DEVELOPMENT AND EVALUATION OF FRACTURE MECHANICS TEST METHODS FOR SANDWICH COMPOSITES

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AMTAS Autumn 2012 Meeting
Seattle, WA **October 31, 2012**

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FAA Sponsored Project Information

- **Principal Investigator: Dr. Dan Adams**
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- **FAA Technical Monitor**
  - **Curt Davies** **David Westlund**
- **Collaborators:**

NASA Langley	**NIAR**
Boeing	**Learjet**
Airbus	**UTC Aerospace Systems**

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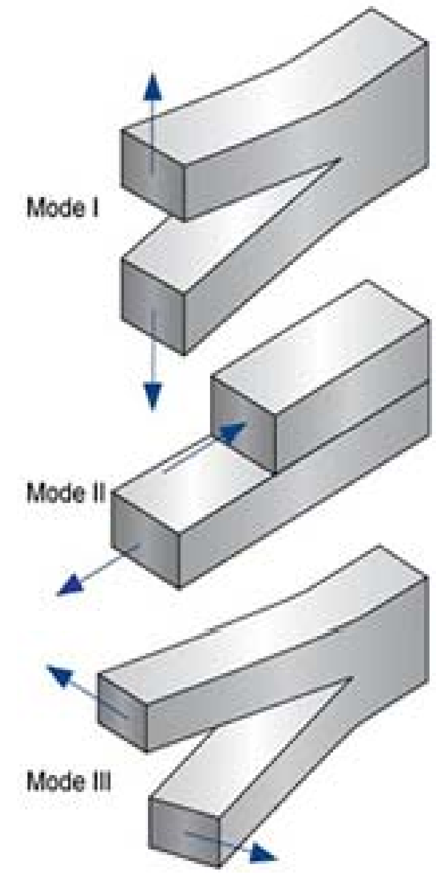
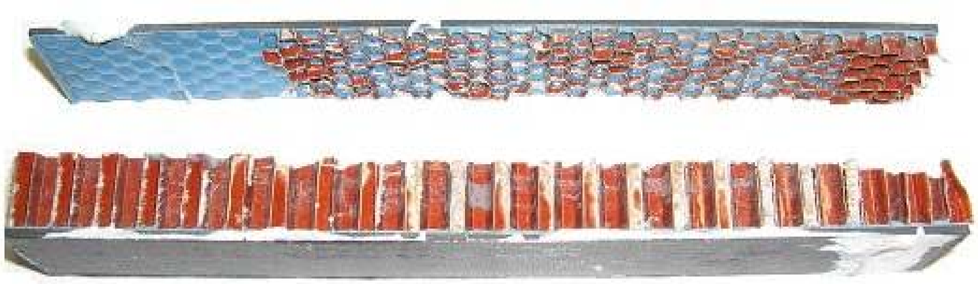
RESEARCH OBJECTIVES:

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**





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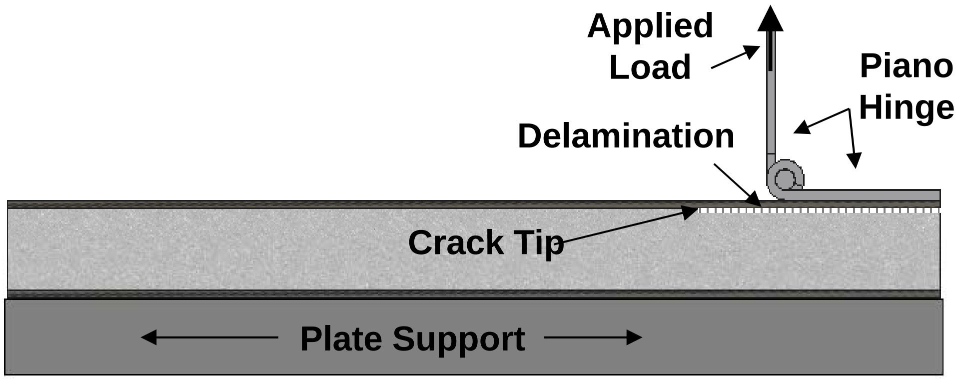
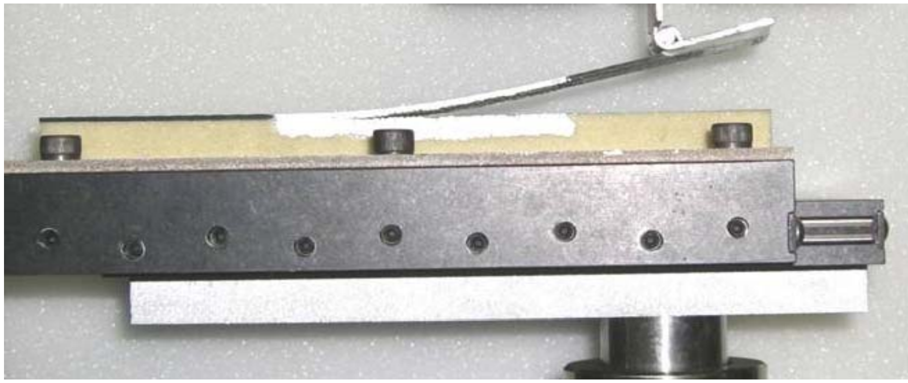
MODE I TEST CONFIGURATION:
Single Cantilever Beam (SCB)

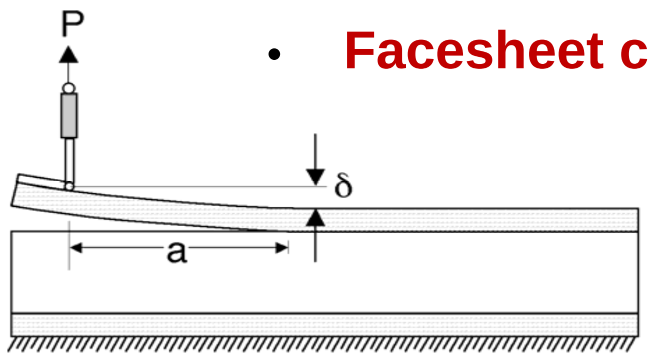
- **Elimination of bending of sandwich specimen**
- **Minimal crack "kinking" observed**
- **Mode I dominant - independent of crack length**
- ***Appears to be suitable for standardization***





PARAMETERS INVESTIGATED:
Single Cantilever Beam (SCB) Test

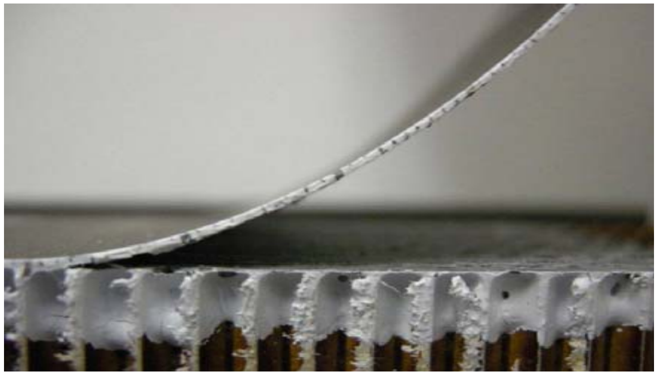
- **Specimen geometry**
  - **Length**
  - **Width**
  - **Initial crack length**
- **Facesheet properties**
  - **Thickness**
  - **Flexural stiffness**
  - **Flexural strength**
- **Core properties**
  - **Thickness**
  - **Density**
  - **Stiffness**
  - **Strength**
- **Mode mixity**
  - **Variations 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

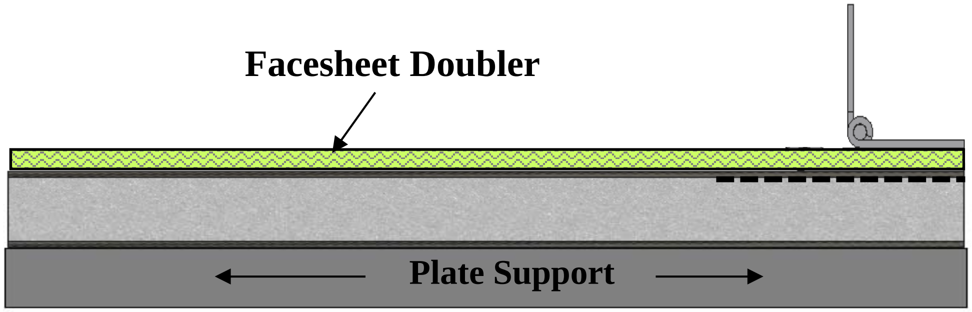
Concern: Excessive facesheet rotation

- 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



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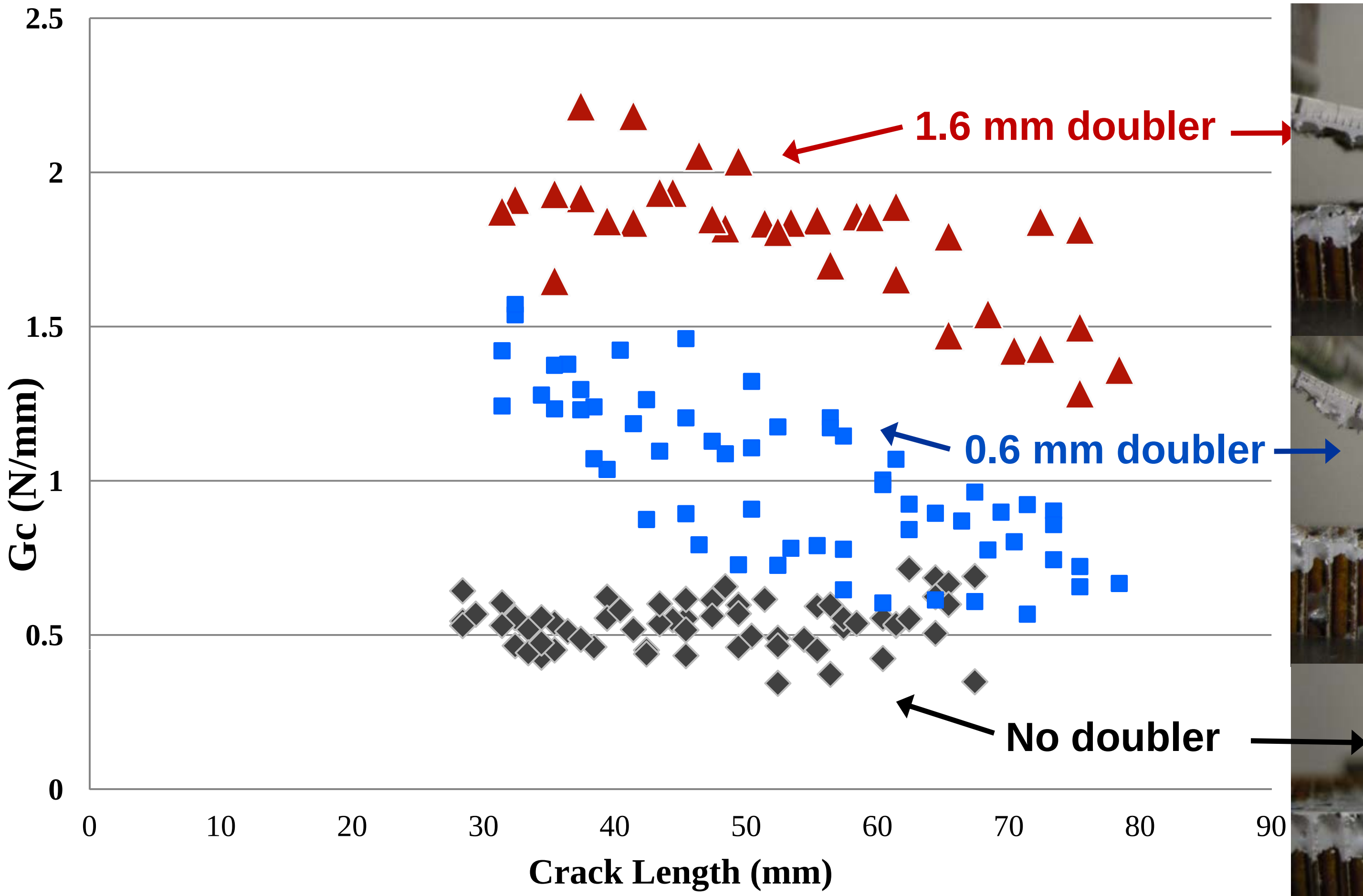
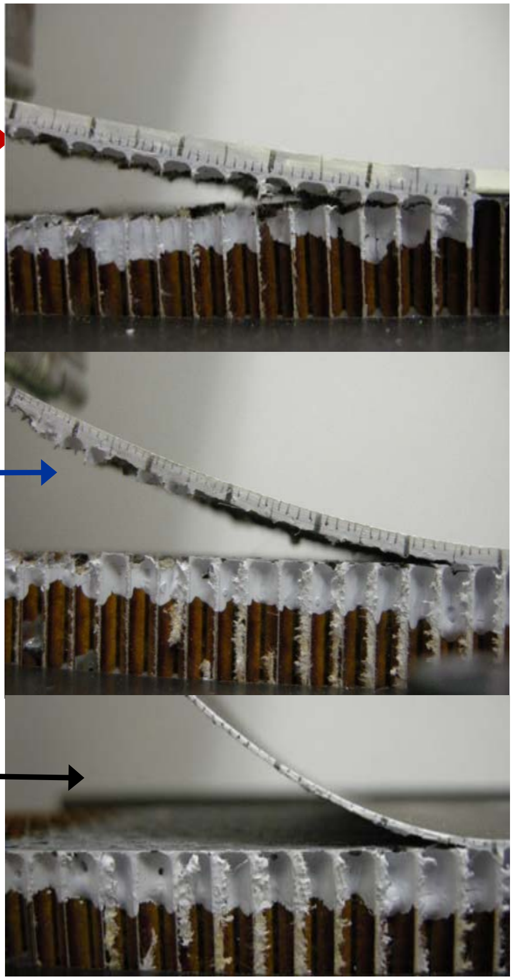
EFFECTS OF FACESHEET DOUBLER:

Different Doubler Thicknesses Produce Different G_c Values…

…and different thru-thickness fracture locations!

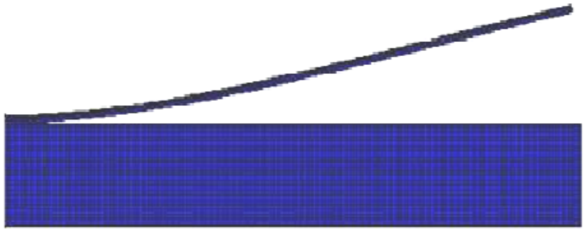


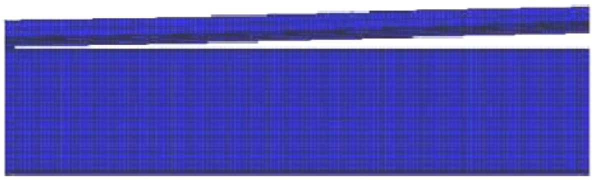


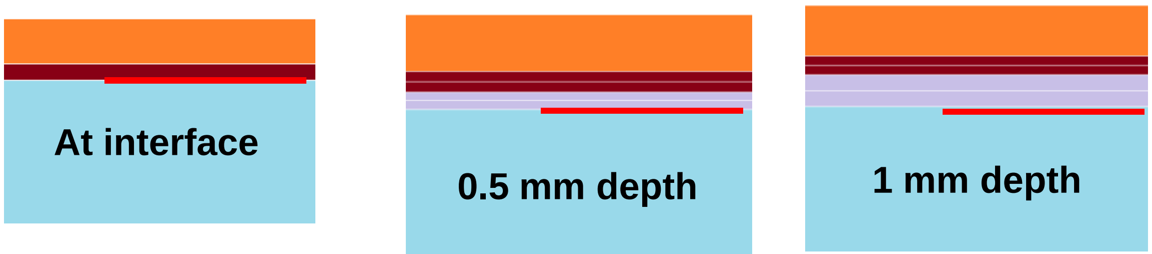
NUMERICAL INVESTIGATION

Effects of Thin Facesheets & Facesheet Doublers

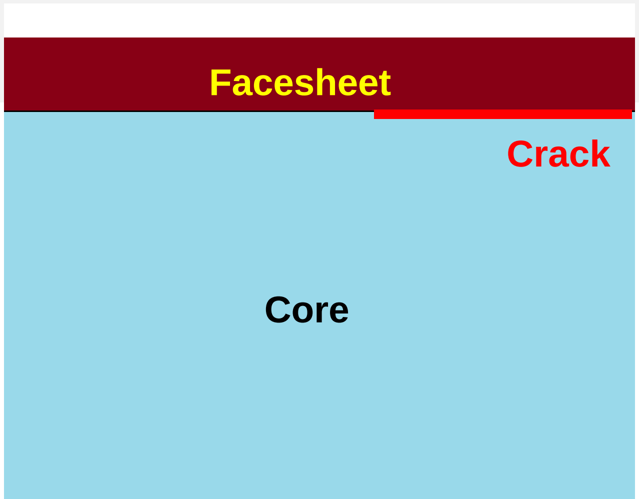
- **Load applied in each model to produce same G_T value**
  - No doubler, "thin" doubler, "thick" doubler
- **Consider crack growth at three through-the-thickness locations**
- **Investigate mode mixity (% G_I)**
- **Investigate orientation of max. principal stress for expected crack growth direction**



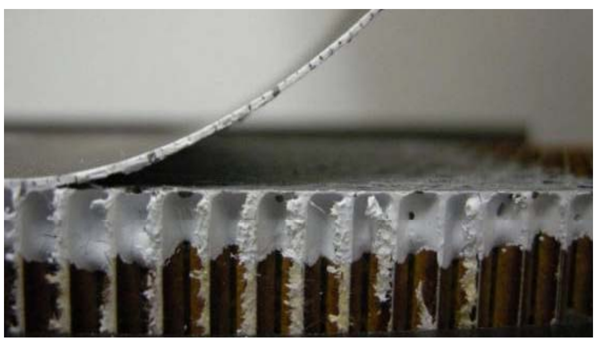


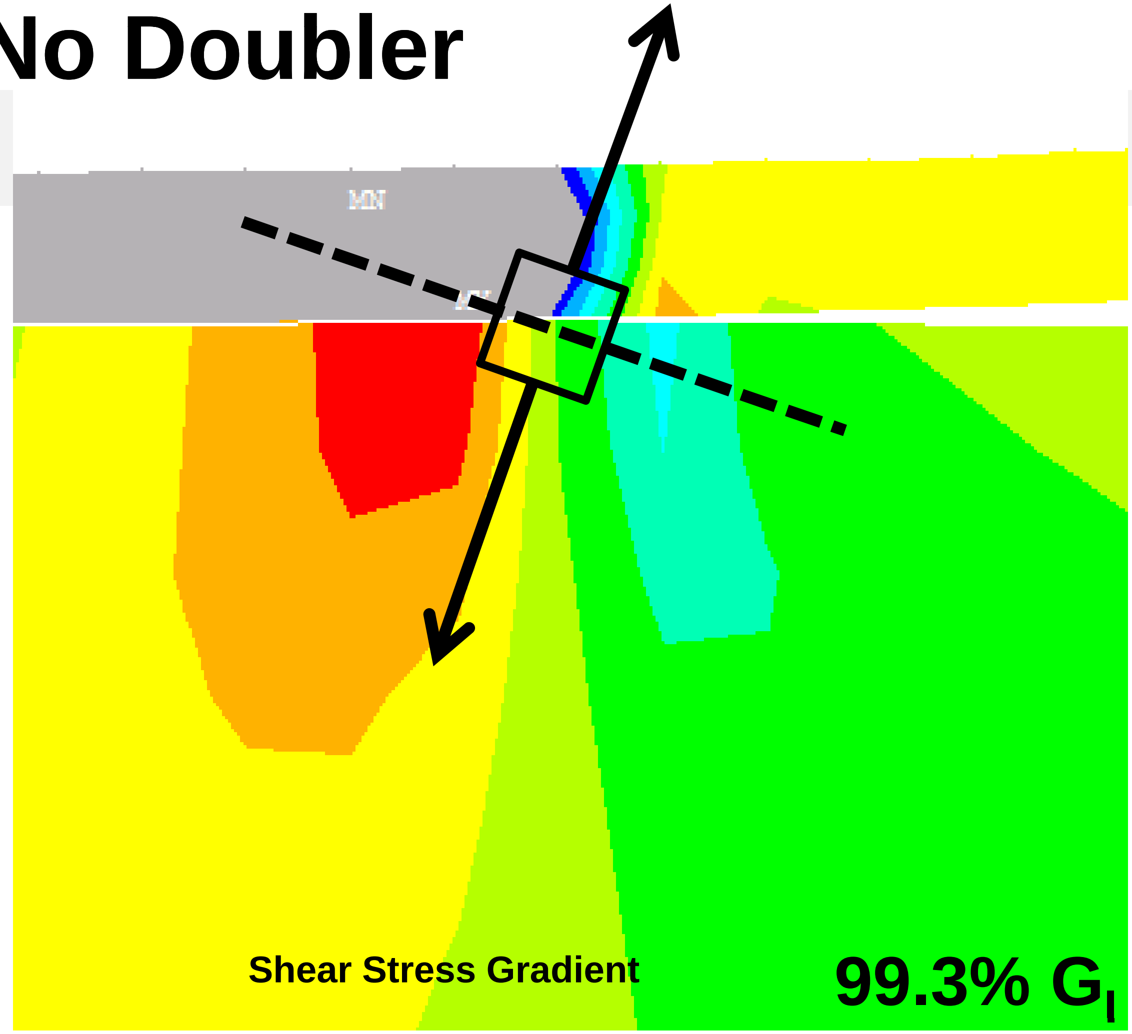


FACESHEET DOUBLER EFFECTS:
No Doubler

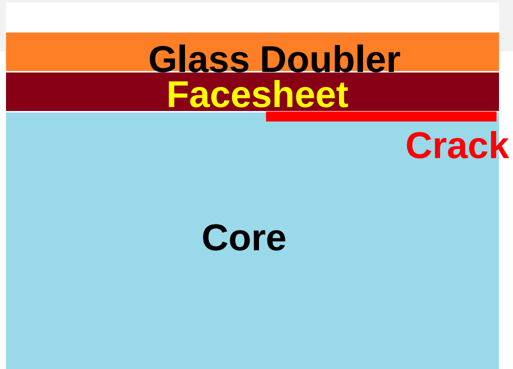


Crack at interface

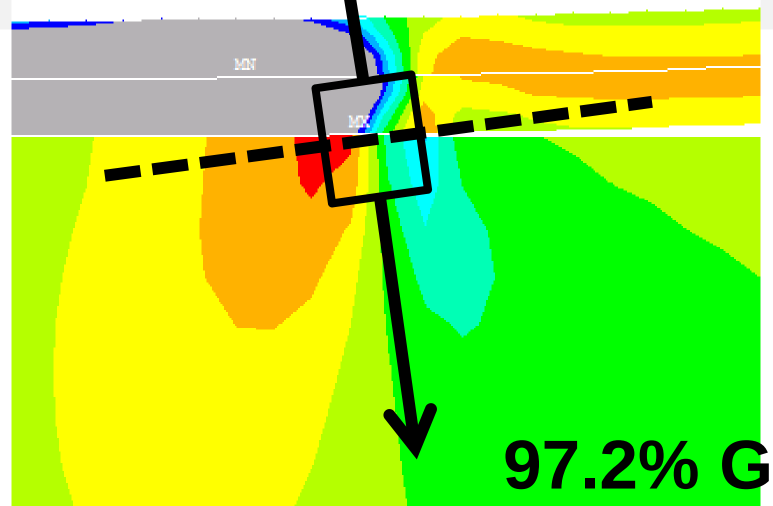


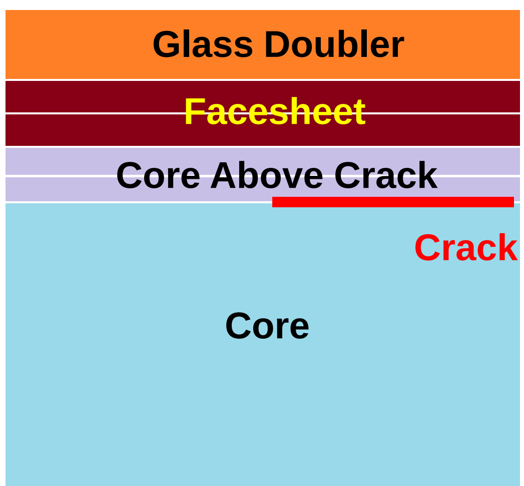


FACESHEET DOUBLER EFFECTS:
Thin Doubler

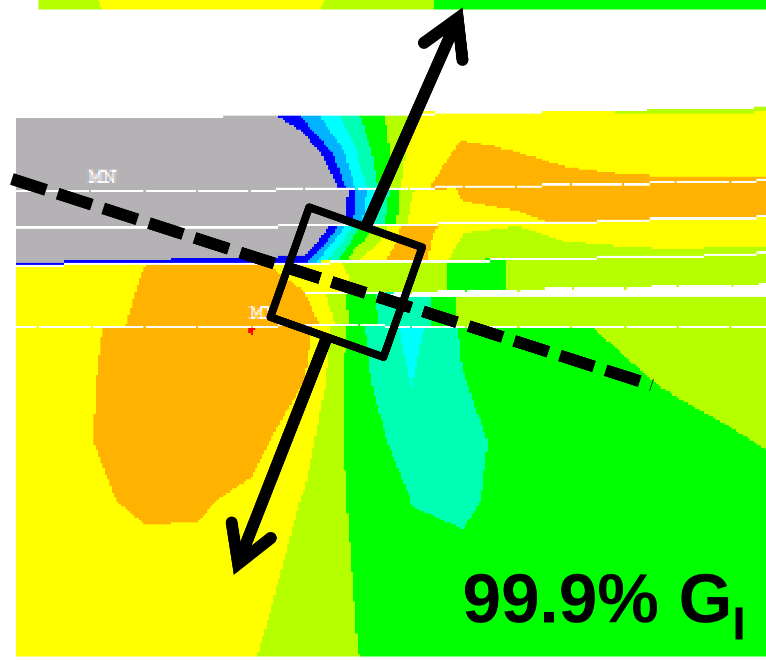


At interface

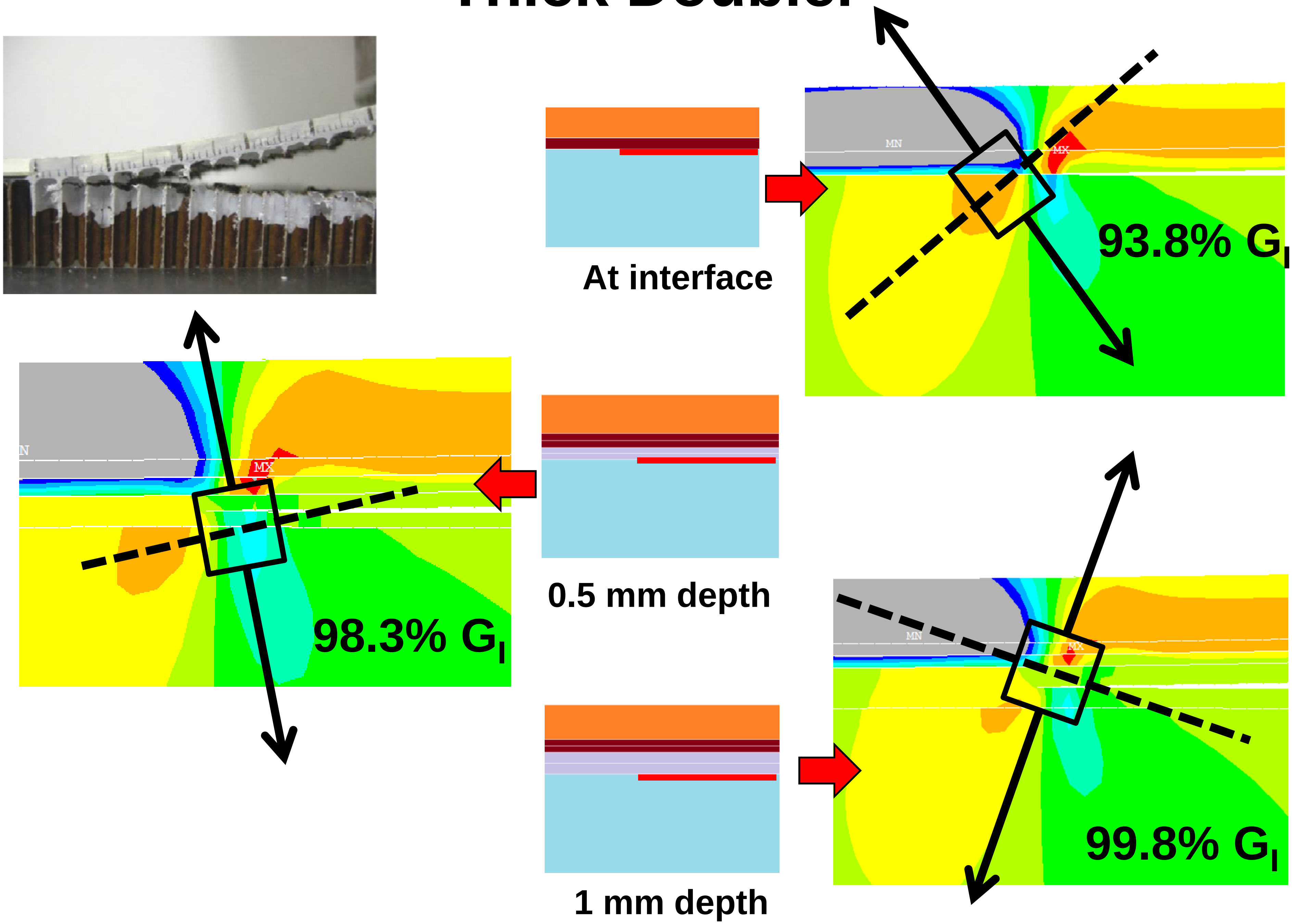




0.5 mm depth

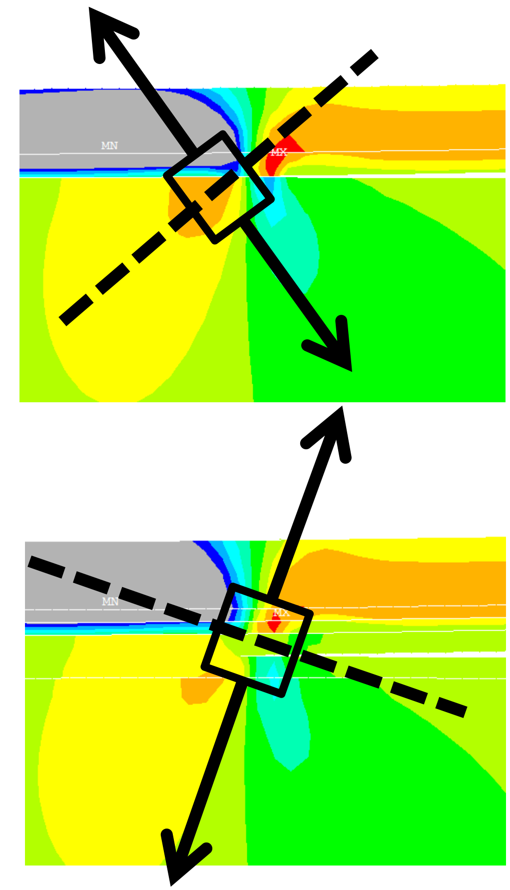


FACESHEET DOUBLER EFFECTS:
Thick Doubler



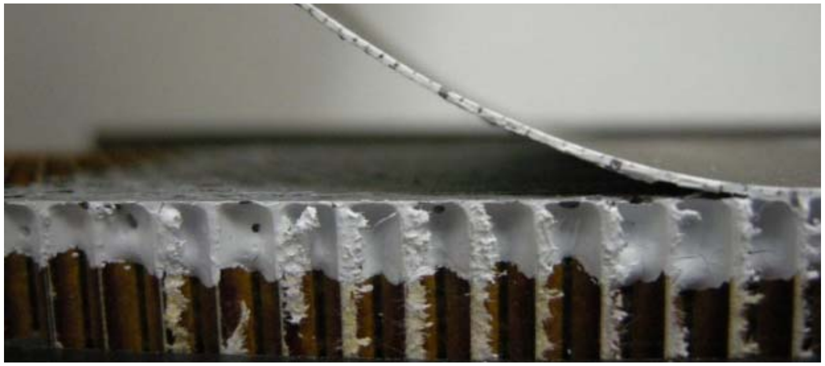
SUMMARY OF FINDINGS:
Numerical Investigation

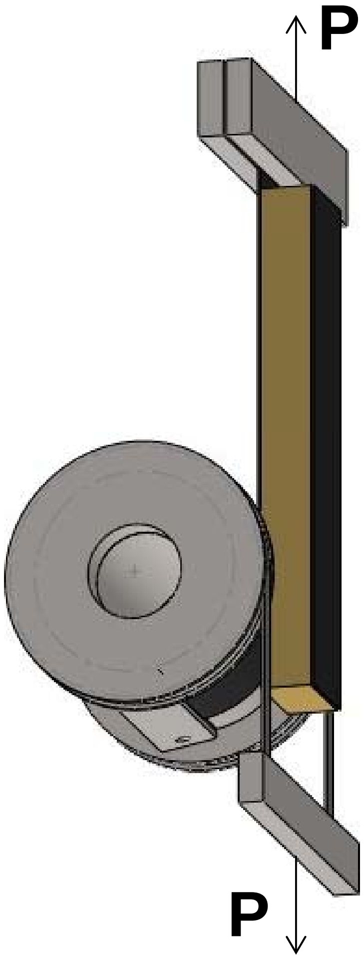
- **SCB test appears to be Mode I dominant for all cases considered**
- **Mode II component produced by shear stresses in vicinity of crack tip**
- **Sign of shear stresses change as a function of:**
  - **Thickness of facesheet**
  - **Crack location in core**
- **Crack predicted to propagate closer 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



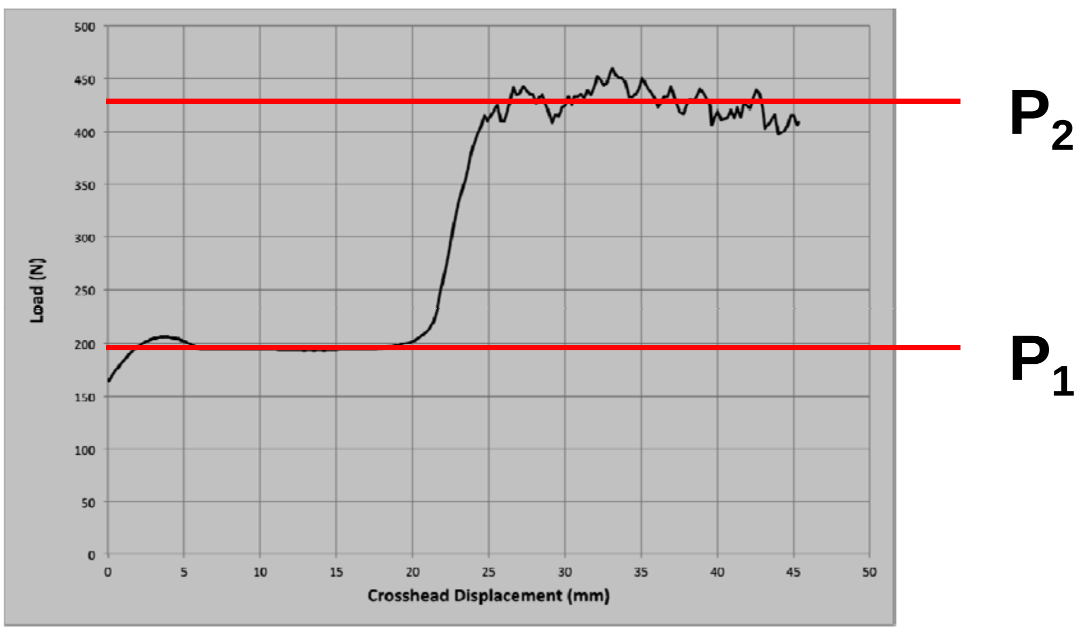


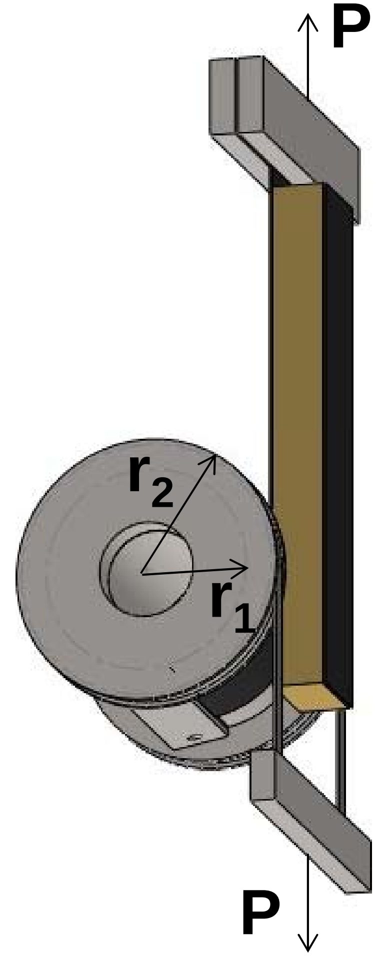
DETERMINATION OF ENERGY RELEASE RATE, G_C: Climbing Drum Peel (CDP) Test

Energy Release Rate, G_{IC}:

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

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





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A.T. Nettles, E.D. Gregory and J.R. Jackson, "Using the Climbing Drum Peel (CDP) Test to Obtain a GIC Value for Core/Face Sheet Bond," *Journal of Composite Materials,* Vol 41, 2007.

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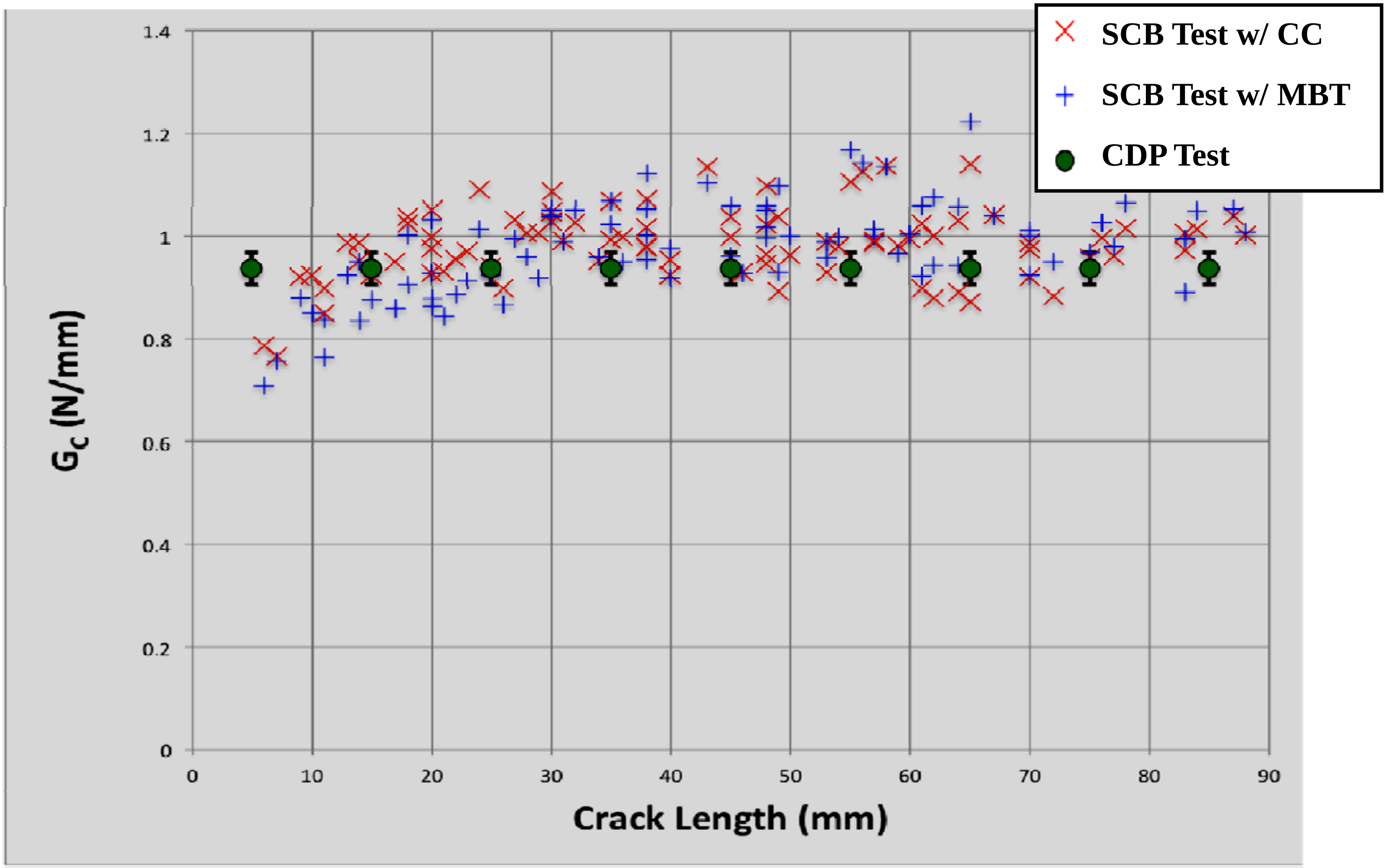
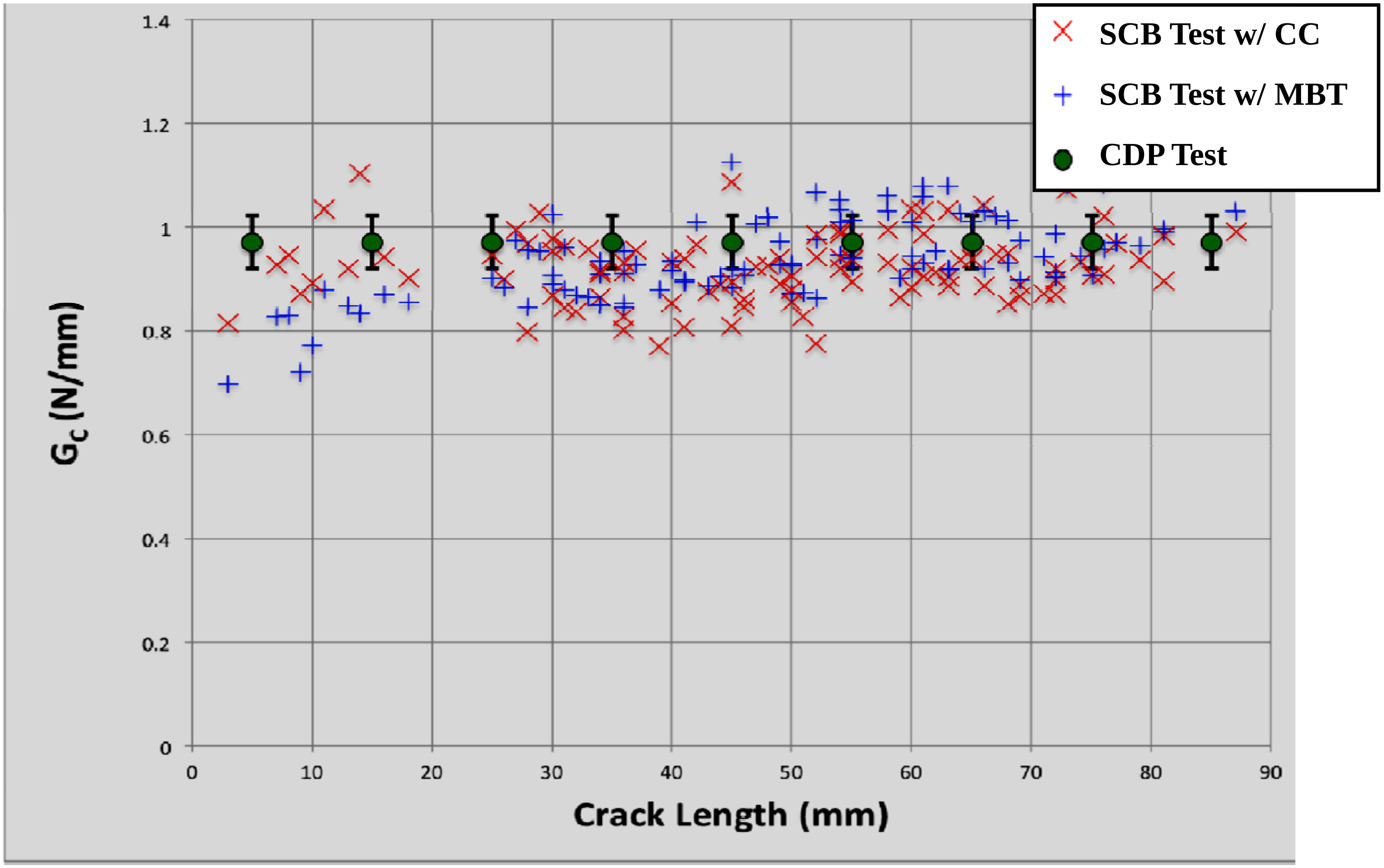
Single Cantilever Beam (SCB) Versus Climbing Drum Peel (CDP)

9 Ply ("Thick") Facesheet



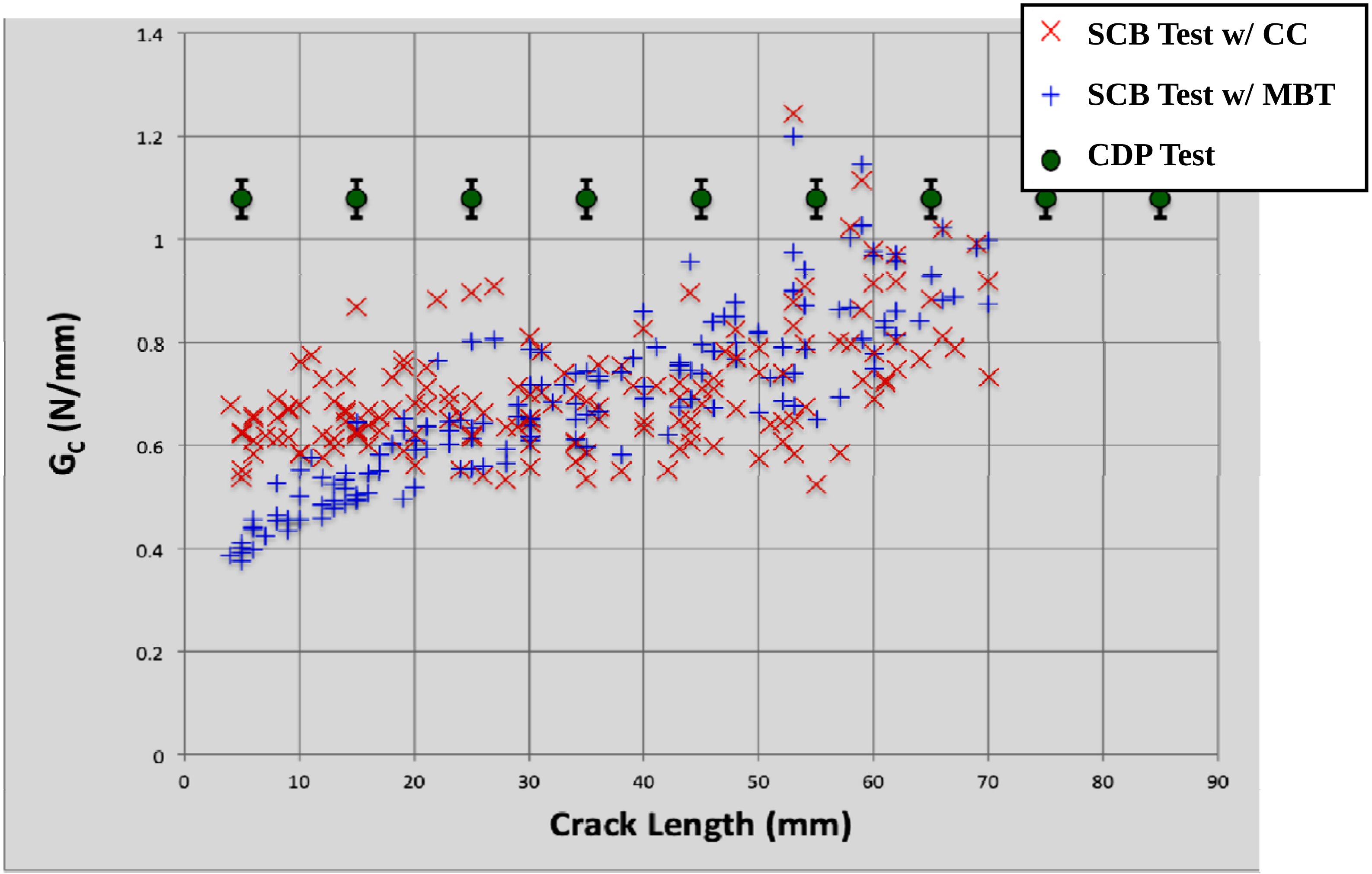
Single Cantilever Beam (SCB) Versus Climbing Drum Peel (CDP)

6 Ply ("Medium") Facesheet



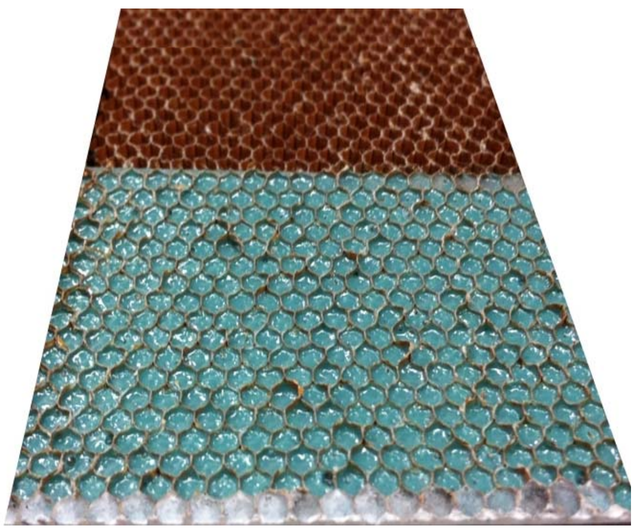
Single Cantilever Beam (SCB) Versus Climbing Drum Peel (CDP)

3 Ply ("Thin") Facesheet

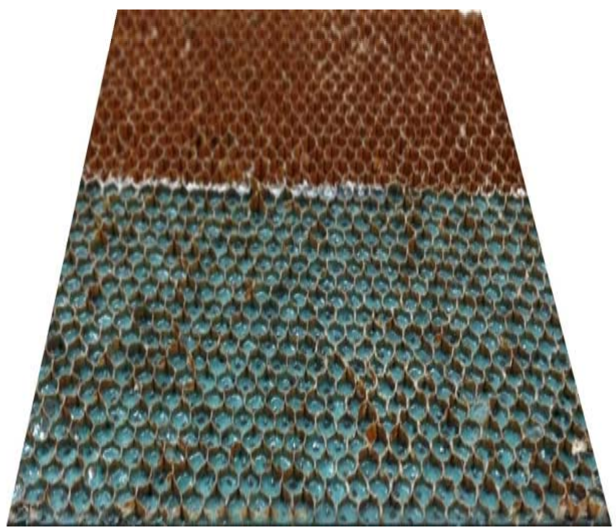


Effect of Facesheet Thickness:
Single Cantilever Beam (SCB) Specimens

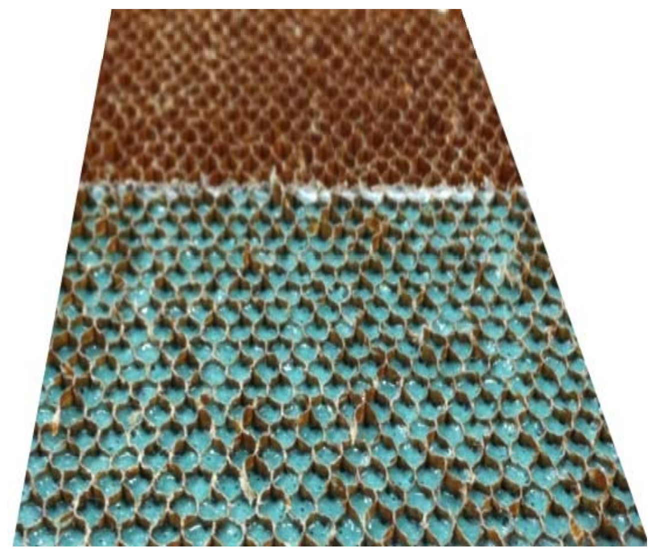
3 Ply Facesheet

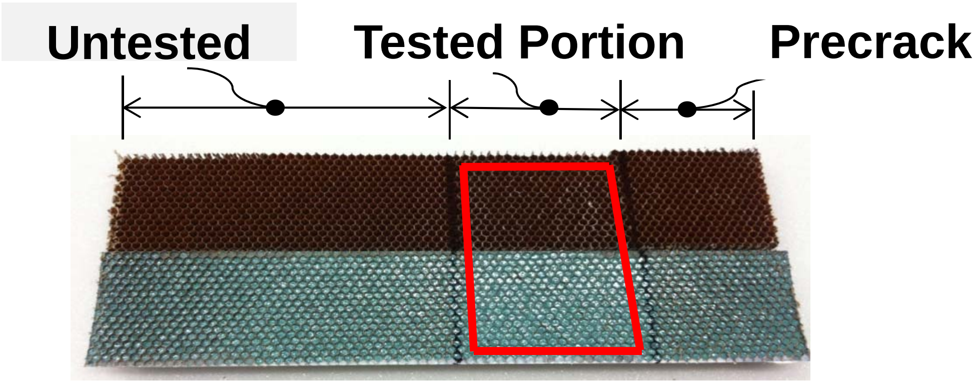


6 Ply Facesheet



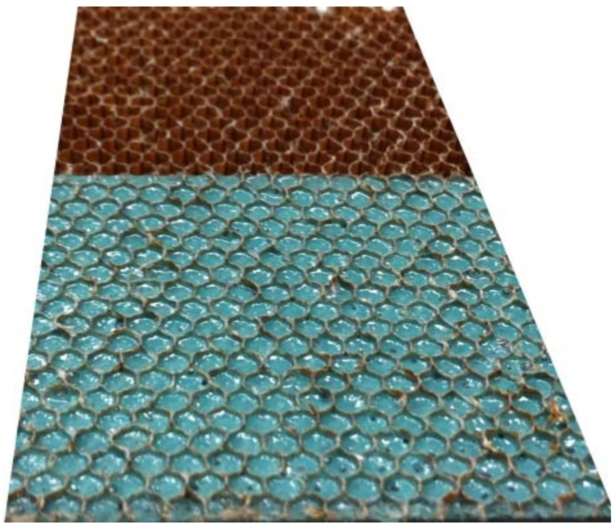
9 Ply Facesheet



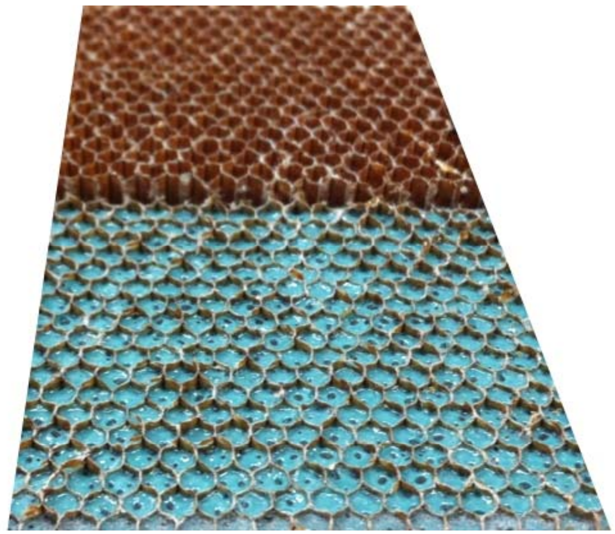


Effect of Facesheet Thickness: Climbing Drum Peel (CDP) Specimens

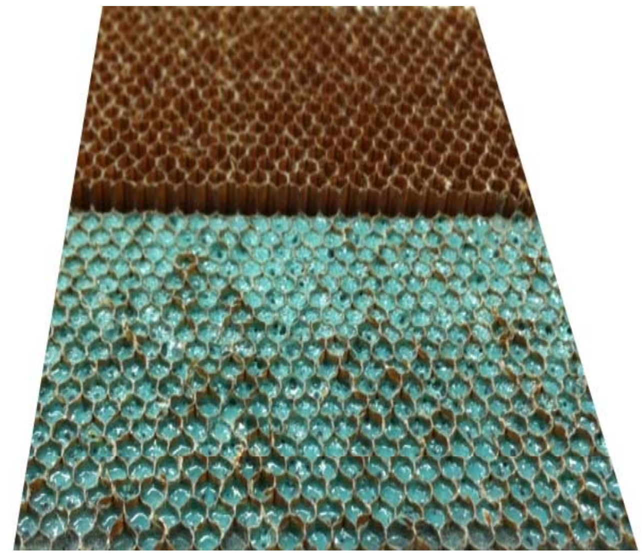
3 Ply Facesheet

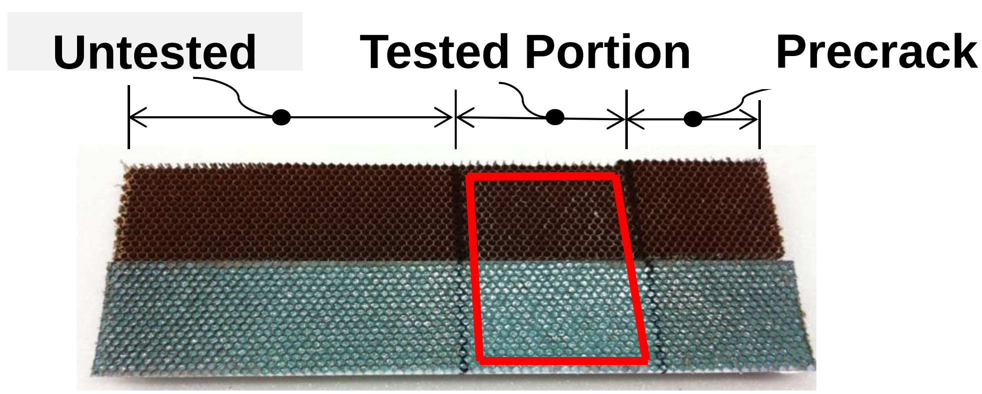


6 Ply Facesheet



9 Ply Facesheet



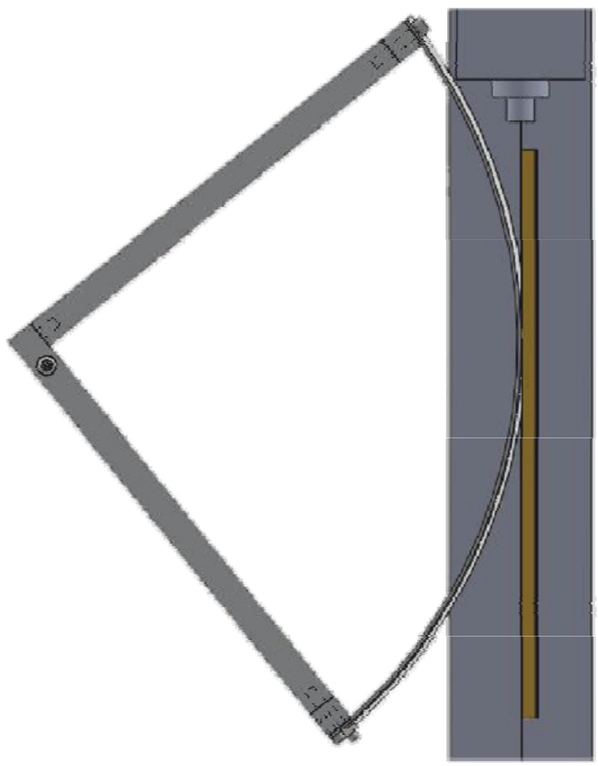


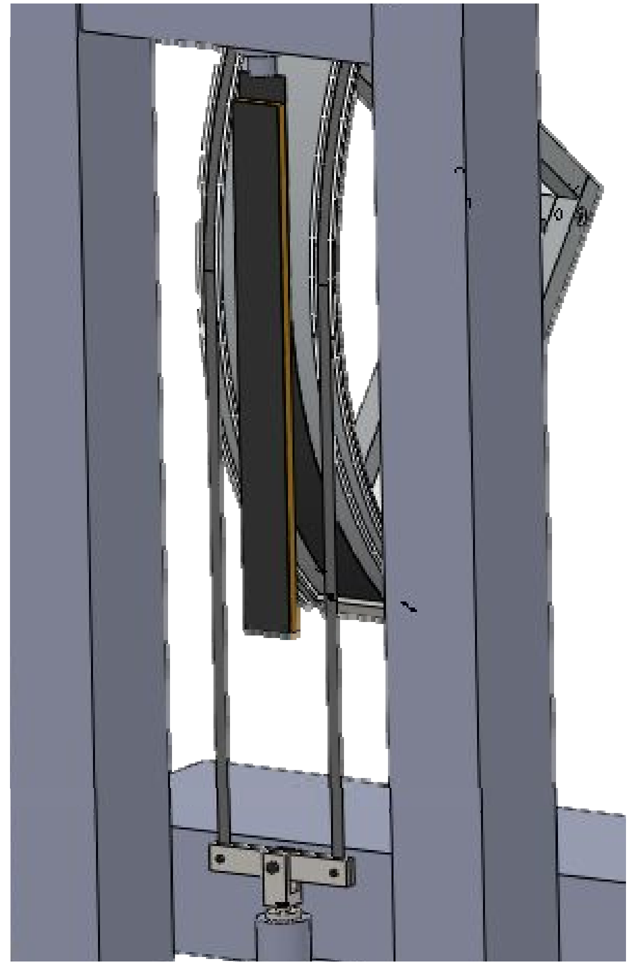
SUMMARY OF PRELIMINARY FINDINGS: Climbing Drum Peel Testing

- 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

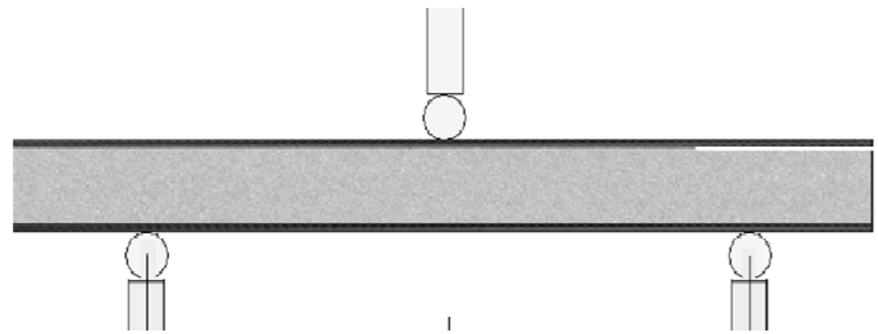
CURRENT FOCUS:
Effects of Facesheet Curvature on Apparent G_c

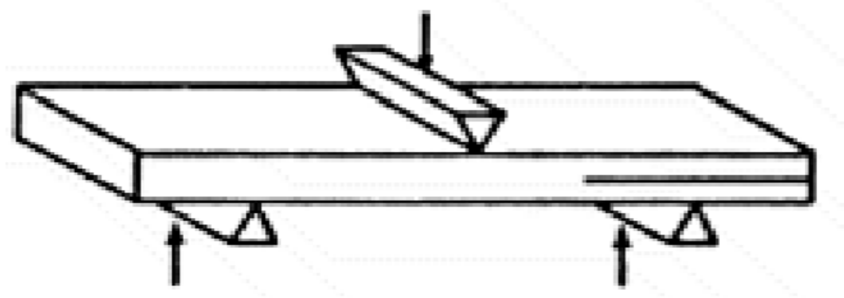
Preliminary design of a large radius Climbing Drum Peel fixture



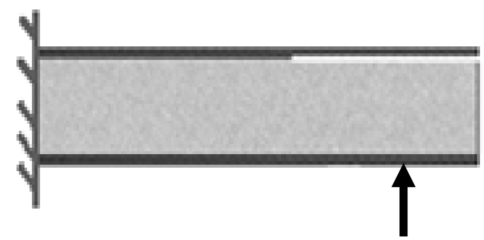


MODE II TEST CONFIGURATION:
Edge-Notched Sandwich Configurations





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



Sandwich Composites:
End Notch Cantilever (ENC)

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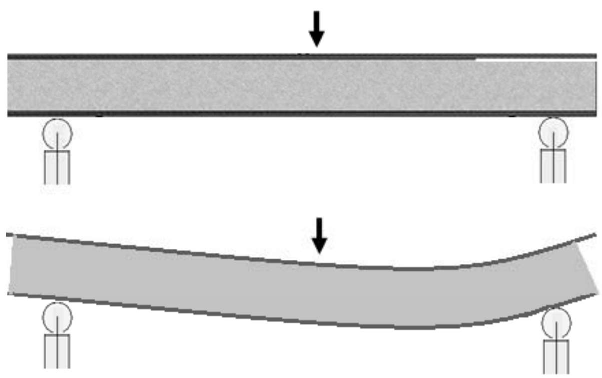
MODE II END NOTCHED CANTILEVER TEST:
Symmetrical Bending Version of 3-ENF

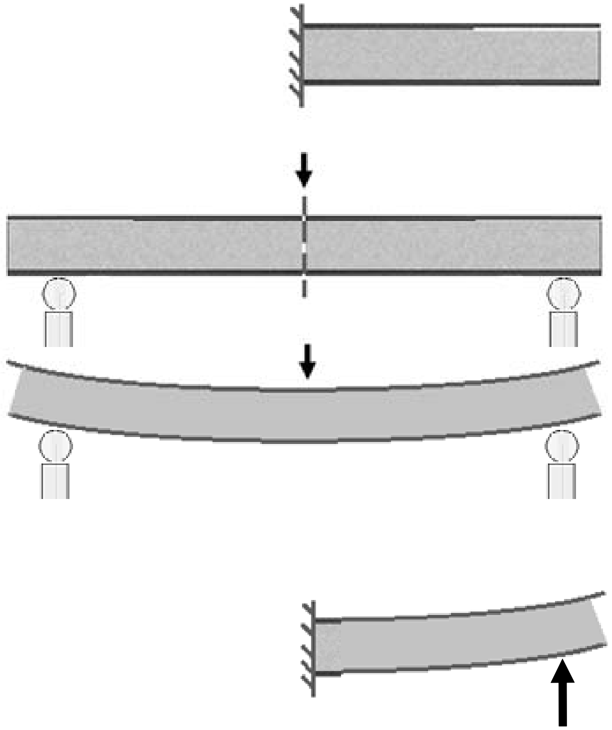
End Notched Flexure

(Unsymmetric bending)



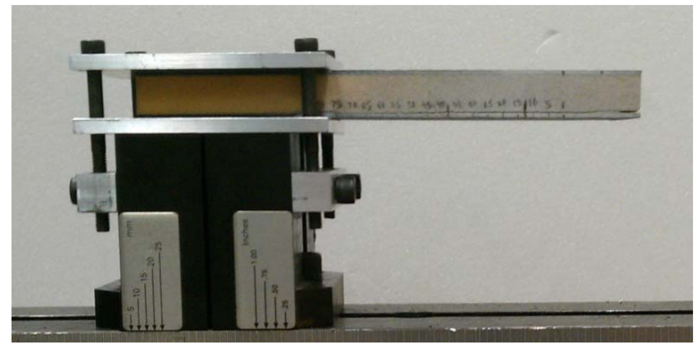
End Notched Cantilever

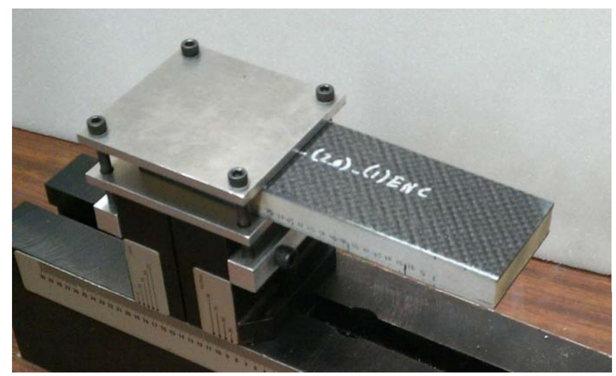
(Symmetric bending)



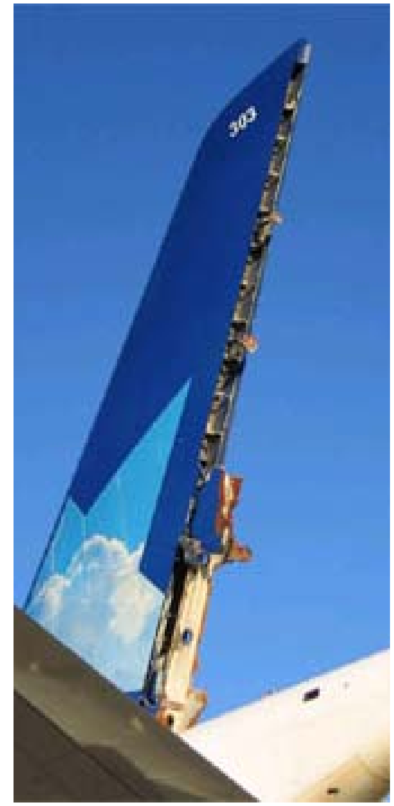
PROPOSED MODE II CONFIGURATION
End Notched Cantilever (ENC) Test

- **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