Investigation of Facesheet/Core Disbonding in Composite Sandwich Panels Using the Single Cantilever Beam Test Method

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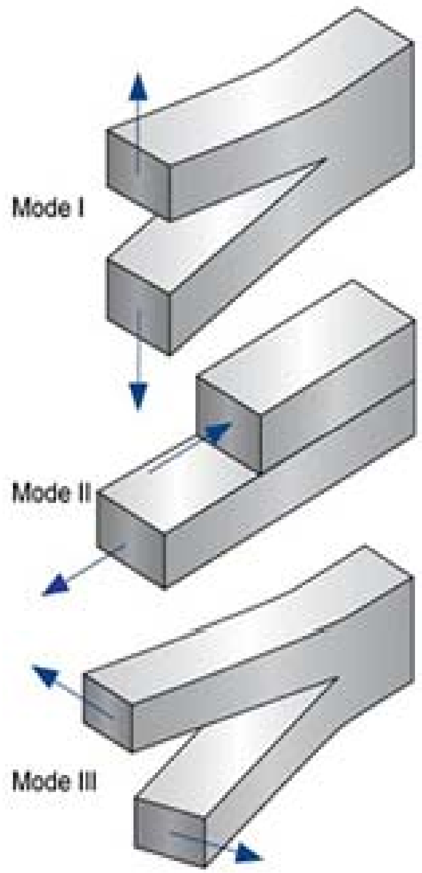
RESEARCH OBJECTIVES:

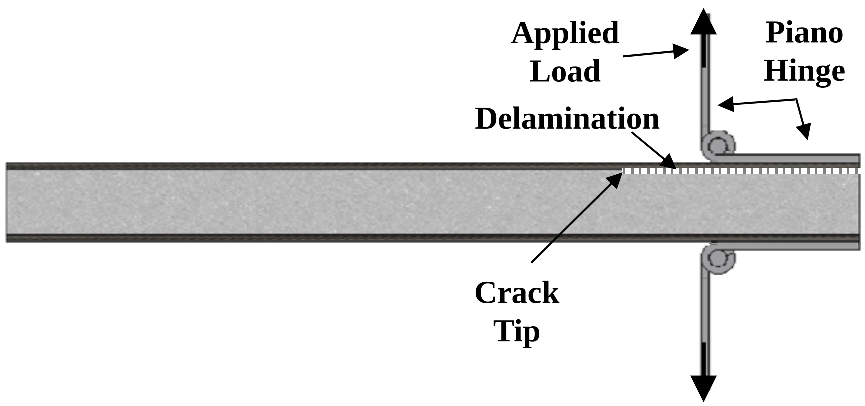
Fracture Mechanics Test Methods for Sandwich Composites

- **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**

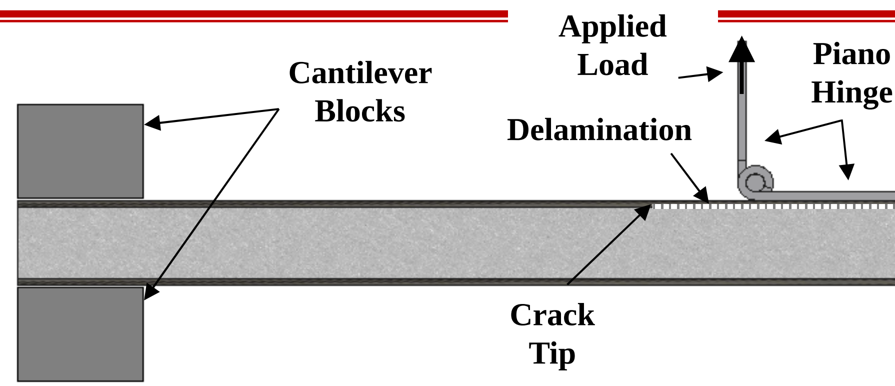


MODE I TEST CONFIGURATION:

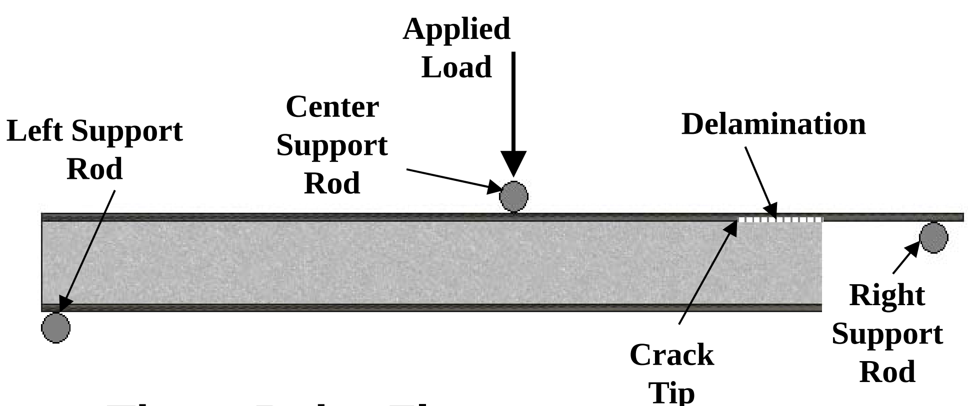
Candidate Configurations Investigated



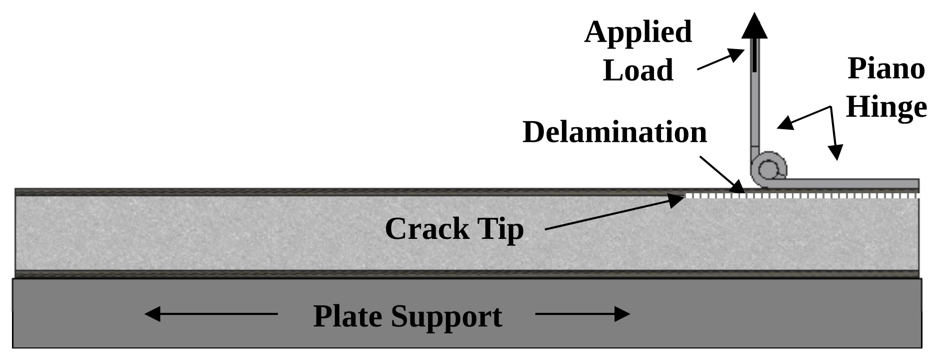
Double Cantilever Beam (DCB)



Clamped Double Cantilever Beam (DCB)



Three-Point Flexure



Single Cantilever Beam (SCB)

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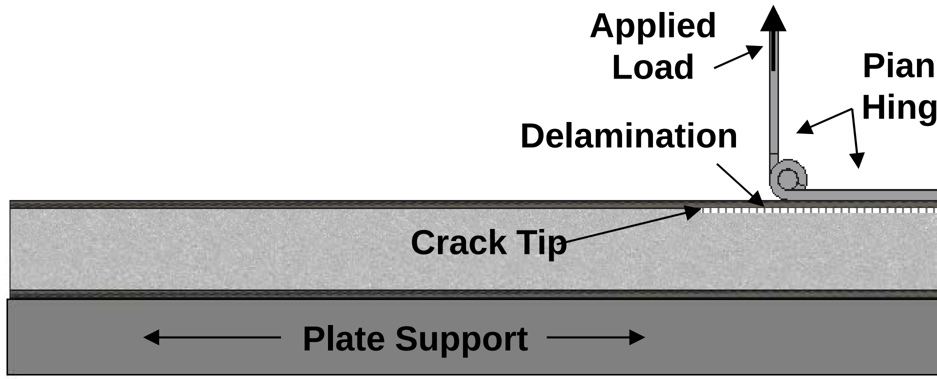
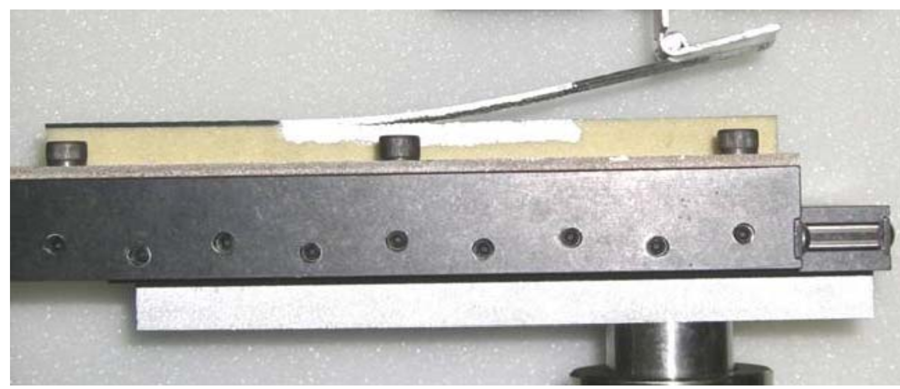
MODE I TEST CONFIGURATION:

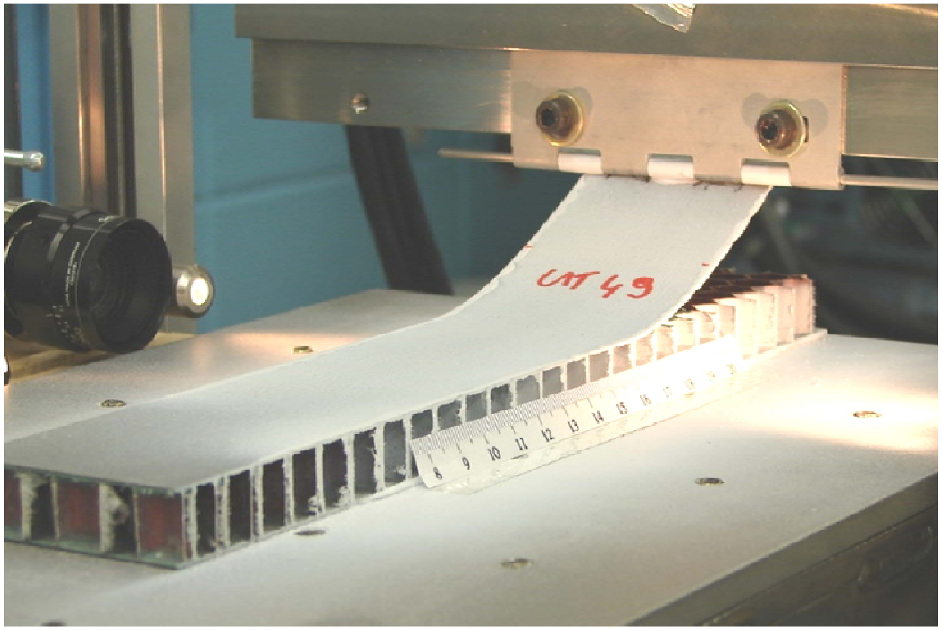
Single Cantilever Beam (SCB)

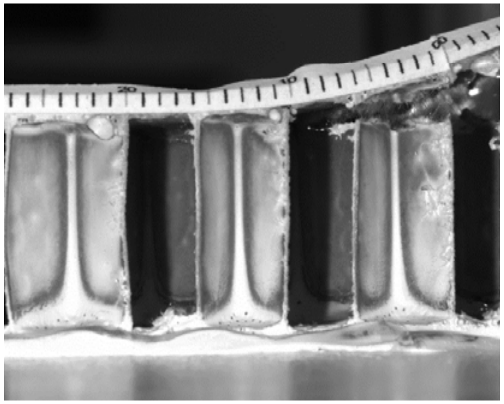
- **Elimination of bending of sandwich specimen**
- **Minimal crack "kinking" observed**
- **Mode I dominant - independent of crack length**
- ***Appears to be suitable for standardization***



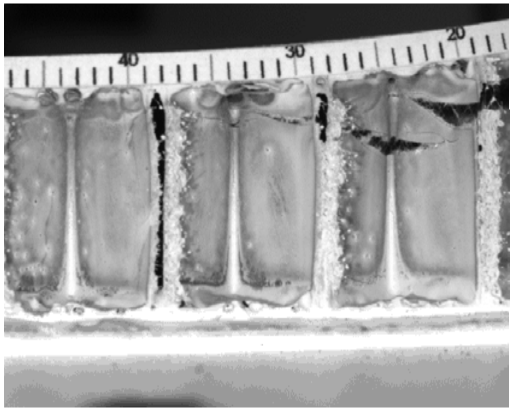


Single Cantilever Beam (SCB) Testing:
NASA Langley Research Center





Crack propagation near facesheet/core interface



Crack propagation within core

Martin Rinker, James G. Ratcliffe, Daniel O. Adams, Ronald Krueger, "Characterizing Facesheet/Core Disbonding in Honeycomb Core Sandwich Structure," NASA/CR-2013-217959, February, 2013

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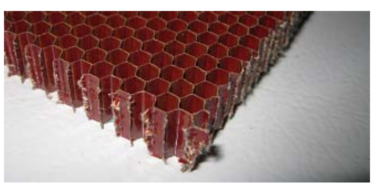
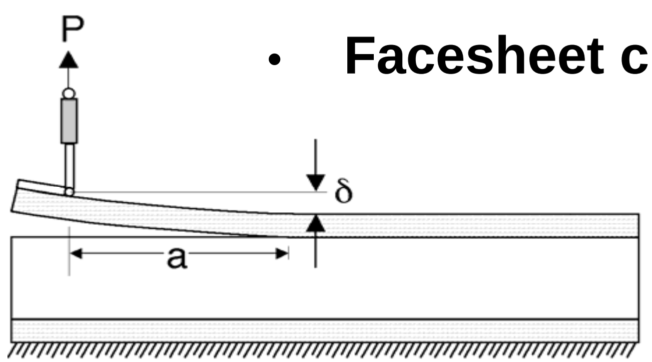
PARAMETERS INVESTIGATED:

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





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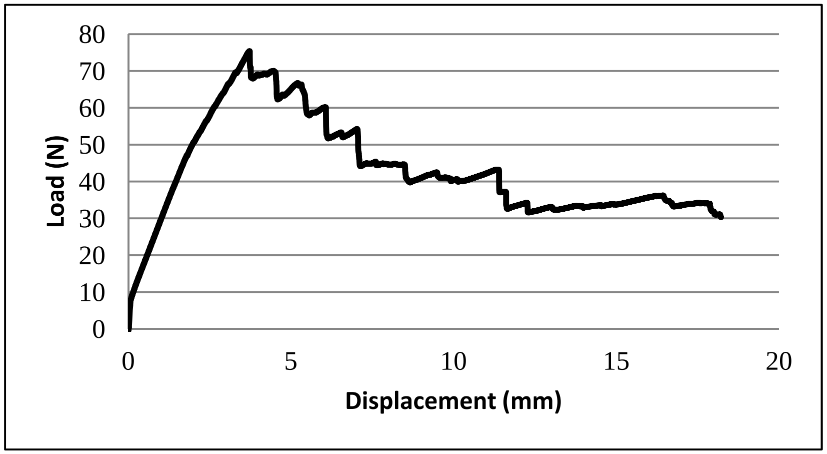
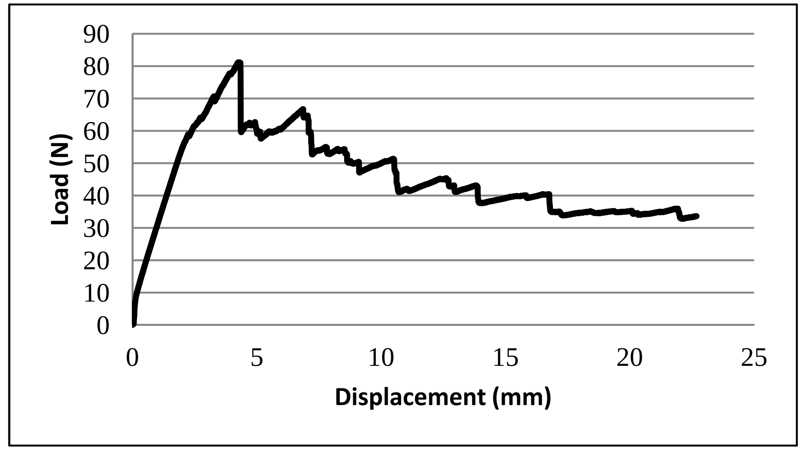
Example SCB Test Results:

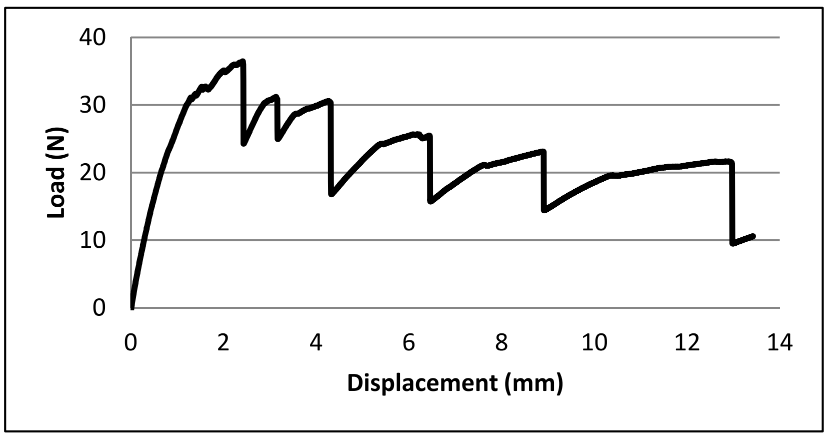
Stable/"Semi-Stable" Crack Growth For Common Core Materials



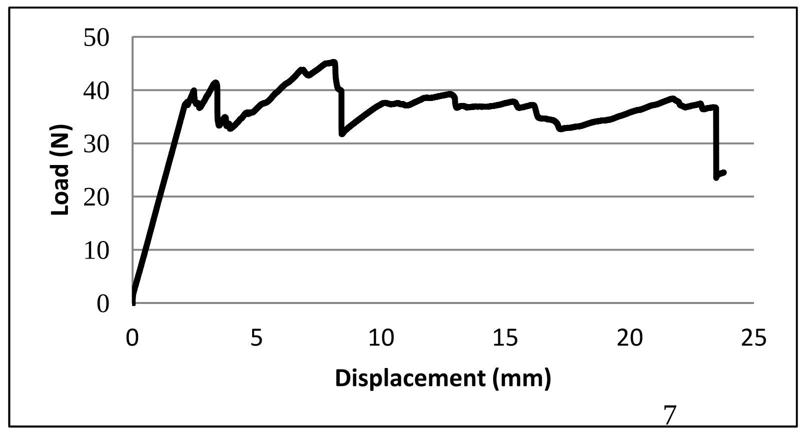
Nomex Honeycomb



Aluminum Honeycomb



Polyurethane Foam



End-Grain Balsa Wood

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SCB Testing of Airbus Rudder Specimens

- 18 specimens provided to University of Utah
  - Both “L” and “W” core orientations
  - Both with and without 4 mm thick aluminum doublers
- Testing performed with four facesheet conditions
  - No doubler (supplied)
  - 1.5 mm glass/epoxy
  - 2.4 mm glass/epoxy
  - 4.1 mm glass/epoxy
  - 4 mm aluminum (supplied)

“L” - honeycomb running continuous across length

“W” - honeycomb running continuous across width

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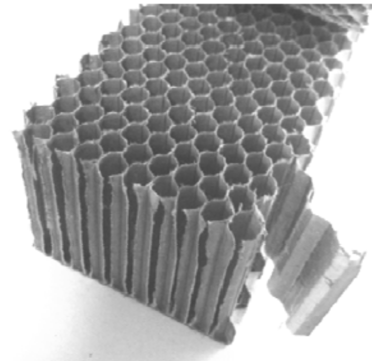
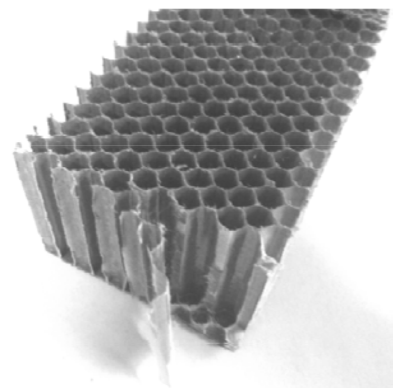
SCB Testing of Airbus Rudder Specimens:
Effects of Core Orientation

Doubler Thickness (mm)/Material	Core Orientation	Ave. G_c (J/m^2)
4.0/Alum.	W	616
4.0/Alum.	L	557
2.4/Gl/Ep	W	647
2.4/Gl/Ep	L	490
1.5/Gl/Ep	W	539
1.5/Gl/Ep	L	468
None	W	322
None	W	376
None	W	375
None	L	363
None	L	353



"L" - honeycomb running continuous across length



"W" - honeycomb running continuous across width

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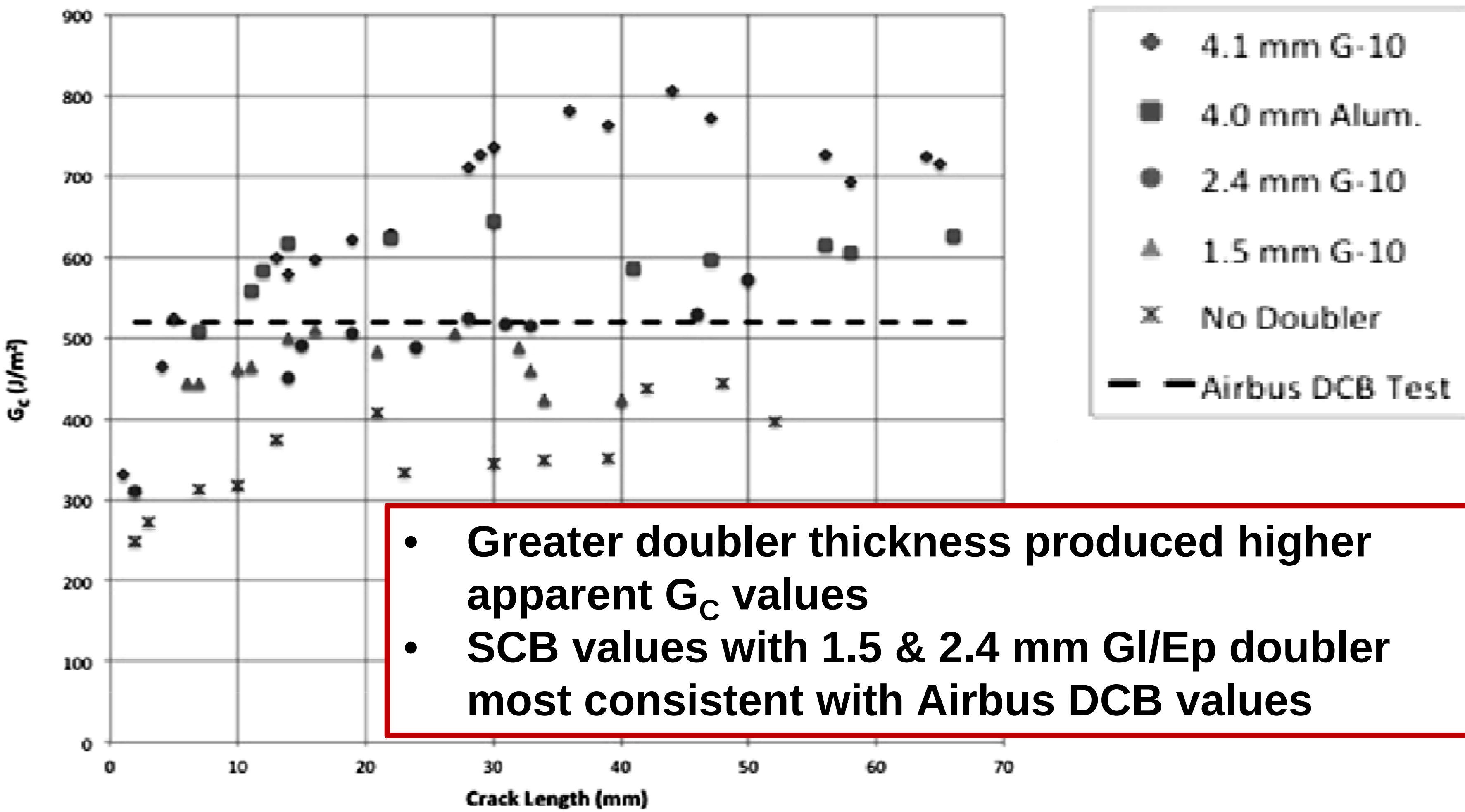
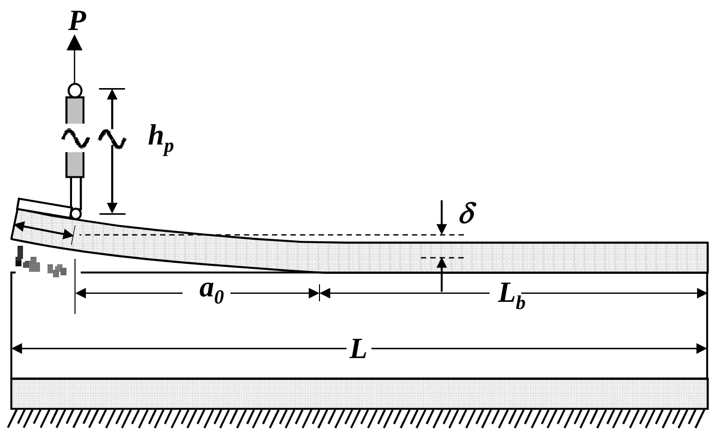
SCB Testing of Airbus Rudder Specimens: Effect of Facesheet Doubler



- Greater doubler thickness produced higher apparent G_C values
- SCB values with 1.5 & 2.4 mm Gl/Ep doubler most consistent with Airbus DCB values

SCB SPECIMEN SIZING:
Determining Suitable Specimen Dimensions



Ratcliffe, J. G, and Reeder, J. R., 2011. "Sizing a Single Cantilever Beam Specimen for Characterizing Facesheet/Core Debonding in Sandwich Structure," *Journal of Composite Materials*, 45(25): 2669-2698.

SCB Dimension	Limitation
Width, b	25mm or 6 honeycomb cells
$L_{b,min}$	$L_{b,min} \geq 2.7\left[\frac{t_c t_f^3 E_f}{3E_c}\right]^{\frac{1}{4}}$
a_0 (bending)	$a_0 \geq \sqrt{\frac{30E_f t_f^2}{G_{xz,f}}} - 0.59L_{b,min}$
a_0 (compliance)	$a_0 \geq L_{b,min}$
t_f (small disps)	$t_f \geq \left[\frac{a_{max}}{\left(\frac{3a_{max}^2 E_f}{200G_c}\right)^{\frac{1}{4}} - \left(\frac{t_c E_f}{3E_c}\right)^{\frac{1}{4}}}\right]^{\frac{4}{3}}$
t_f (strength)	$t_f \geq \frac{6E_f G_c a_{max}^2}{\sigma_c^2}\left[a_{max} + \left(\frac{t_c \left(t_f^{smalldisp}\right)^3 E_f}{3E_C}\right)^{\frac{1}{4}}\right]^{-2}$
L_{min}	$a_0 \geq L_{hinge} + a_{max} + L_{b,min}$
$h_{p,min}$	$h_{p,min} \approx 1.062a_{max}$

PARAMETERS INVESTIGATED:
Single Cantilever Beam (SCB) Test

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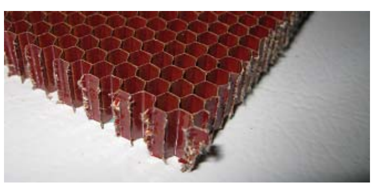

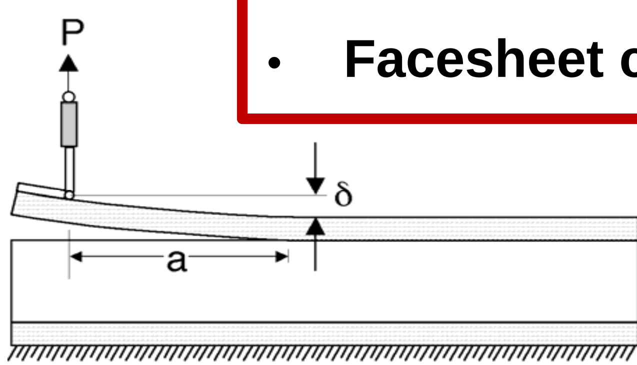

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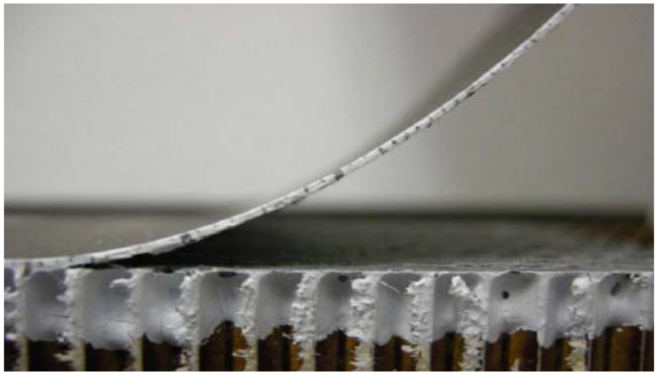
SCB TEST METHOD DEVELOPMENT:
Sandwich Configurations with Thin Facesheets

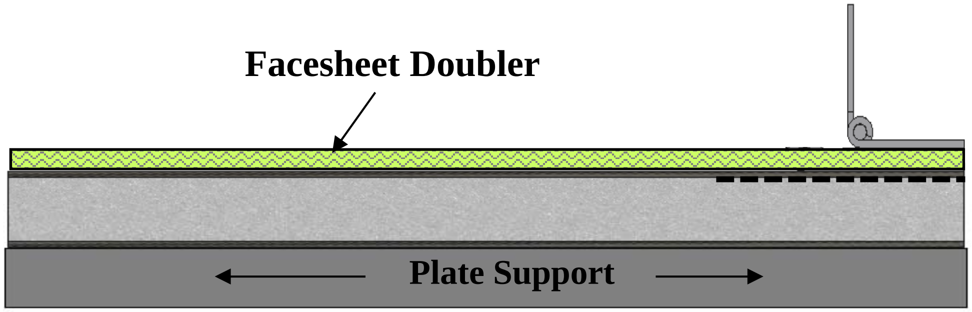
Concern: Excessive facesheet rotation

- 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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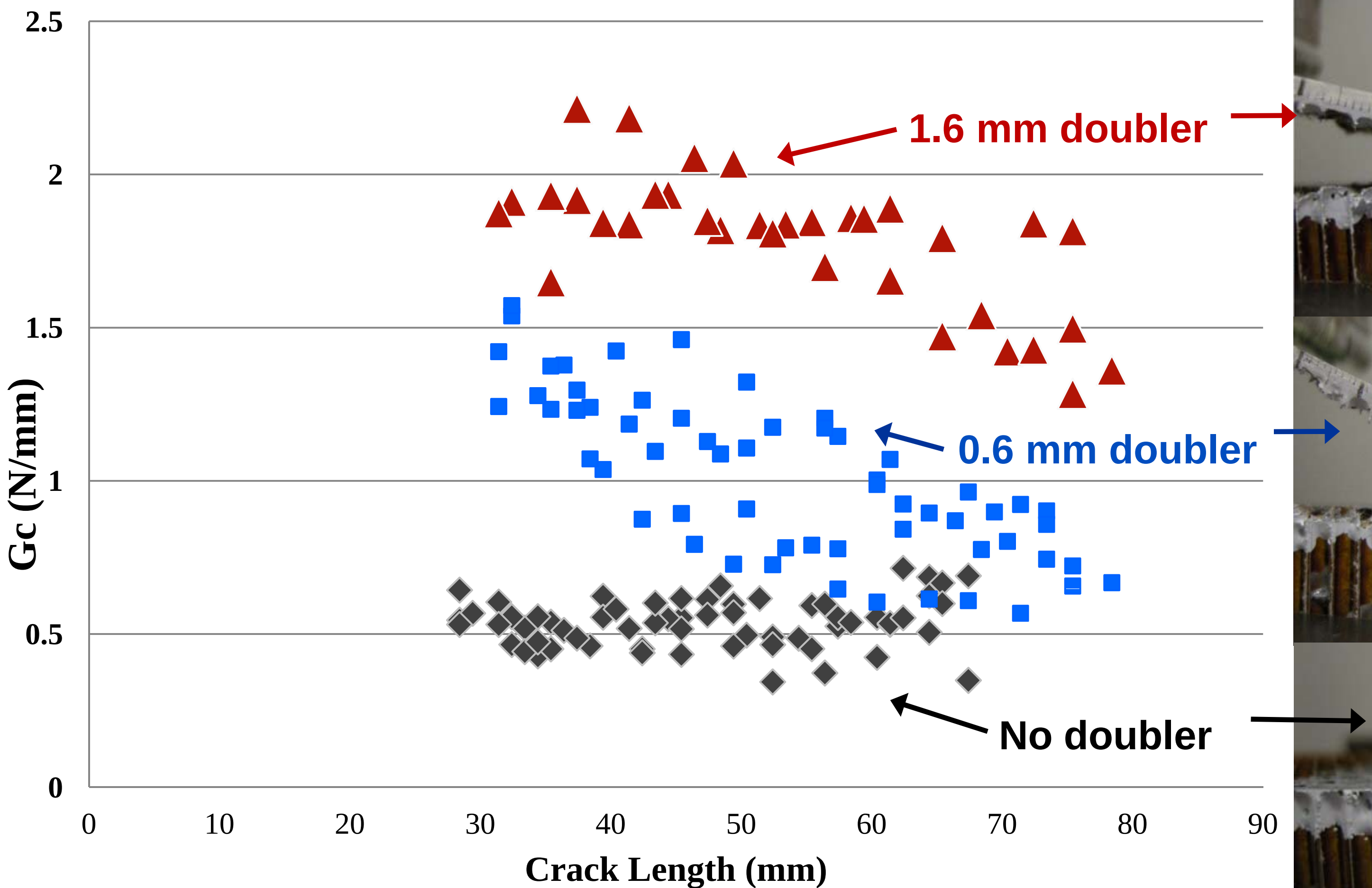
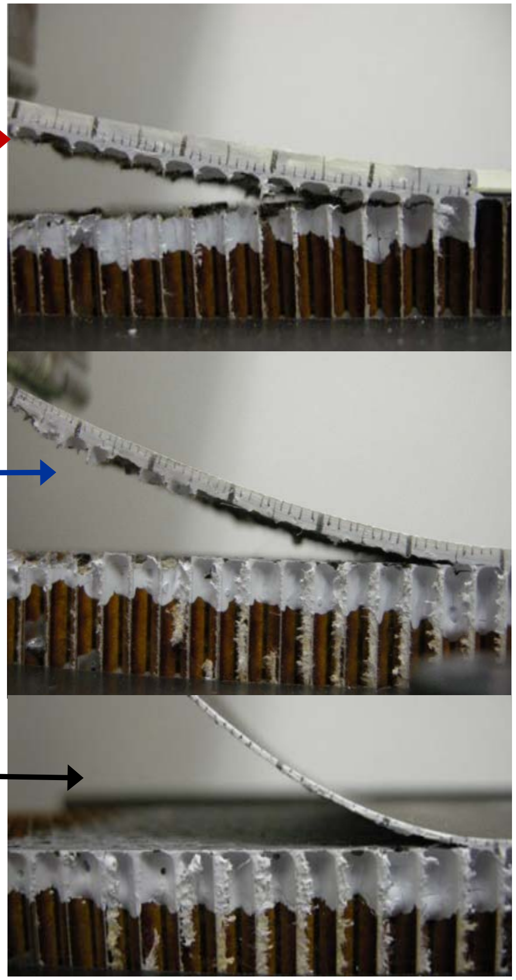
EFFECTS OF FACESHEET DOUBLER:

Results of SCB Testing With Nomex Honeycomb Core

Adding doubler changes delivered G_c values…

…and thru-thickness fracture locations!

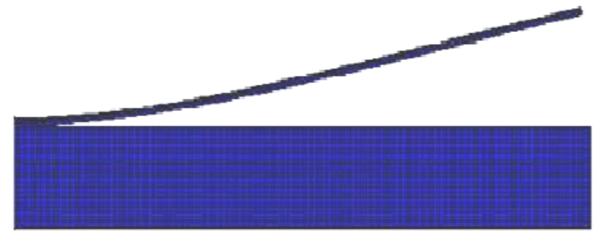


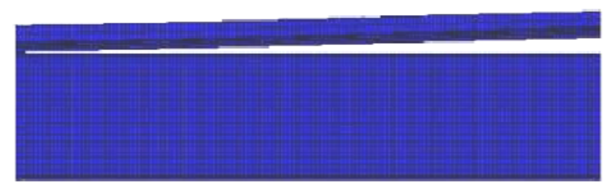


NUMERICAL INVESTIGATION

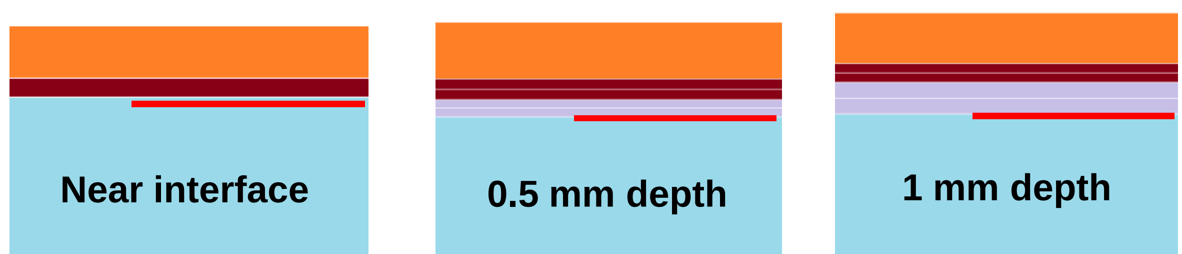
Effects of Thin Facesheets & Facesheet Doublers

- **Load applied in each model to produce same G_T value**
  - **No doubler, "thin" doubler, "thick" doubler**

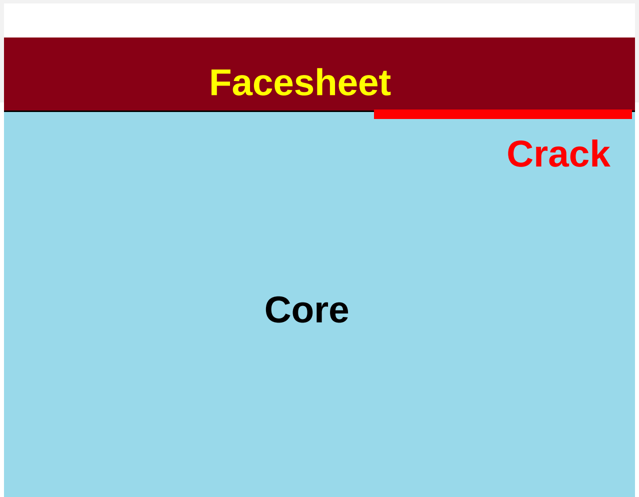




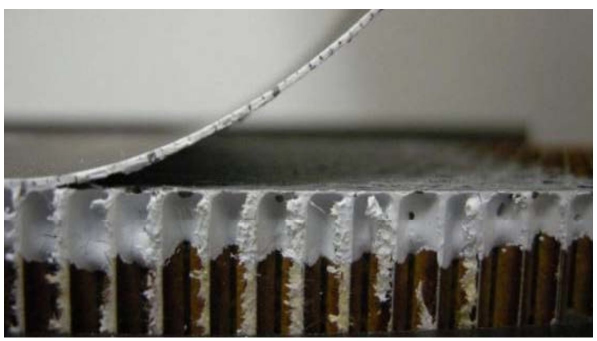
- **Considered crack growth at three through-the-thickness locations**
- **Investigate mode mixity (% G_I)**
- **Investigate orientation of max. principal stress for expected crack growth direction**

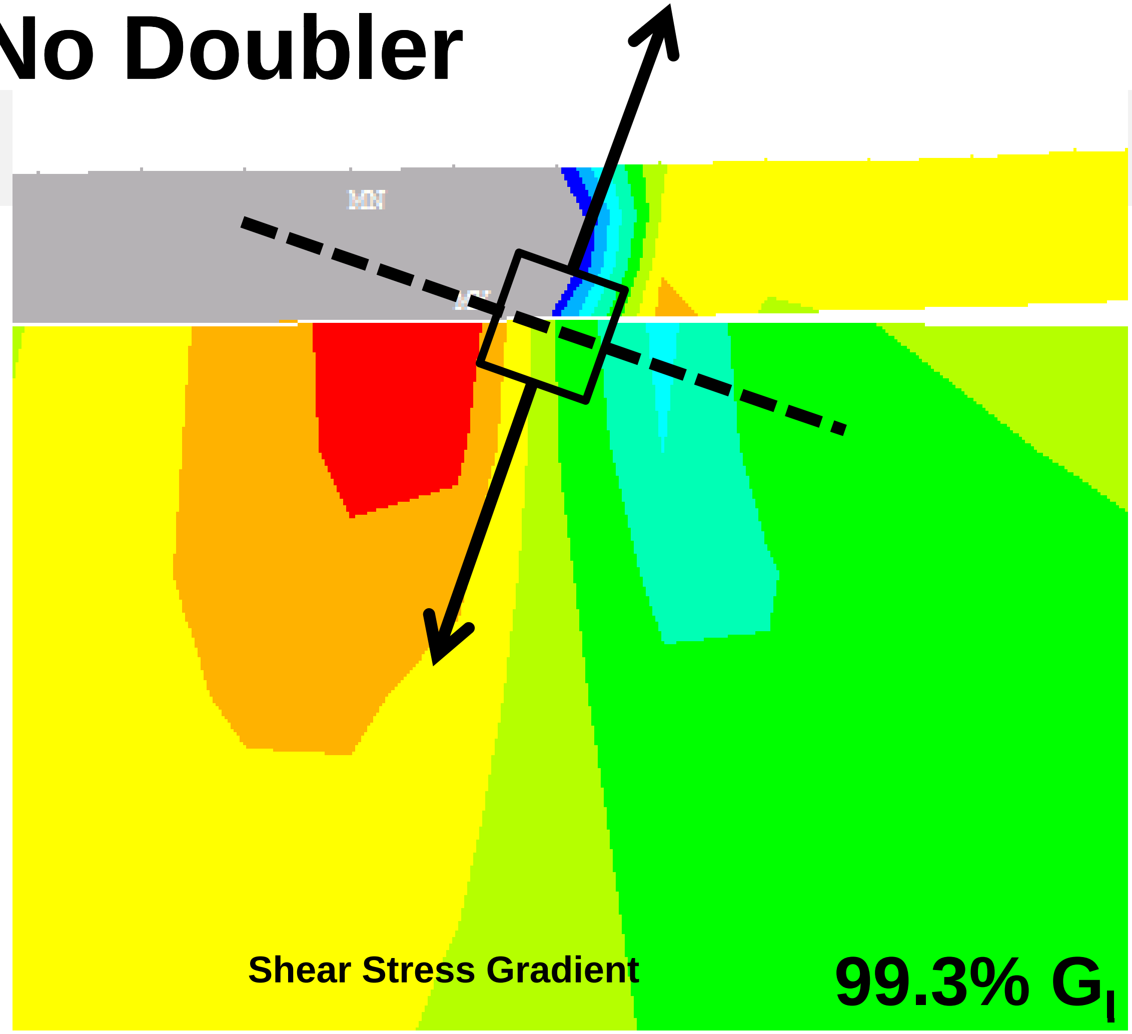


FACESHEET DOUBLER EFFECTS:
No Doubler

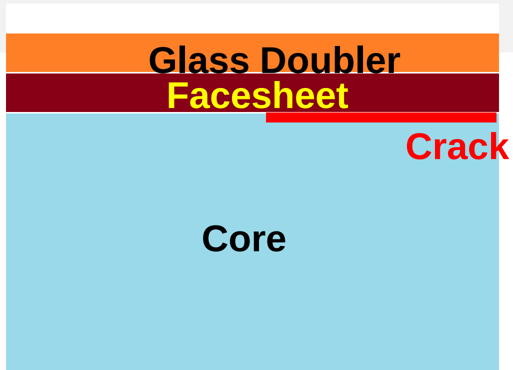


Crack at interface

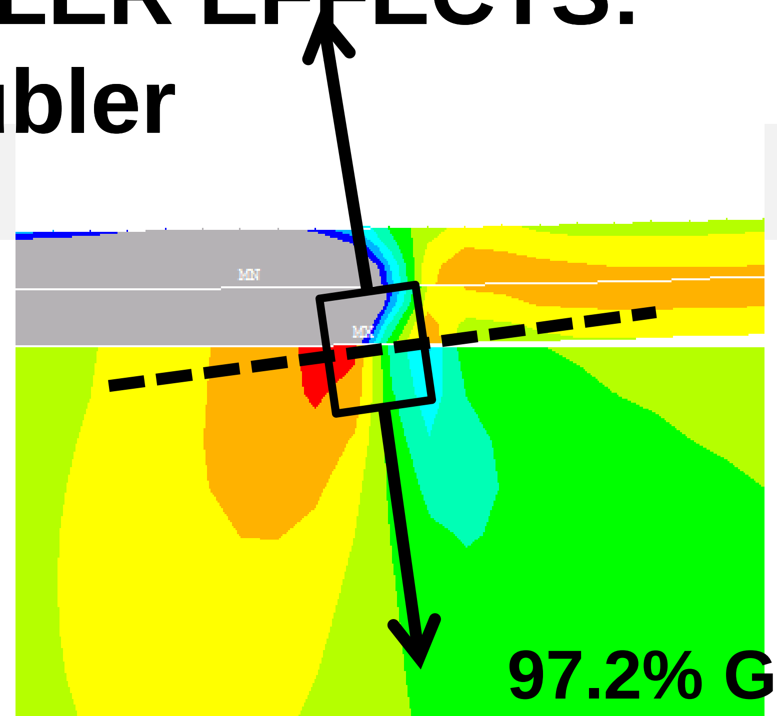


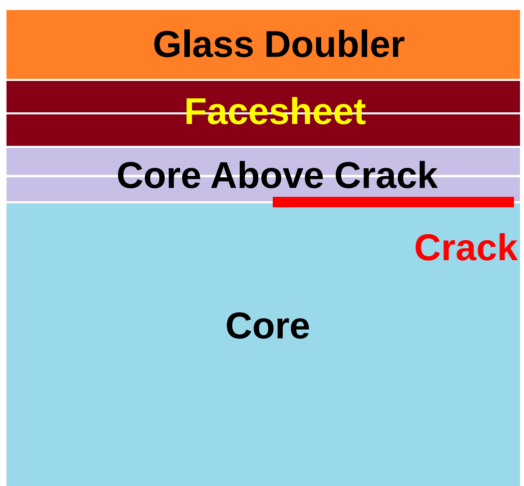


FACESHEET DOUBLER EFFECTS: Thin Doubler

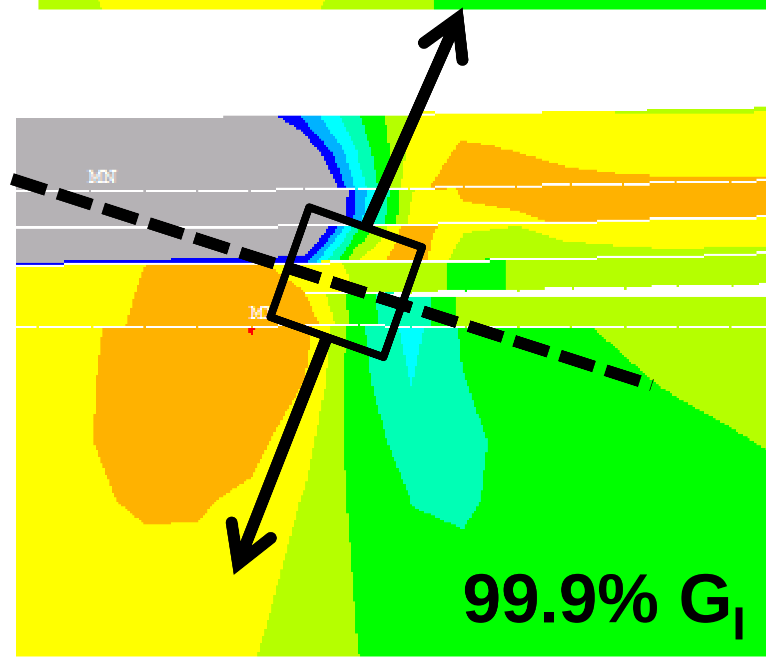


At interface

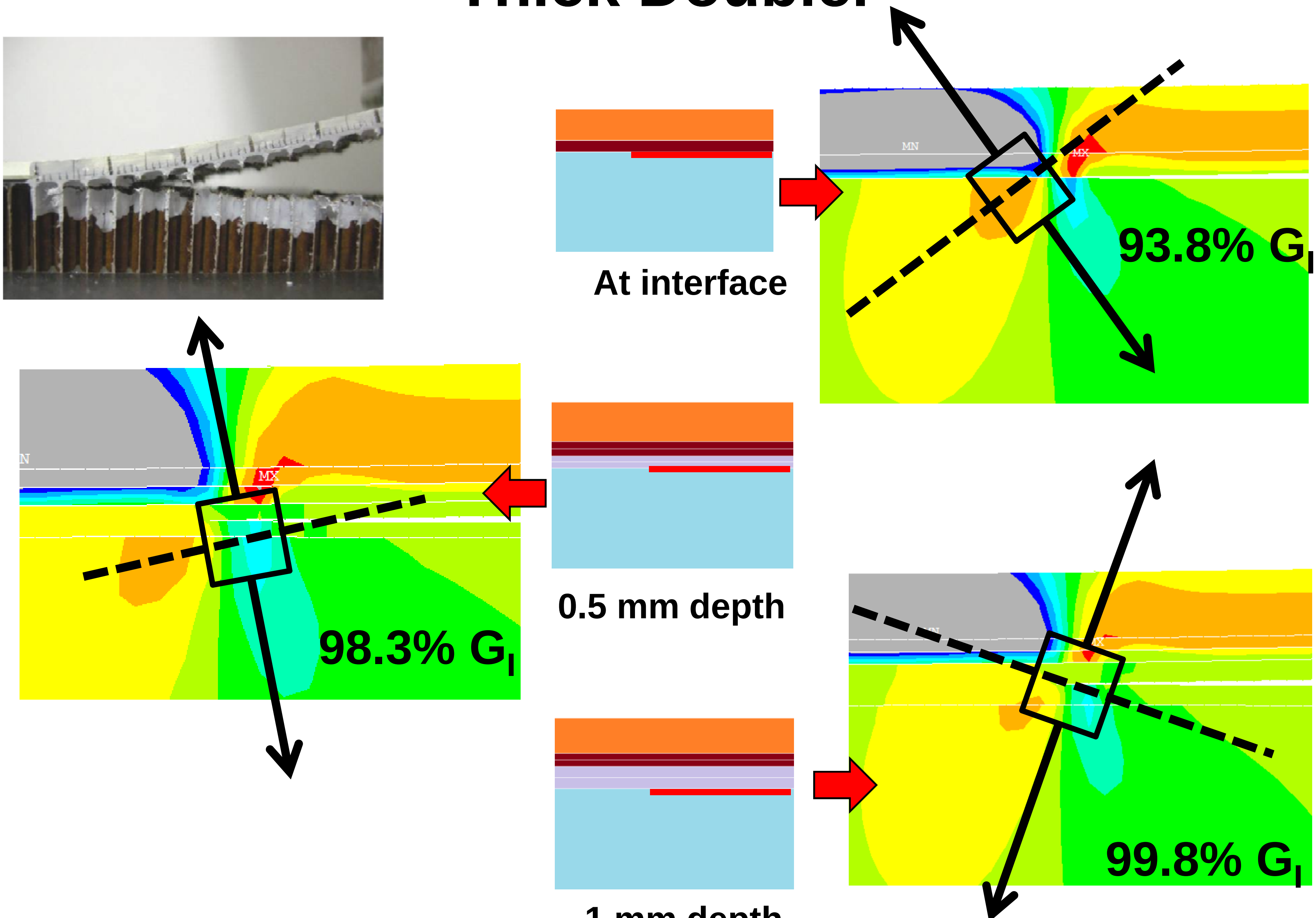




0.5 mm depth

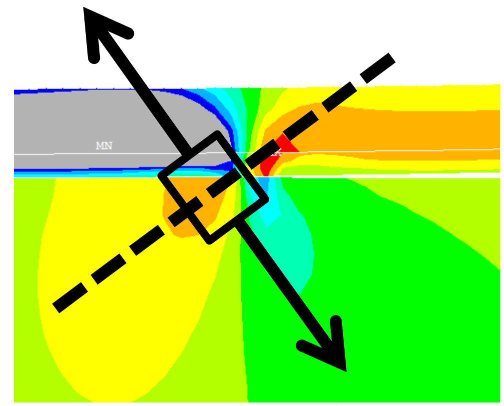


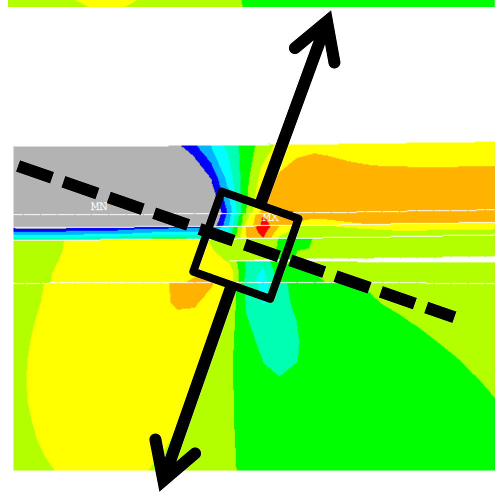
FACESHEET DOUBLER EFFECTS:
Thick Doubler



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





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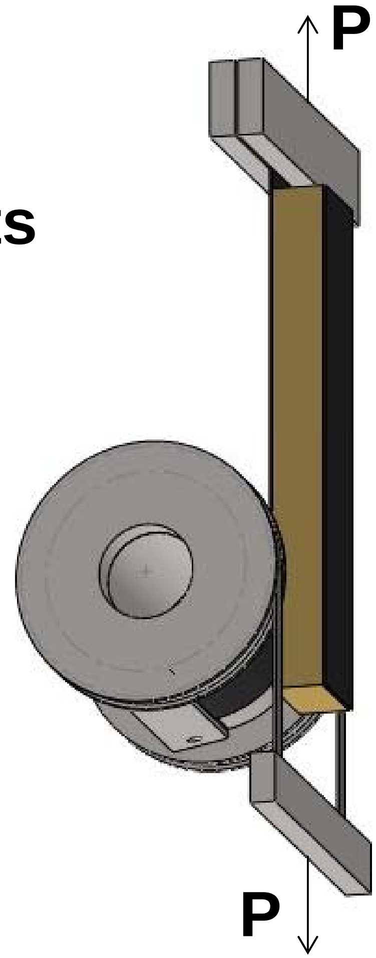
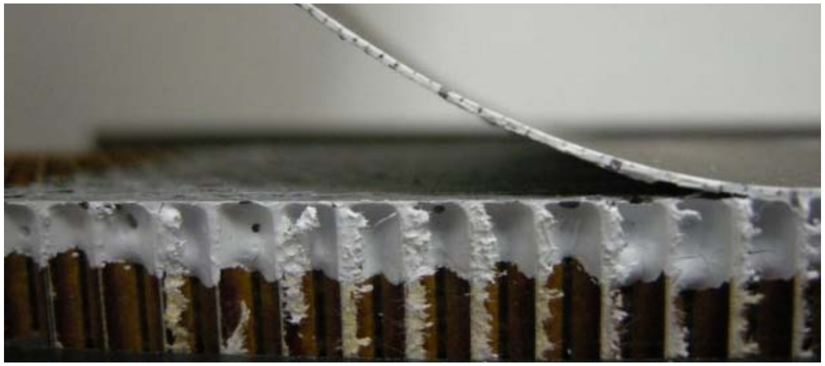
EFFECTS OF FACESHEET CURVATURE:
Use of Climbing Drum Peel (CDP) Test

- **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**





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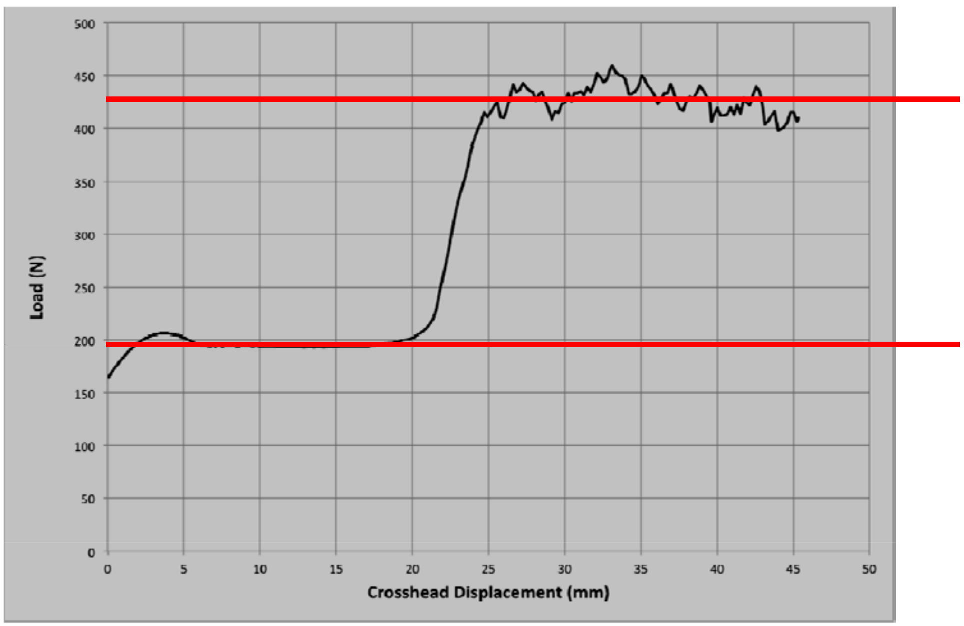
DETERMINATION OF ENERGY RELEASE RATE, G_C:
Climbing Drum Peel (CDP) Test

Energy Release Rate, G_{IC}:

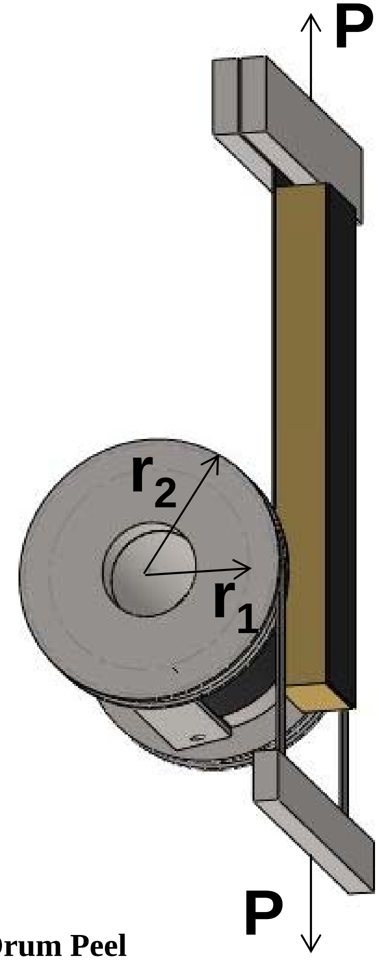
$$G_{IC} = \frac{(P_2 - P_1)(r_2 - r_1)}{w\ r_1}$$

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



P_2

P_1



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

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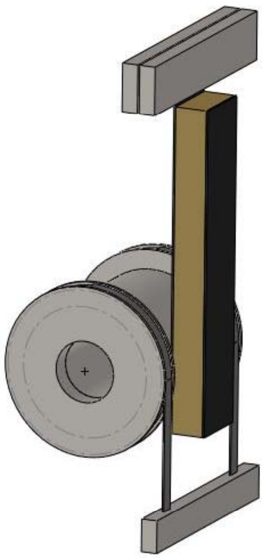
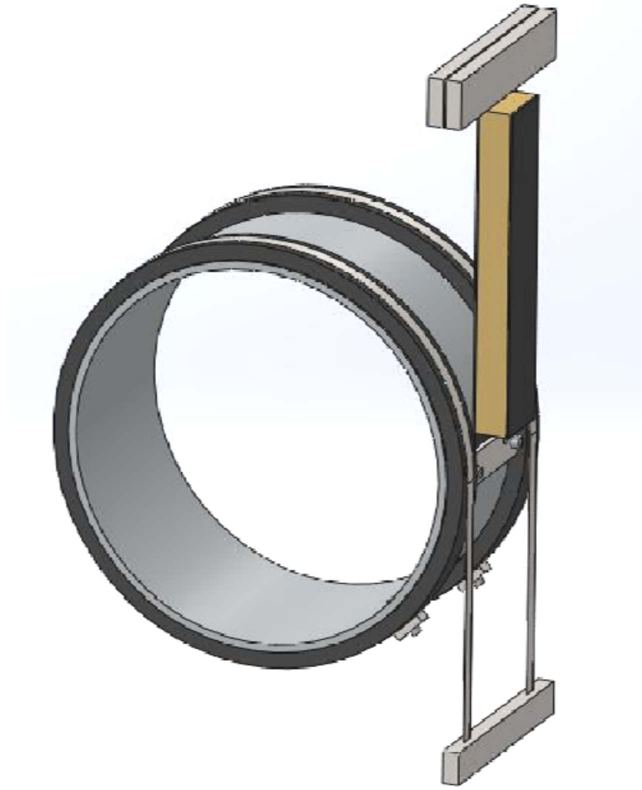
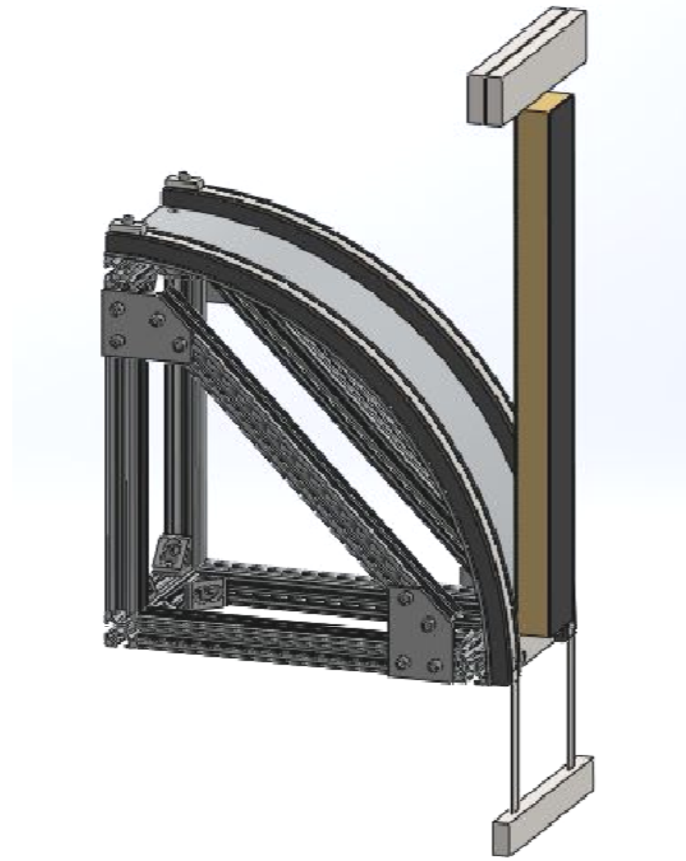
CLIMBING DRUM PEEL (CDP) TESTING:
Investigating Facesheet Curvature Effects



Standard CDP Fixture
ASTM D 1781
r = 2 in.



Large CDP Fixture
r = 6 in.



***Very* Large CDP Fixture**
r = 12 in.

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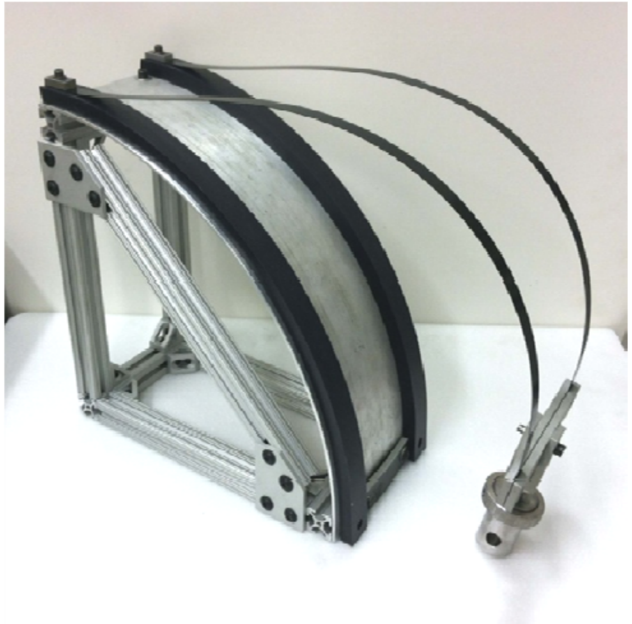
CLIMBING DRUM PEEL (CDP) TESTING: Investigating Facesheet Curvature Effects

Standard CDP Fixture
ASTM D 1781
r = 2 in.

Large CDP Fixture
r = 6 in.



***Very* Large CDP Fixture**
r = 12 in.

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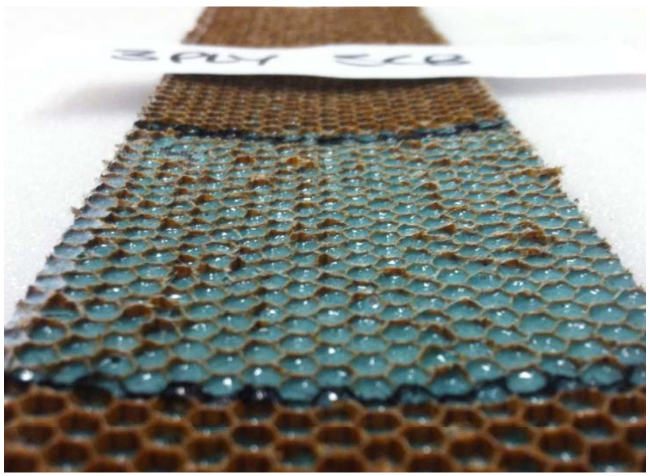
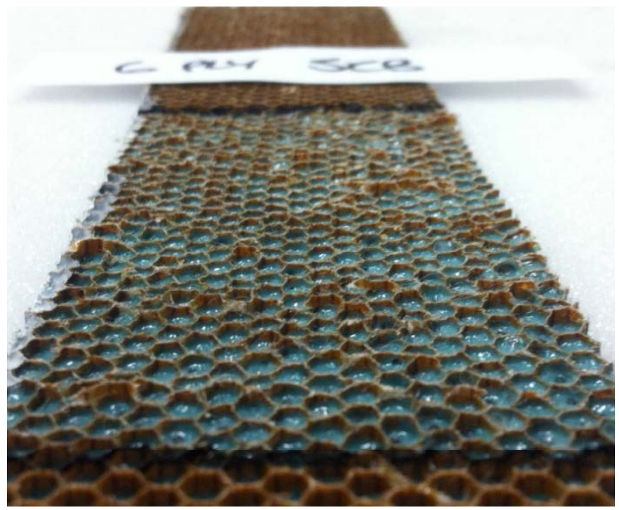
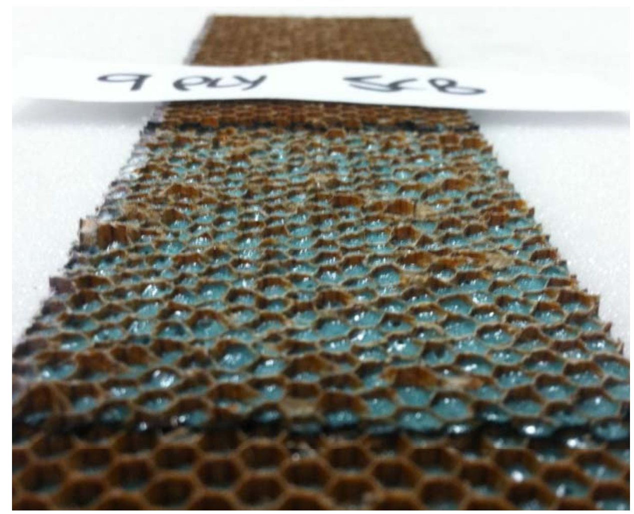
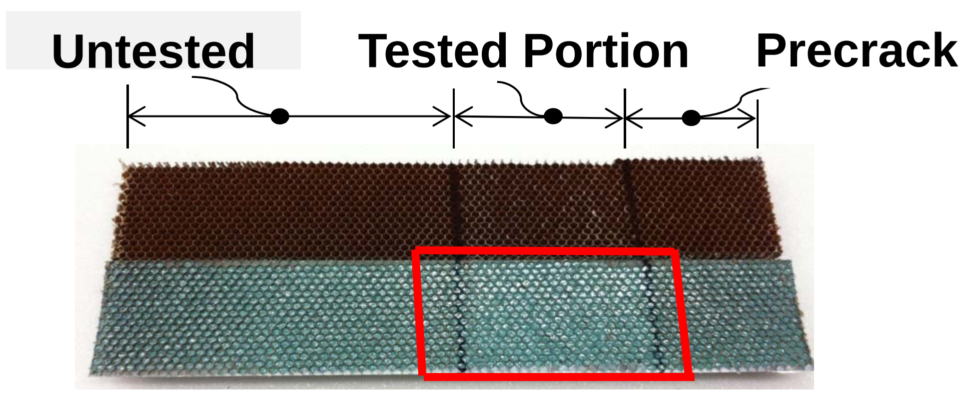
Effect of Facesheet Thickness:
Single Cantilever Beam (SCB) Specimens

Change in fracture location with facesheet thickness

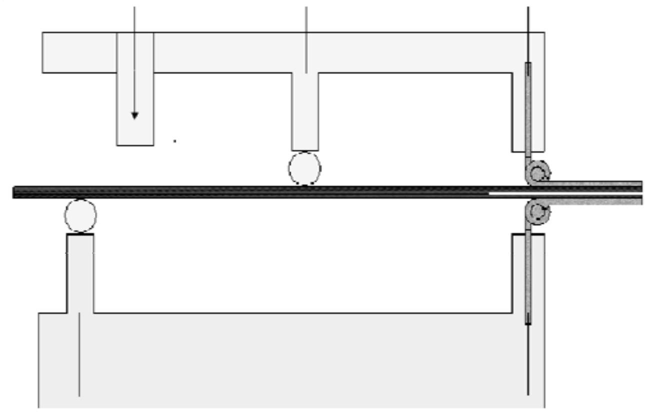
<u>3 Ply Facesheet</u>	<u>6 Ply Facesheet</u>	<u>9 Ply Facesheet</u>
		



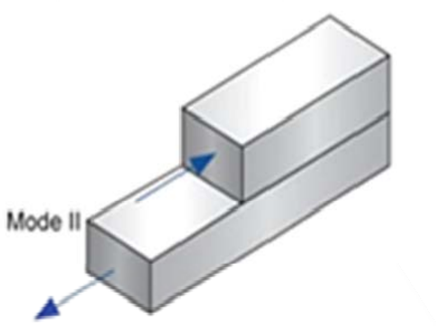
MODE II TEST METHOD DEVELOPMENT:

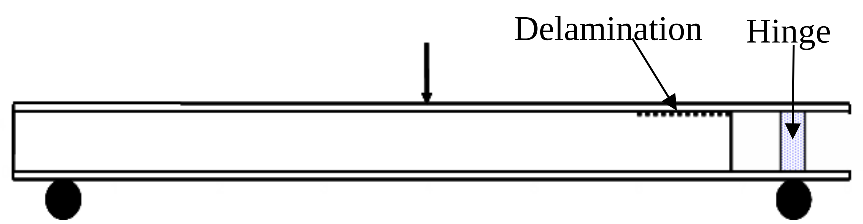
Challenges in Developing a Suitable Test

- **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

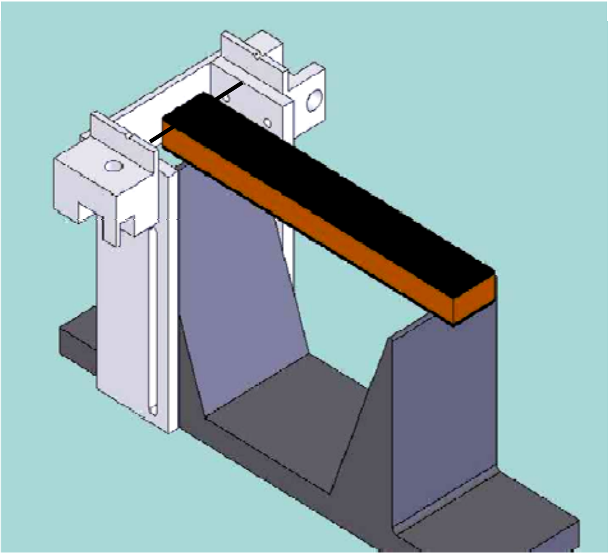


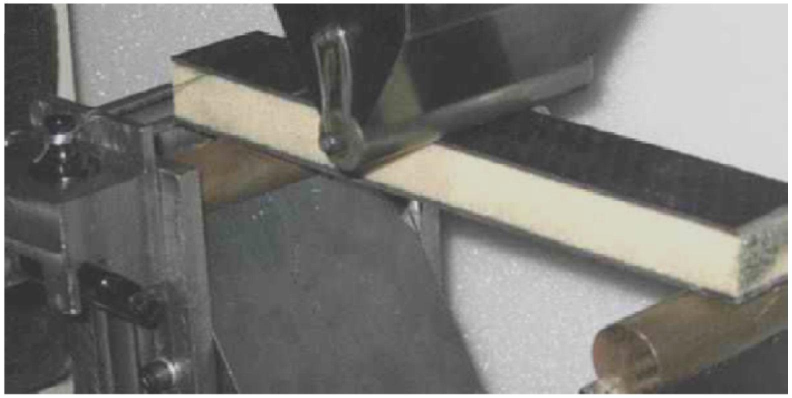


Cracked Sandwich Beam with Hinge

CANDIDATE MODE II CONFIGURATION:
End Notched Sandwich 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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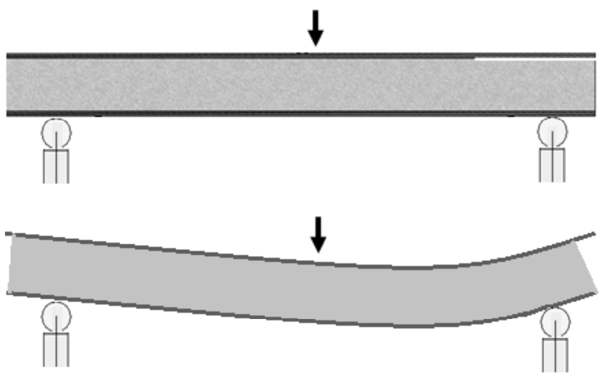
END-NOTCHED TEST CONFIGURATIONS:

Three-Point Flexure Vs. Cantilever Support

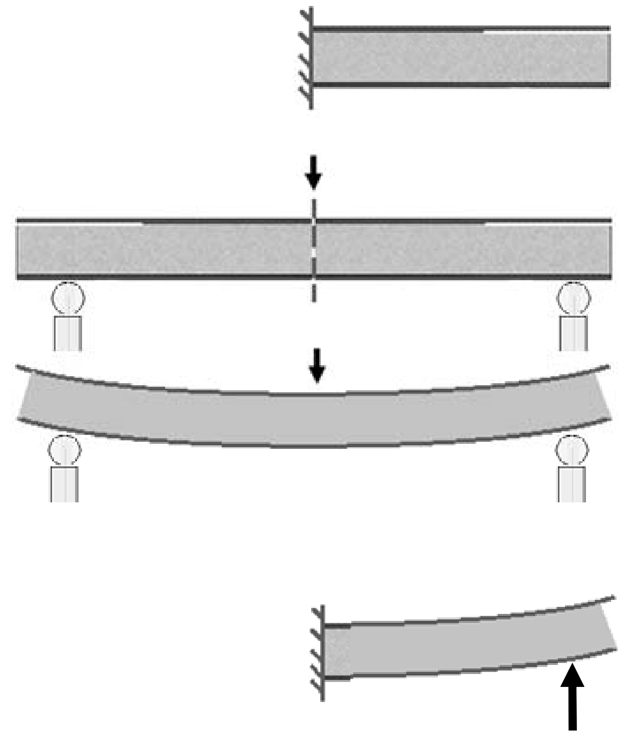
End Notched Flexure

(Unsymmetric bending)



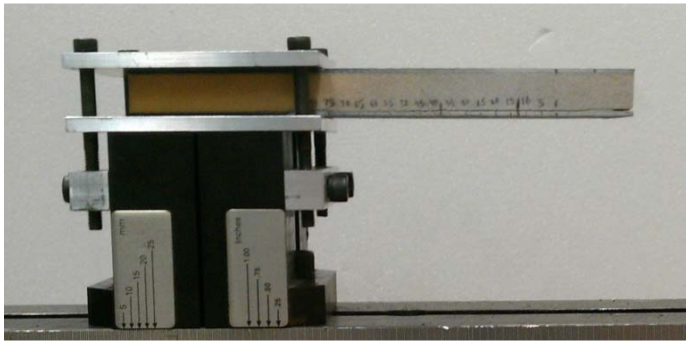
End Notched Cantilever

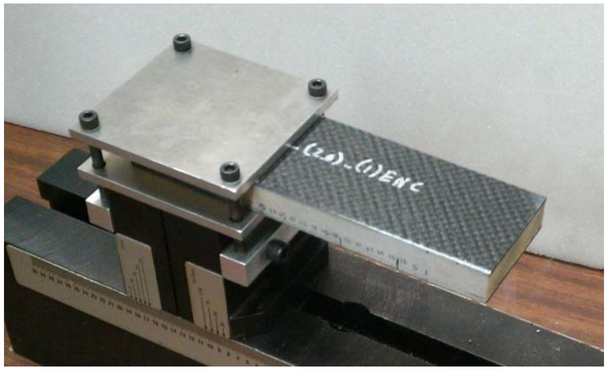
(Symmetric bending)



MODIFIED MODE II CONFIGURATION
End Notched Cantilever (ENC) Test

- **Cantilever beam configuration**
- **Upward or downward loading**
- **Performance meets or exceeds 3-point flexure configuration for all sandwich configurations considered to date**
- **Requires specialized fixturing**
- **Allows for reduced specimen length**
- ***Currently under further examination***





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CURRENT STATUS:

Fracture Mechanics Test Methods for Sandwich Composites

- **Completion of remaining testing and analysis**
- **Documentation of findings**
  - **FAA Reports**
  - **Journal publications**
- **Submission of Draft SCB Test Method to ASTM Committee D30 on Composites**