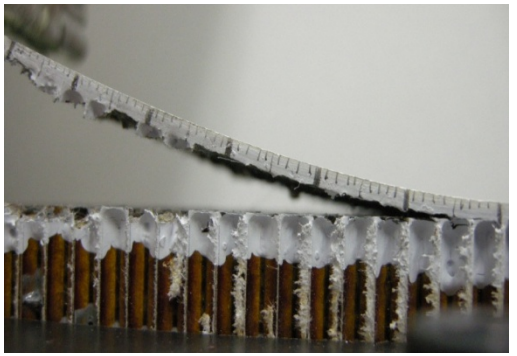




CURRENT FOCUS:

Single Cantilever Beam (SCB) Test

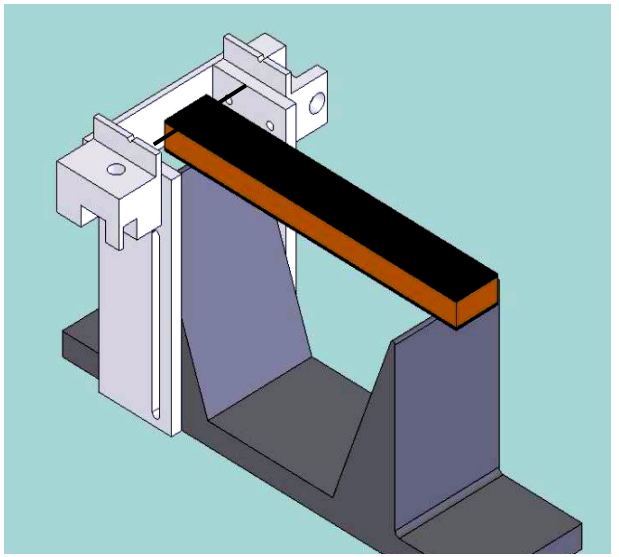


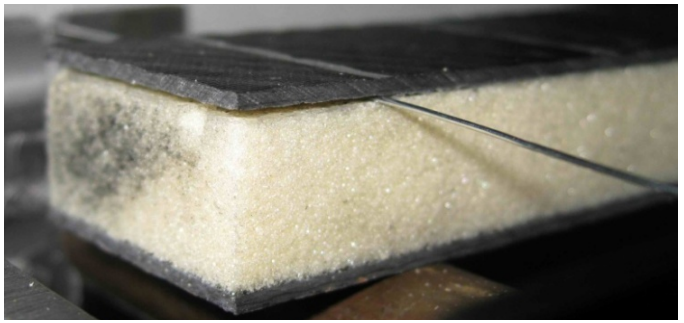


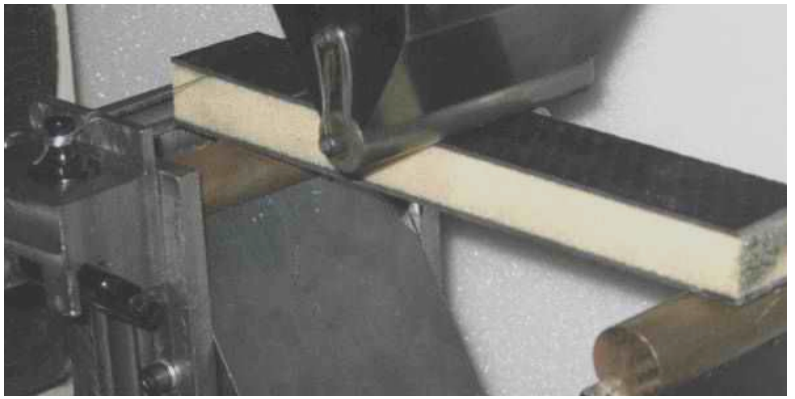
- **Further investigation: Effects of thru-thickness location of starter crack**
- **Further investigation: Effects of facesheet thickness variations and doublers on crack location and fracture toughness**
- ***Composing draft ASTM standard***

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***

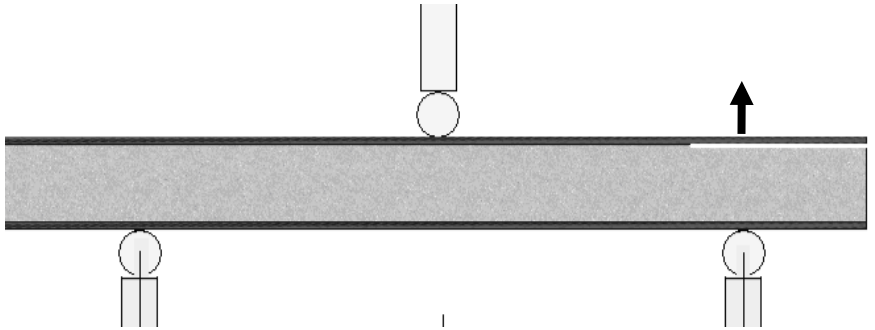


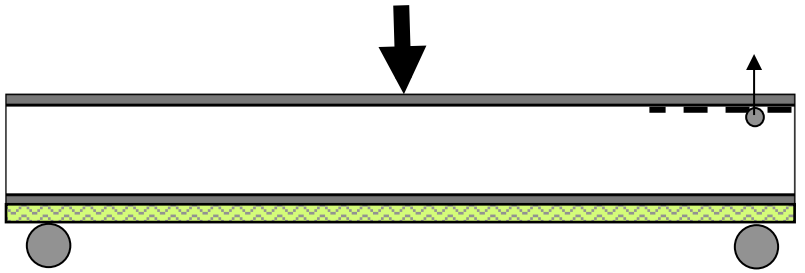




MODE II END NOTCHED SANDWICH TEST: Numerical Investigations Performed

- 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

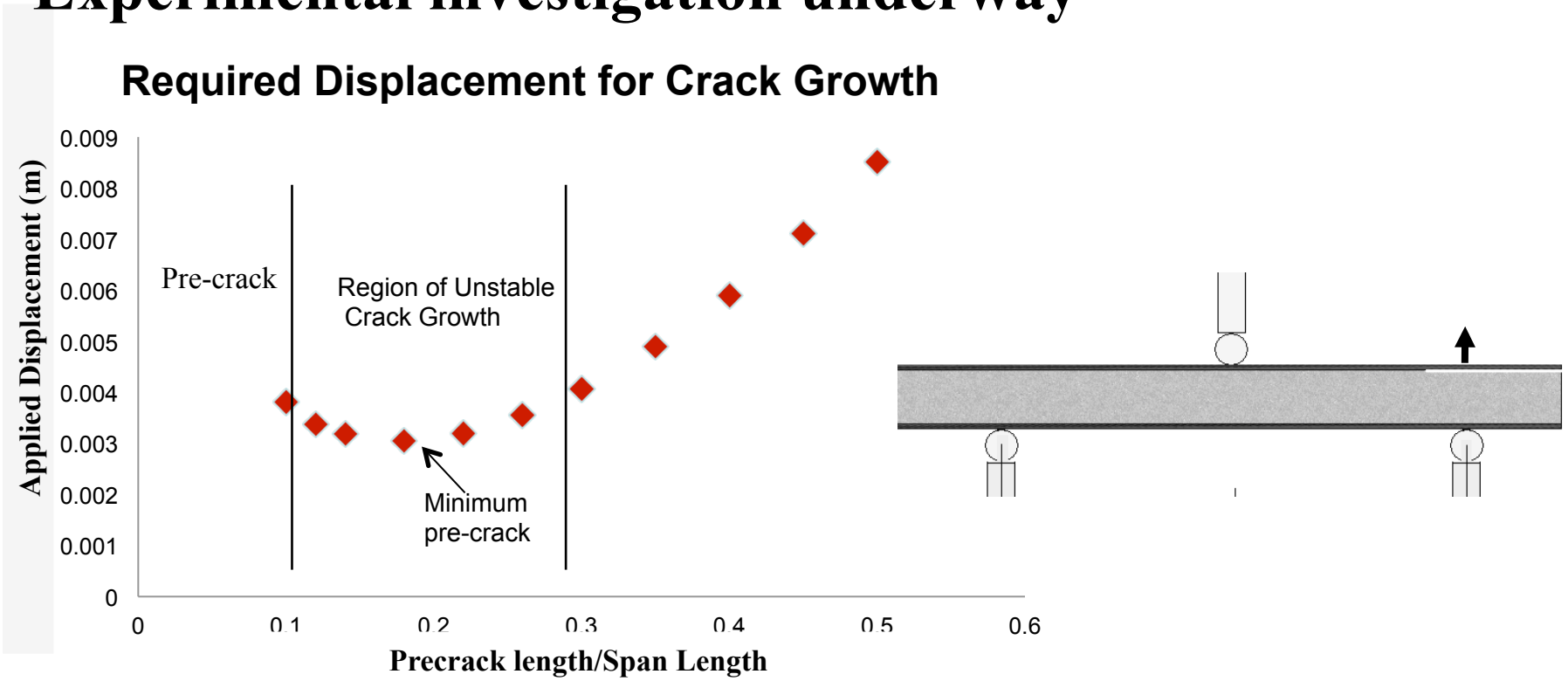




ADDRESSING CRACK GROWTH STABILITY:

Specimen Span Length and Precrack Length

- **Selection of proper precrack length/span length expected to produce stable crack growth**
- **Experimental investigation underway**



TOWARDS STANDARDIZATION…

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

- **Last presentation: October 18, 2011 in Ft. Worth TX**

Overview presentations at CMH-17 Testing Working Group

- **Next presentation: November 15, 2011 in Wichita, KS**

Performing SCB testing at the University of Utah for interested parties