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Development and Evaluation of Fracture Mechanics Test Methods for Sandwich Composites

2013 Technical Review

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THE UNIVERSITY OF UTAH

FAA Sponsored Project Information

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- Graduate Student Researchers:

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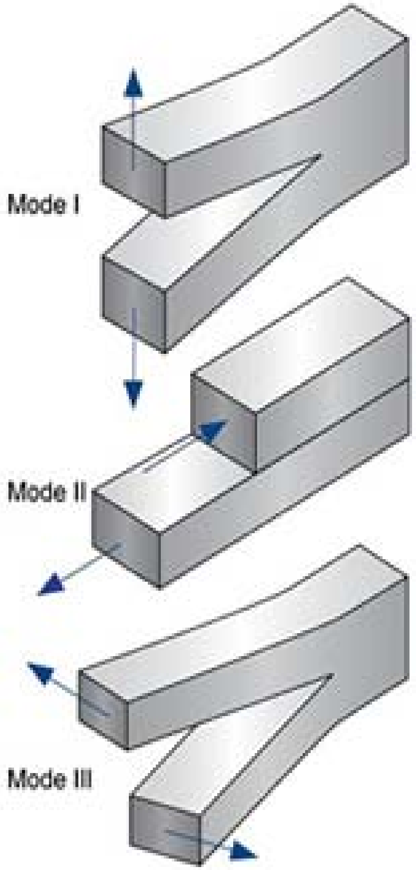
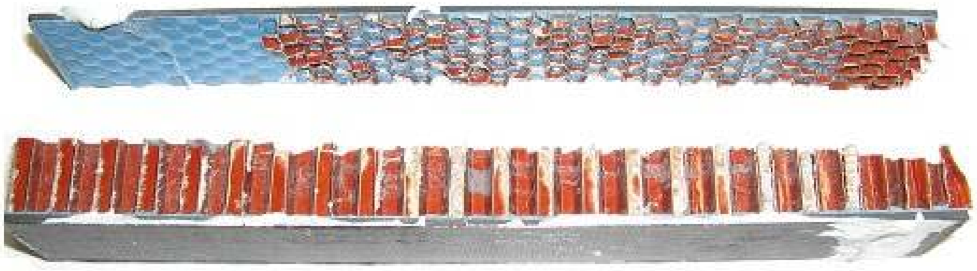
  NASA Langley
  Boeing
  Airbus
  NIAR
  Learjet
  UTC Aerospace Systems

RESEARCH OBJECTIVES:

Fracture Mechanics Test Methods for Sandwich Composites

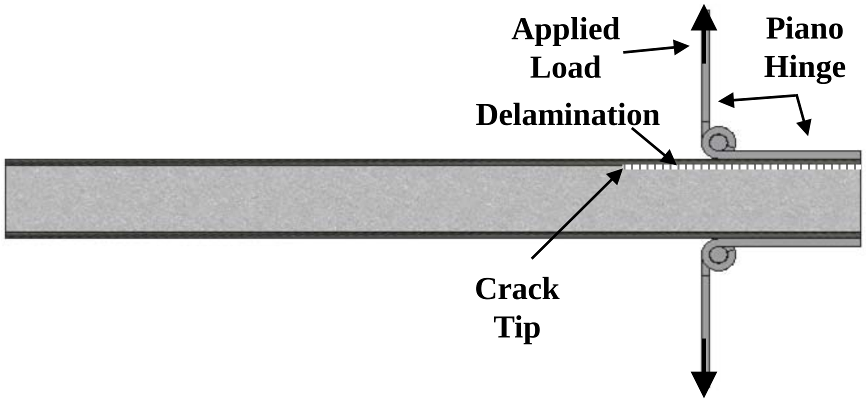
- Focus on facesheet-core debonding
- Mode I and Mode II
  - **Identification and initial assessment of candidate test methodologies**
  - **Selection and optimization of best suited Mode I and Mode II test methods**
  - **Development of draft ASTM standards**



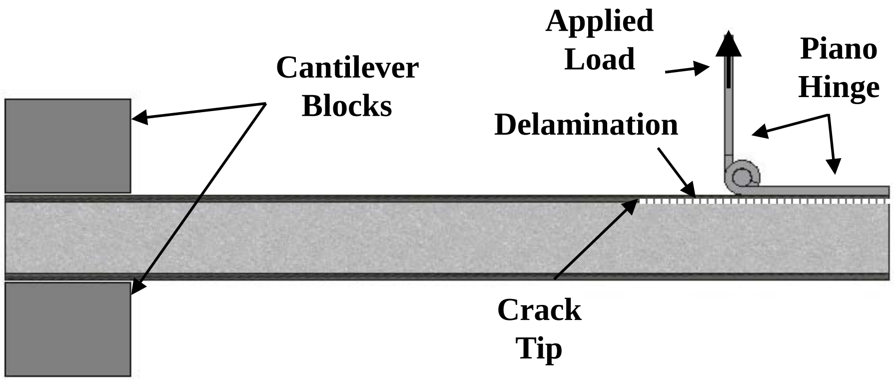


MODE I TEST CONFIGURATION:

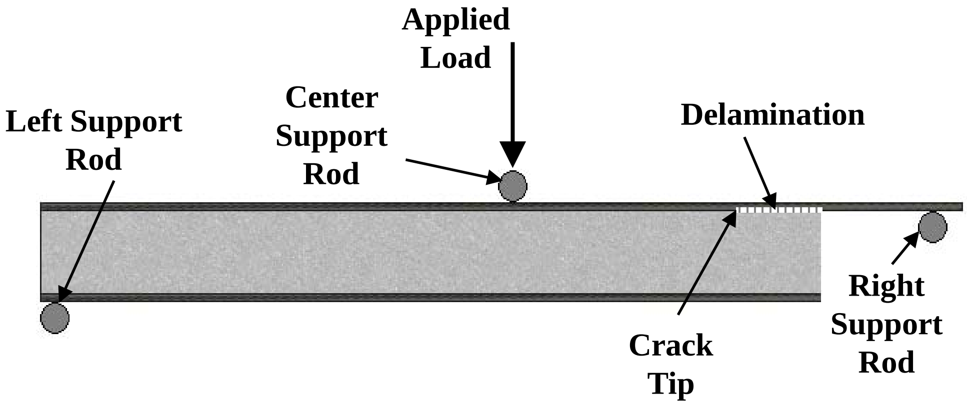
Candidate Configurations Investigated



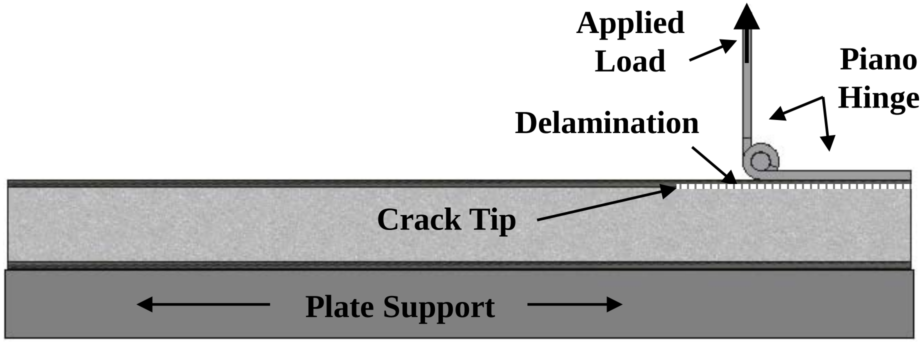
Double Cantilever Beam (DCB)



Clamped Double Cantilever Beam (DCB)



Three-Point Flexure

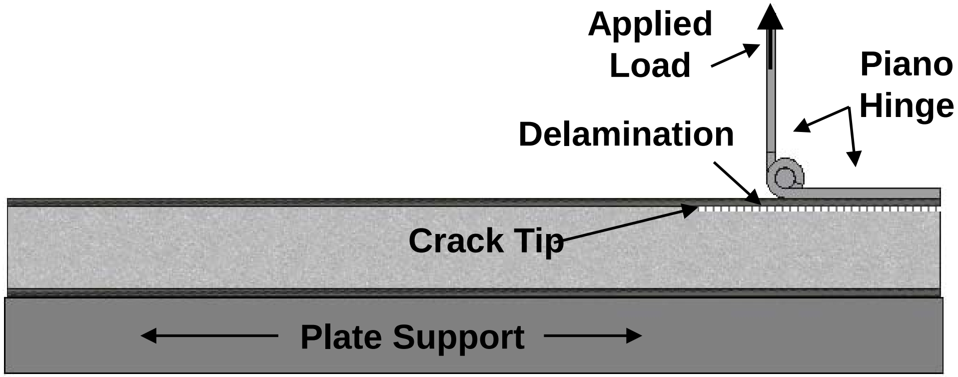


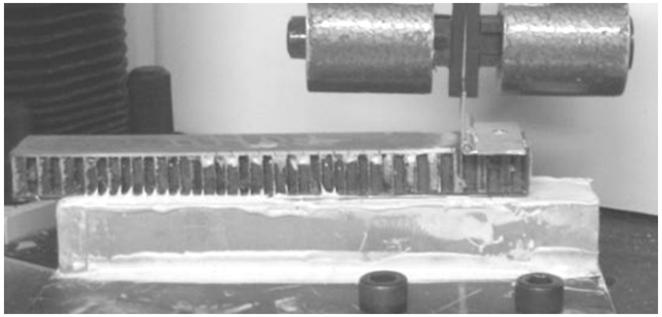
Single Cantilever Beam (SCB)

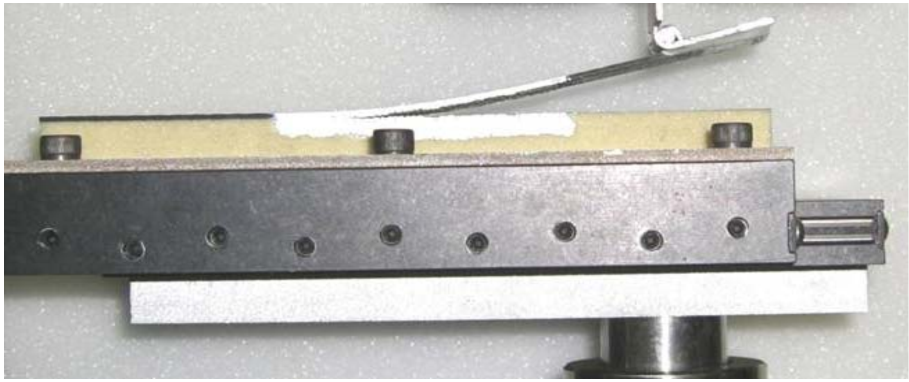
MODE I TEST CONFIGURATION:

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***





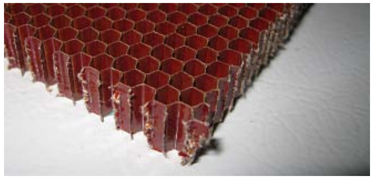


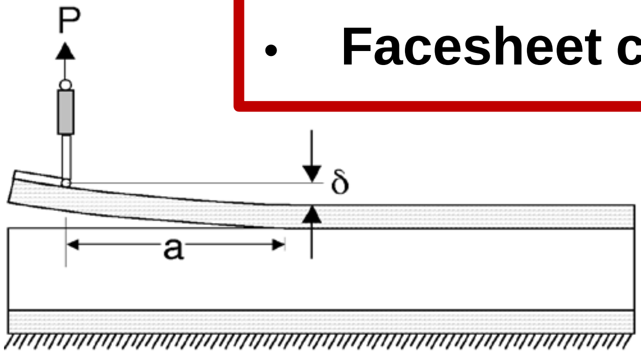
PARAMETERS INVESTIGATED:

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

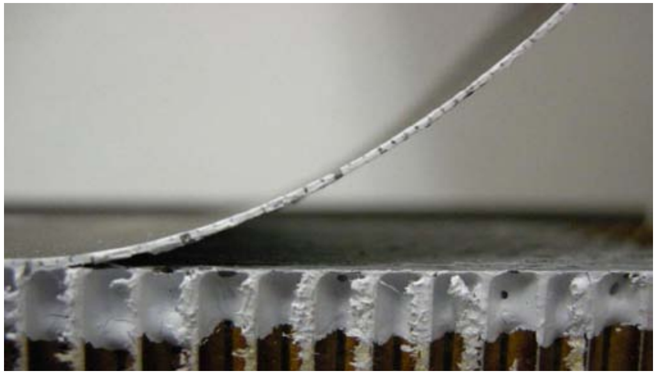




SCB TEST METHOD DEVELOPMENT:
Sandwich Configurations with Thin Facesheets

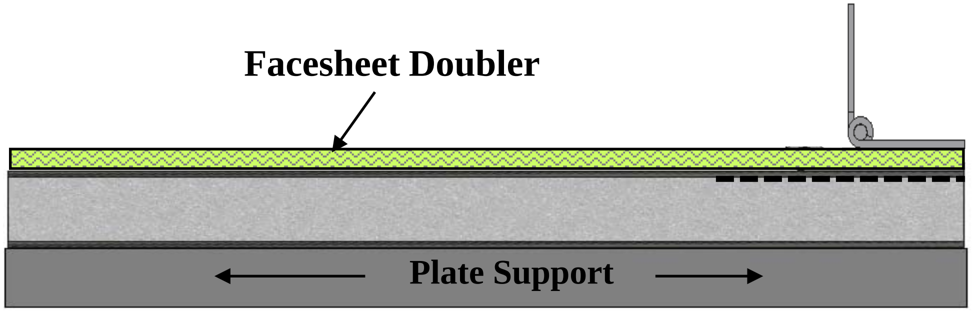
Concern: Excessive facesheet rotation

- 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

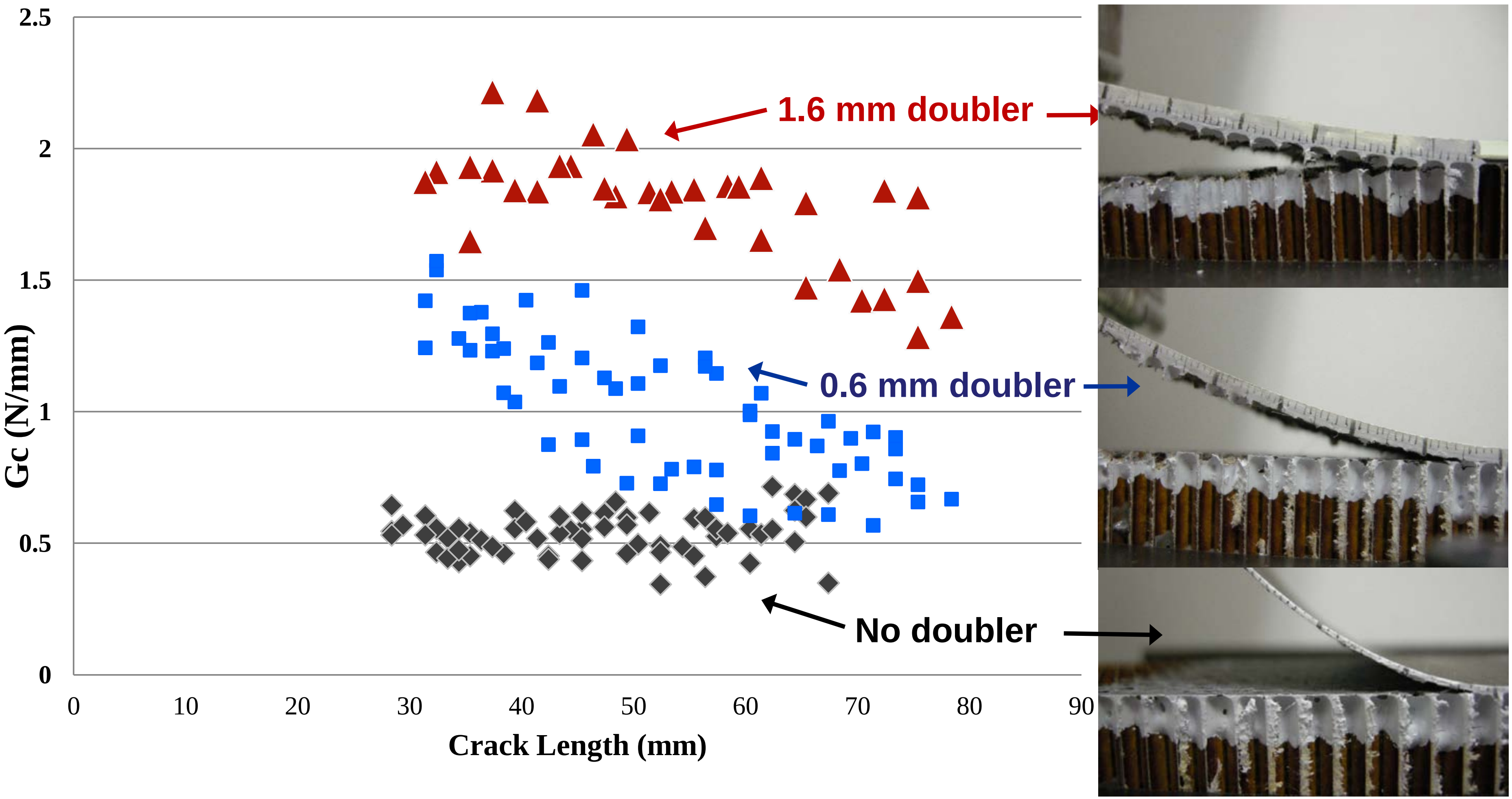


EFFECTS OF FACESHEET DOUBLER:

Results of SCB Testing With Nomex Honeycomb Core

Adding doubler changes delivered G_c values…

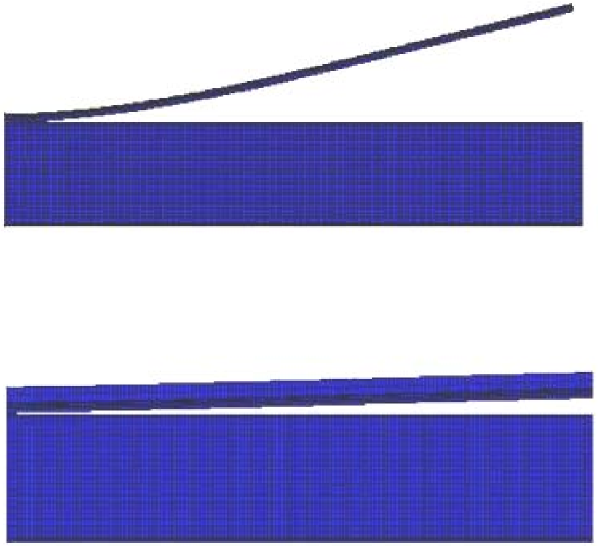
…and thru-thickness fracture locations!

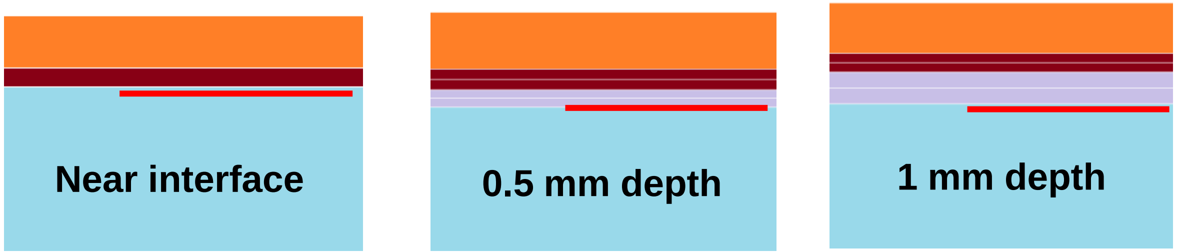


NUMERICAL INVESTIGATION

Facesheet Thickness Effects

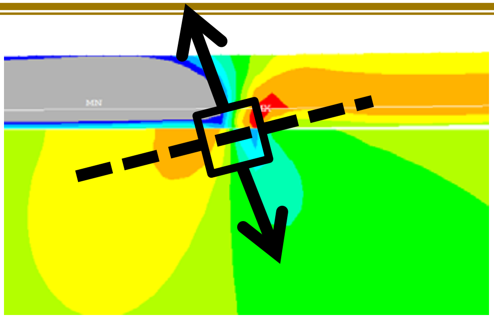
- Load applied in each model to produce same G_T value
  - No doubler, “thin” doubler, “thick” doubler
- Considered crack growth at three through-the-thickness locations
- Investigate mode mixity (% G_I)
- Investigate orientation of max. principal stress for expected crack growth direction

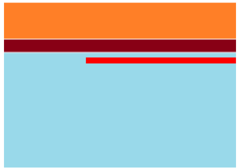




SUMMARY OF FINDINGS:
Numerical Investigation

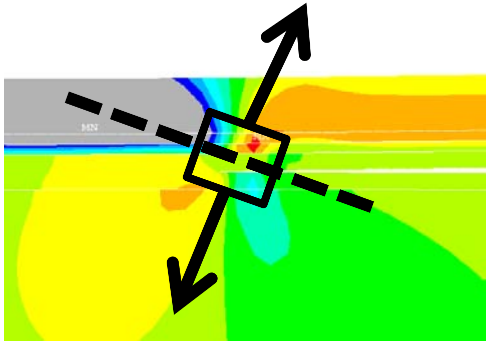
- **SCB test appears to be Mode I dominant for all cases considered**
- **Small Mode II component produced by shear stresses in vicinity of crack tip**
- **Sign of shear stresses change as a function of:**
  - **Crack location in core**
  - **Thickness of facesheet**
- **Crack predicted to propagate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

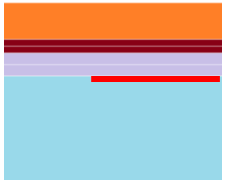




Disbond near interface

(in core)





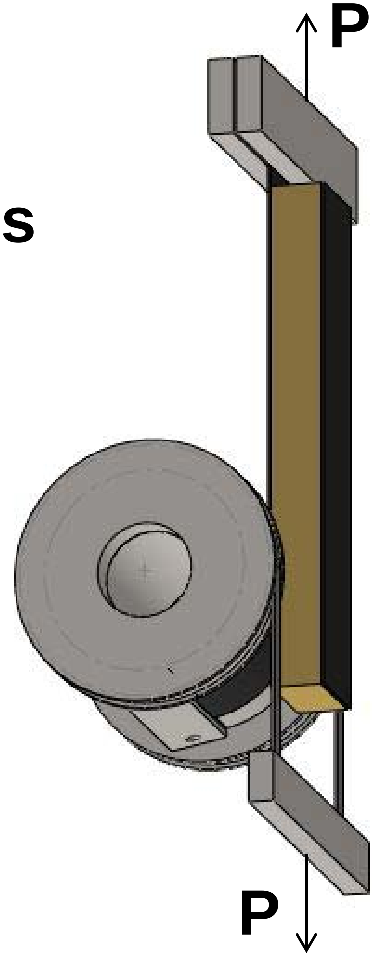
Disbond 1 mm below interface

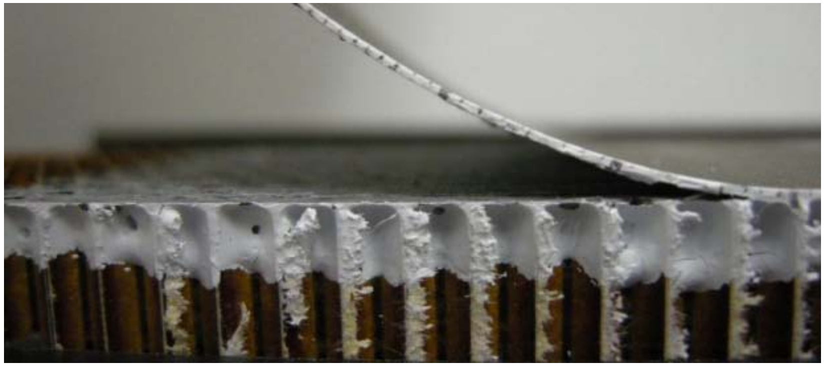
(in core)

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

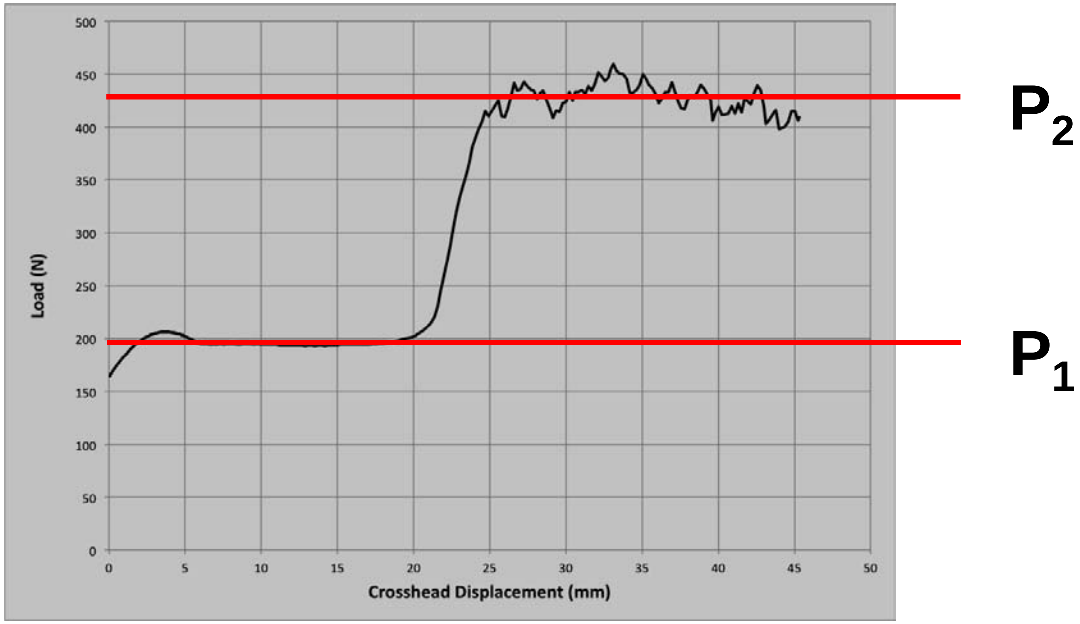
Energy Release Rate, G_{IC}:

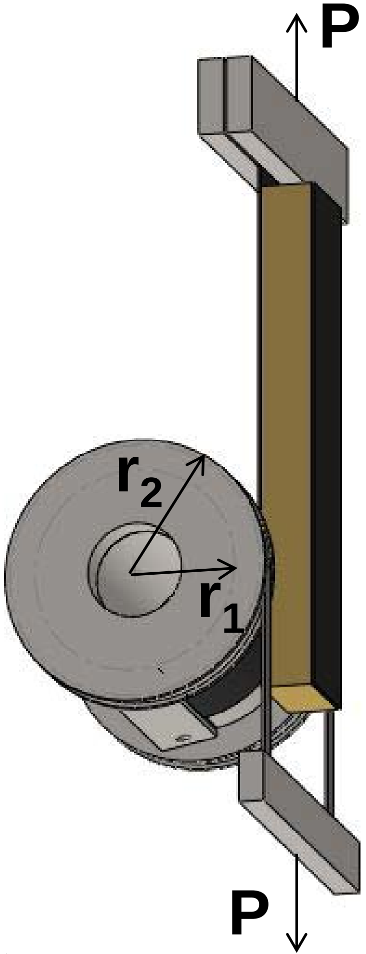
$$G_{IC} = \frac{\left(P_2 - P_1\right)\left(r_2 - r_1\right)}{w\ r_1}$$

r_2 = flange radius

r_1 = drum radius + facesheet thickness

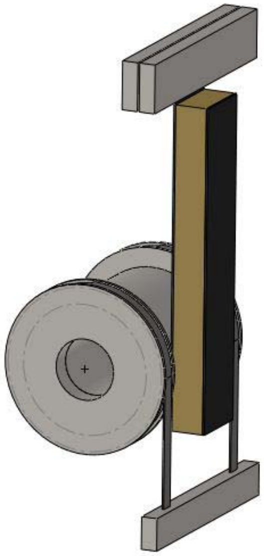
w = specimen width



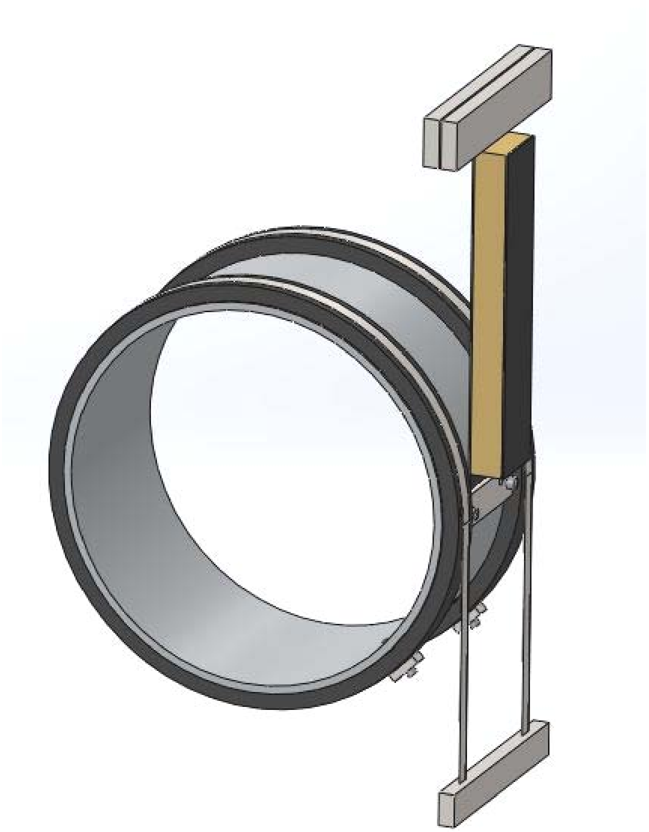


A.T. Nettles, E.D. Gregory and J.R. Jackson, "Using the Climbing Drum Peel (CDP) Test to Obtain a G_{IC} Value for Core/Face Sheet Bond," *Journal of Composite Materials*, Vol 41, 2007.

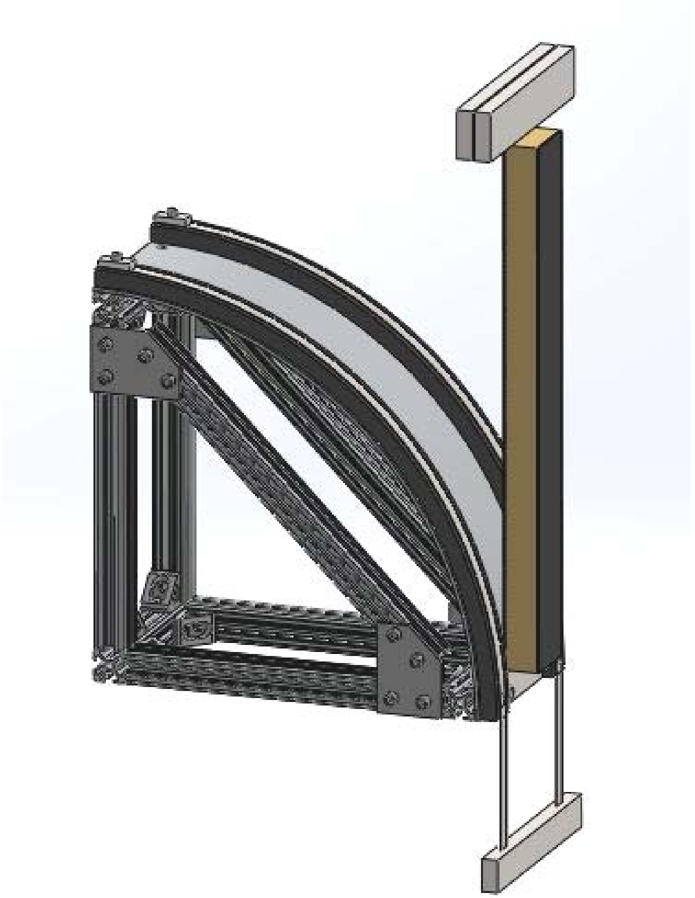
CLIMBING DRUM PEEL (CDP) TESTING:
Investigating Facesheet Curvature Effects



Standard CDP Fixture
ASTM D 1781
r = 2 in.



Large CDP Fixture
r = 6 in.

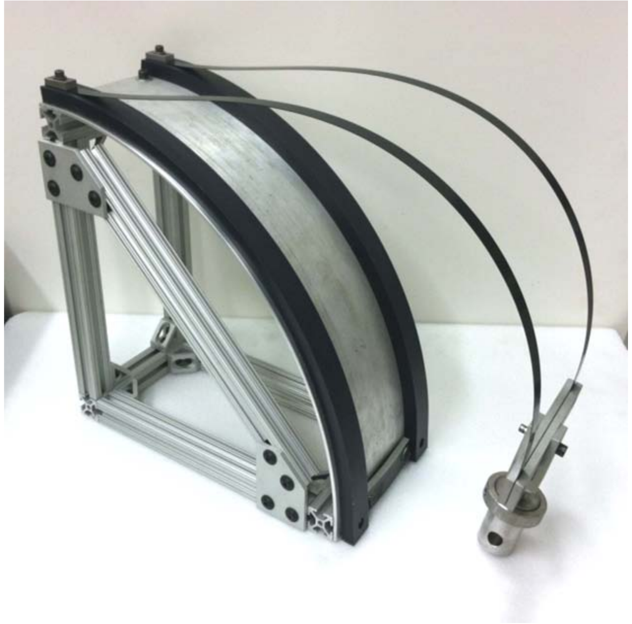


***Very* Large CDP Fixture**
r = 12 in.

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

Standard CDP Fixture
ASTM D 1781
r = 2 in.

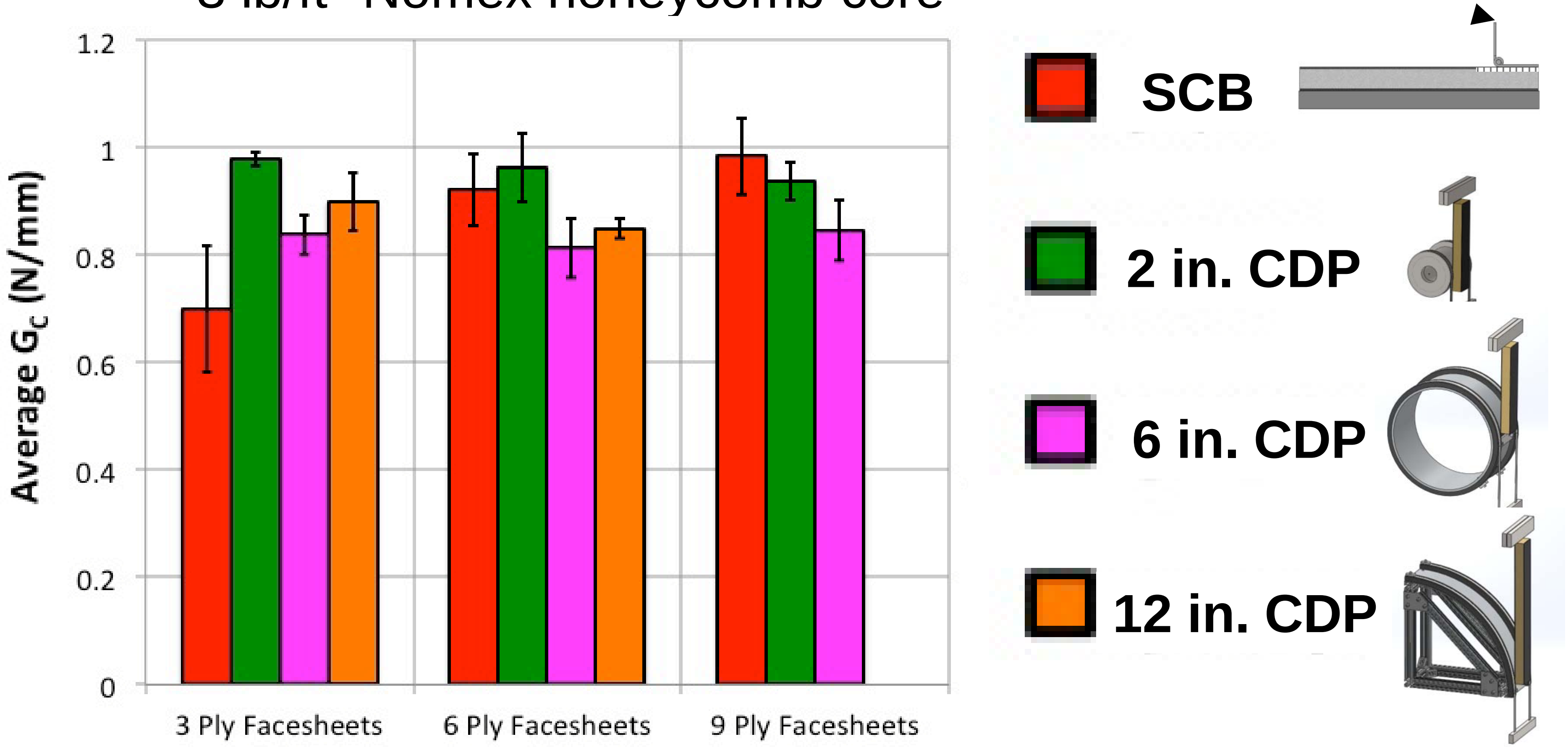
Large CDP Fixture
r = 6 in.



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

PRELIMINARY:
Effects of Facesheet Curvature on Apparent G_c

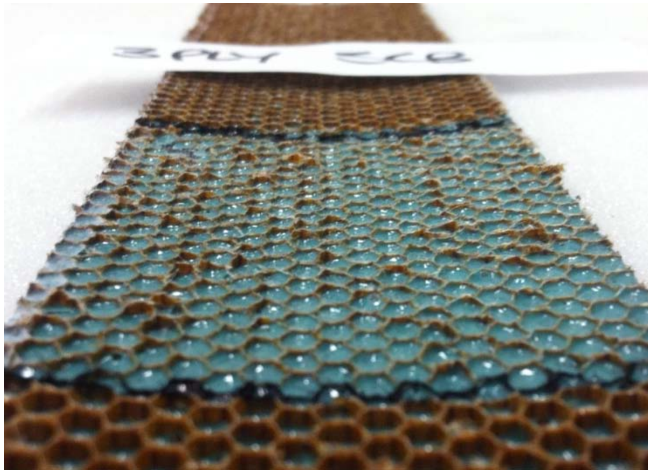
- $[0/90/0]_{nT}$ IM7/8552 carbon/epoxy facesheets
- 3 lb/ft^3 Nomex honeycomb core



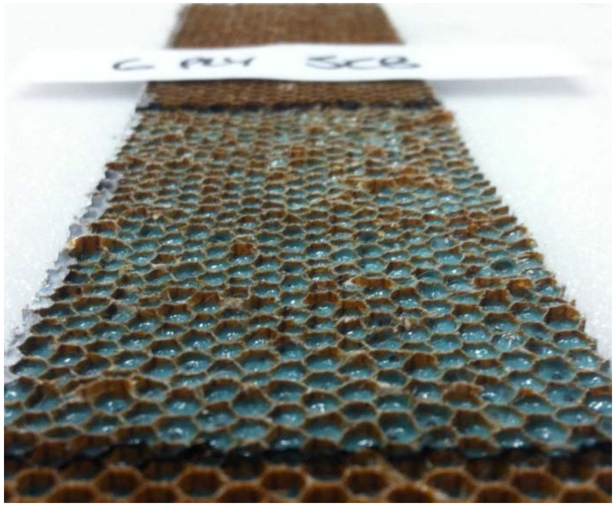
Effect of Facesheet Thickness: Single Cantilever Beam (SCB) Specimens

Change in fracture location with facesheet thickness

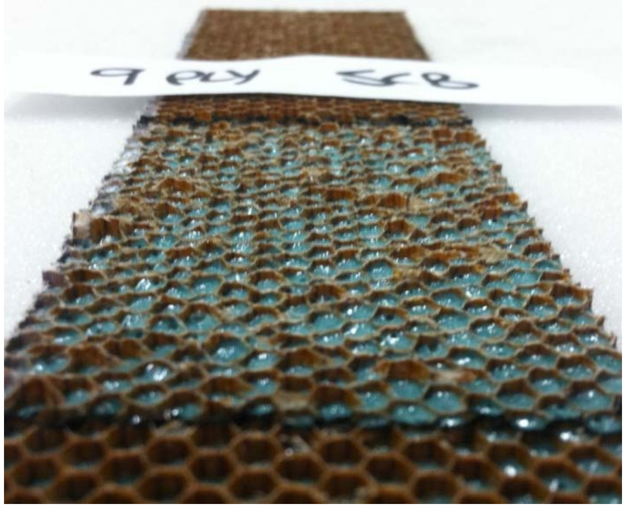
3 Ply Facesheet

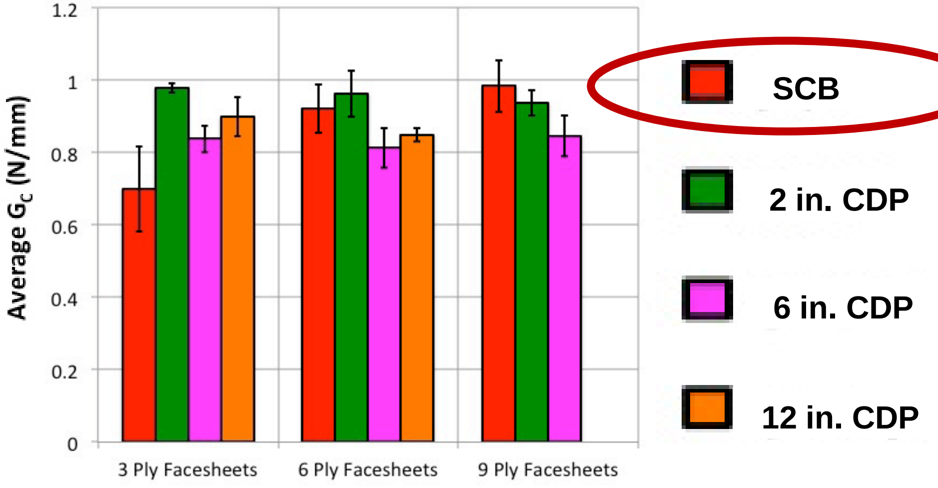


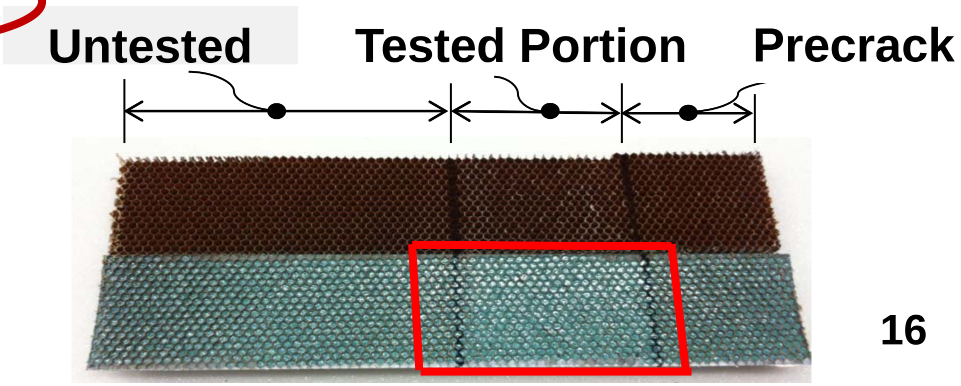
6 Ply Facesheet



9 Ply Facesheet



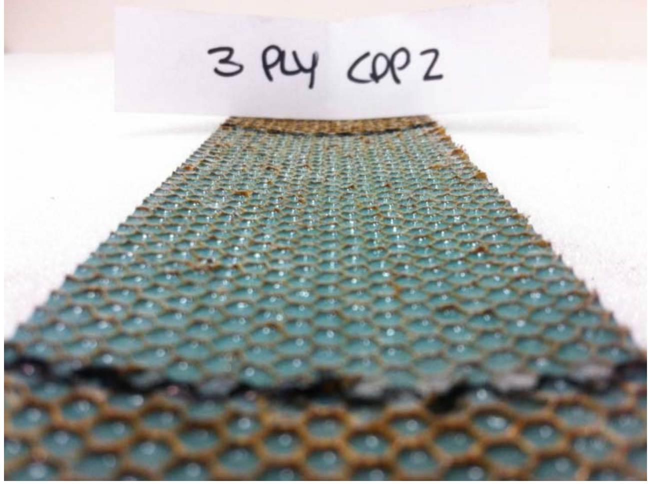




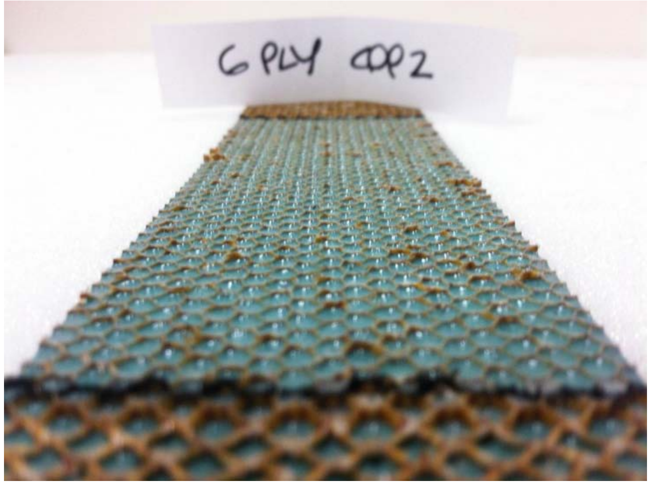
Effect of Facesheet Thickness: 6 in. Radius Climbing Drum Peel (CDP) Specimens

Minimal change in fracture location with facesheet thickness

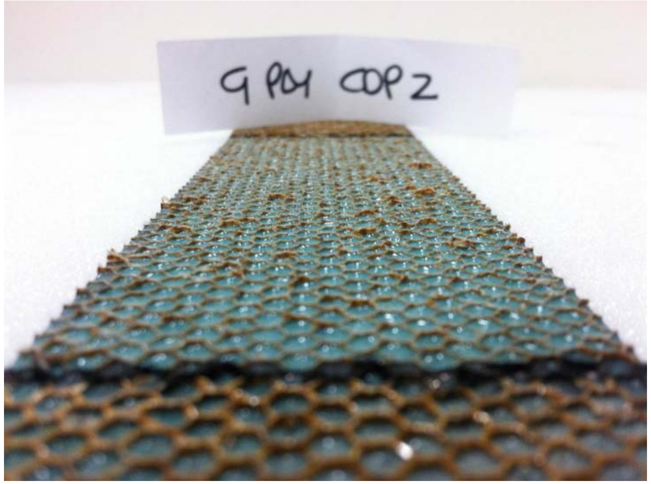
3 Ply Facesheet

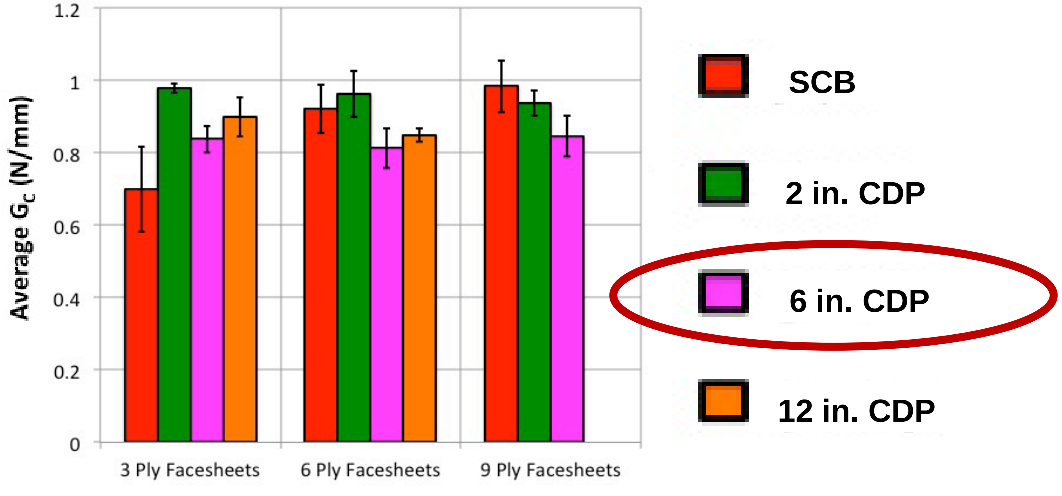


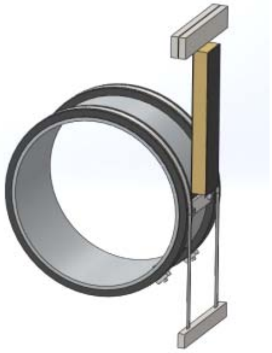
6 Ply Facesheet



9 Ply Facesheet



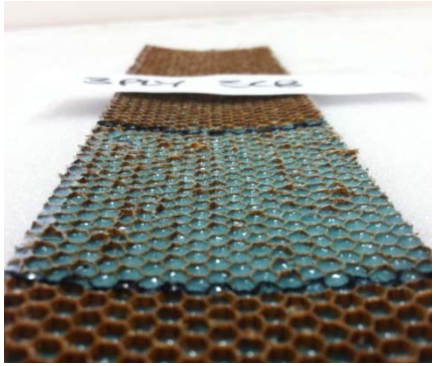




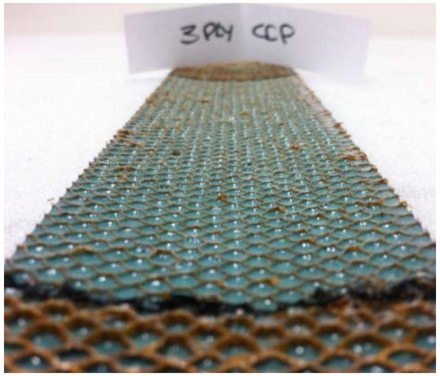
Effect of Facesheet Curvature
3 Ply Facesheet Specimens

Minimal change in fracture location with facesheet curvature

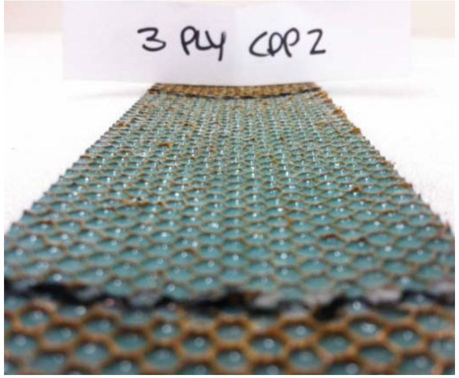
SCB



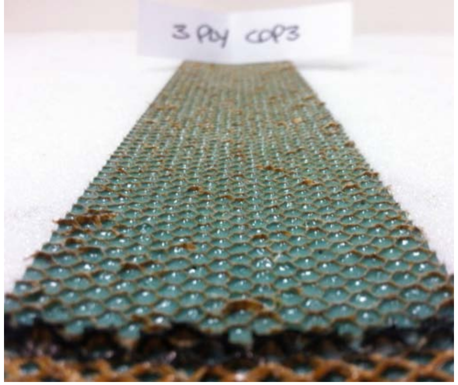
2 in. CDP

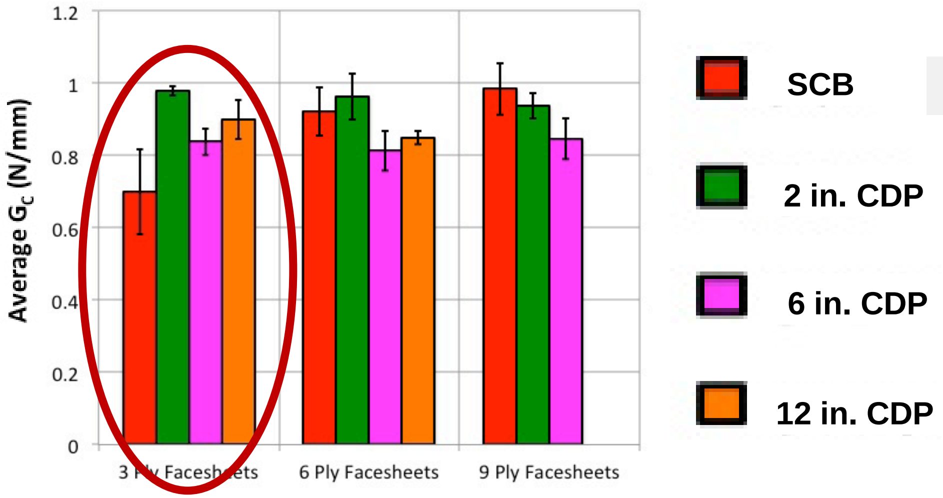


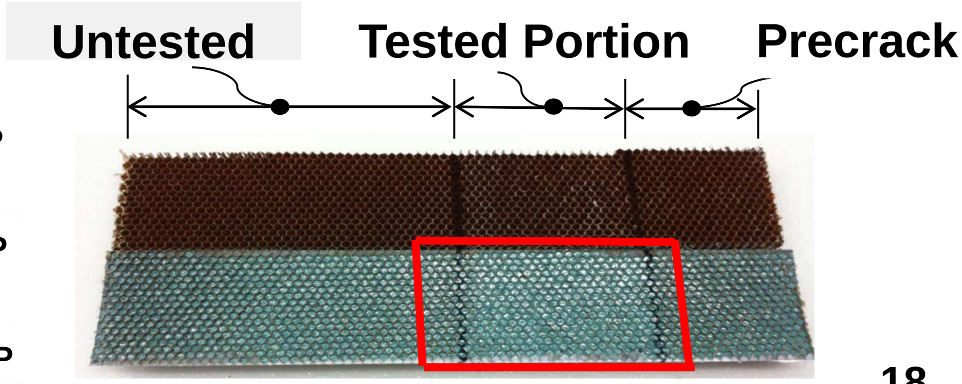
6 in. CDP



12 in CPD



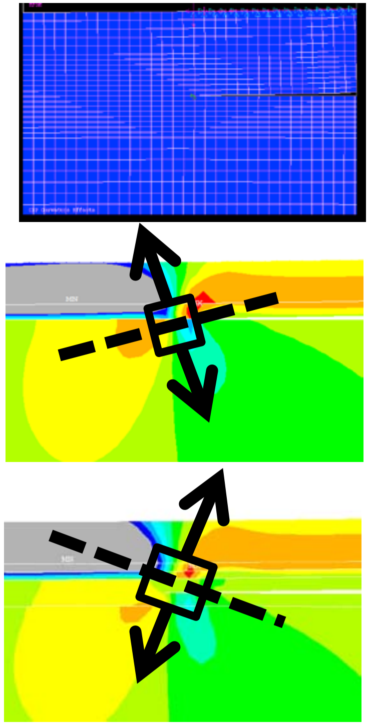




RESULTS FROM NUMERICAL INVESTIGATION: Predicted Depth of Crack Growth in Nomex Core

- *Increasing depth of crack for increasing facesheet thickness*
- *Crack location independent of test method*

Test Method	3 Ply Facesheets	6 Ply Facesheets	9 Ply Facesheets
SCB	0.25 mm (0.010 in.)	0.75 mm (0.030 in.)	1.0 mm (0.039 in.)
2 in. CDP	0.38 mm (0.015 in.)	0.75 mm (0.030 in.)	1.0 mm (0.039 in.)
6 in. CDP	0.38 mm (0.015 in.)	0.75 mm (0.030 in.)	1.0 mm (0.039 in.)
12 in. CDP	0.38 mm (0.015 in.)	0.75 mm (0.030 in.)	1.0 mm (0.039 in.)



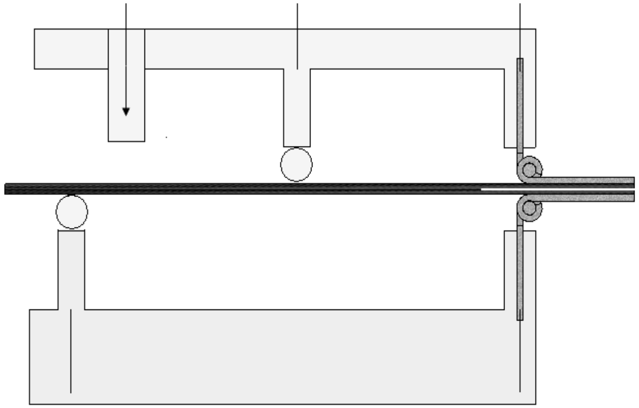
SUMMARY OF PRELIMINARY FINDINGS: Facesheet Thickness Effects

- SCB test results show differences in apparent G_c values and through-thickness locations of crack growth as a function of facesheet thickness
- CDB test results to date do not indicate differences in apparent G_c or through-thickness locations of crack growth as a function of facesheet thickness
- Numerical simulations suggest through-thickness locations of crack growth is a function of facesheet thickness for all test methods investigated
- Additional testing to be performed using specimens from single sandwich panel

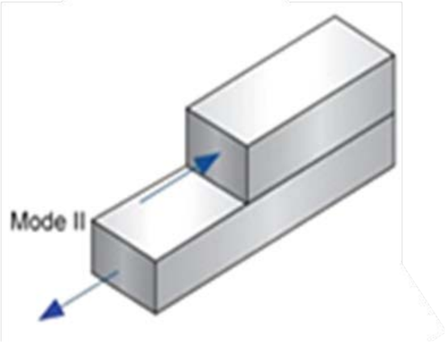
MODE II TEST METHOD DEVELOPMENT:

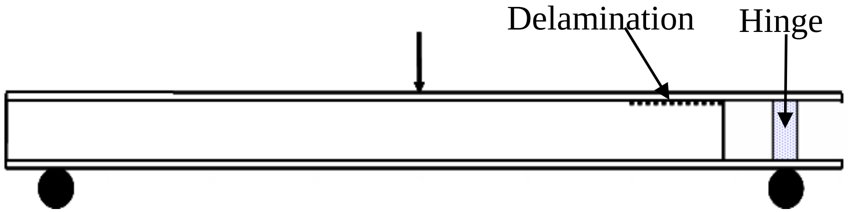
Challenges in Developing a Suitable Test

- **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

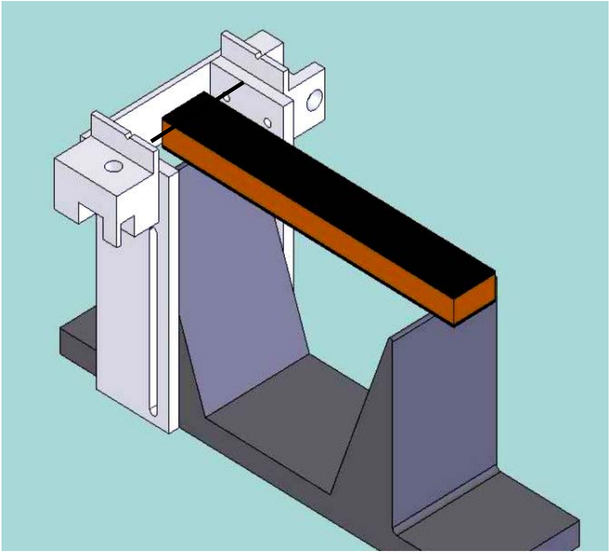


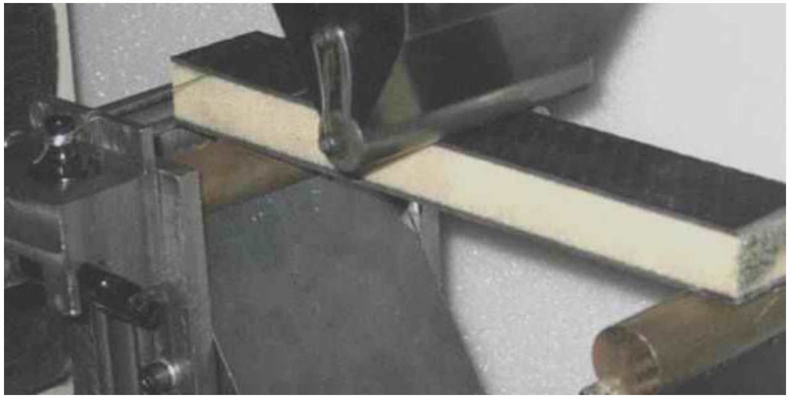


Cracked Sandwich
Beam with Hinge

SELECTED 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***

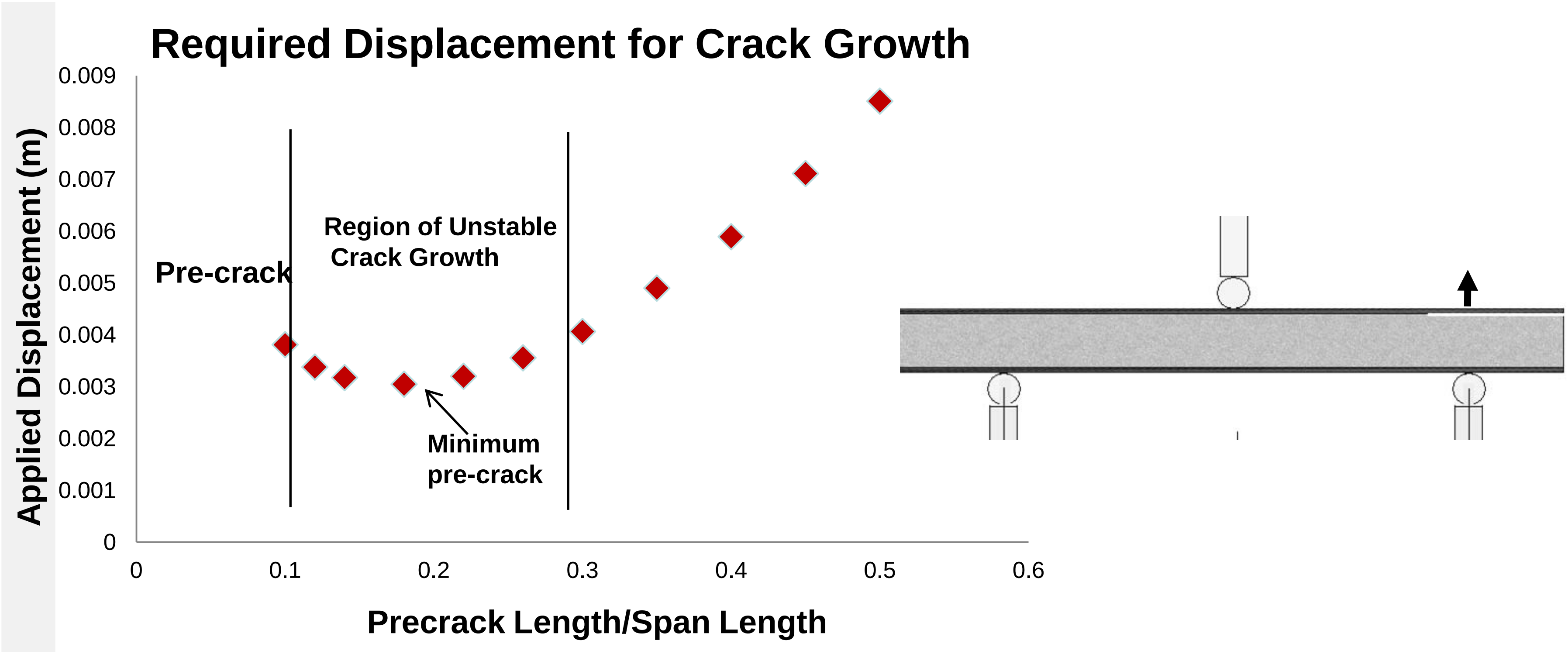




ADDRESSING CRACK GROWTH STABILITY:

Specimen Span Length and Precrack Length

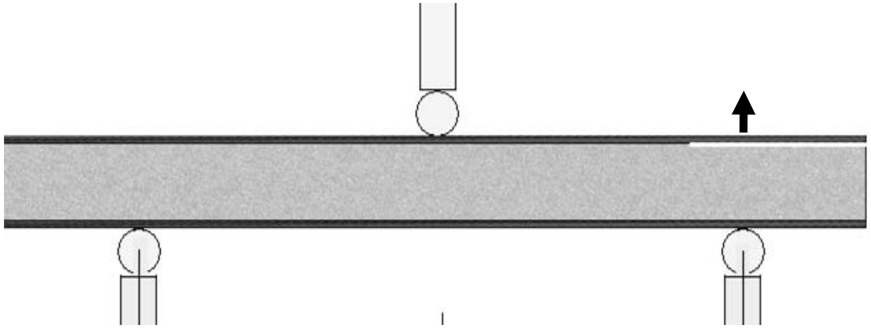
- Selection of proper precrack length/span length predicted to produce stable crack growth
- Test results have confirmed this prediction

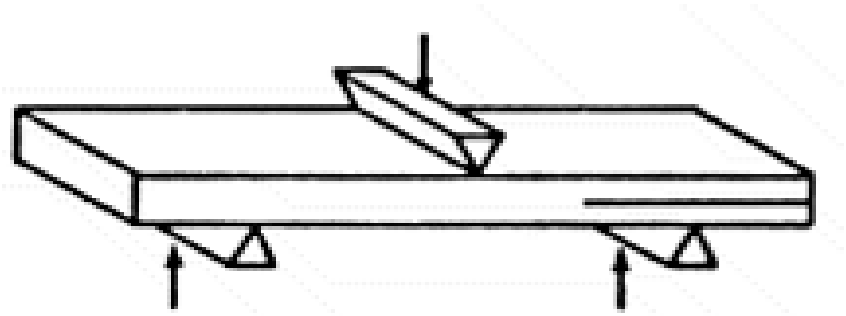


Required Displacement for Crack Growth

END-NOTCHED TEST CONFIGURATIONS:

Three-Point Flexure Vs. Cantilever Support

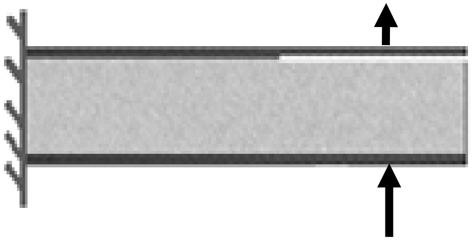




Monolithic Composites:

3 Point End Notch Flexure (3ENF)

(Currently proposed for ASTM standardization)



Sandwich Composites:

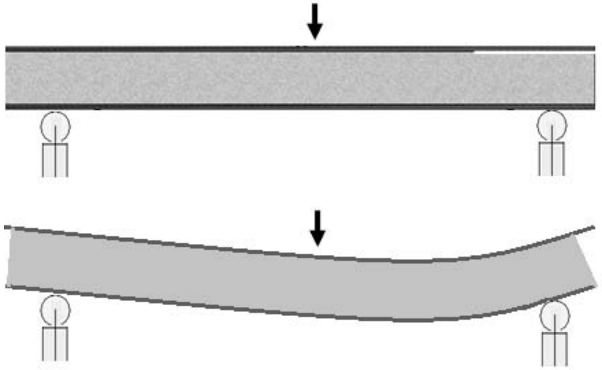
End Notch Cantilever (ENC)

END-NOTCHED TEST CONFIGURATIONS:

Three-Point Flexure Vs. Cantilever Support

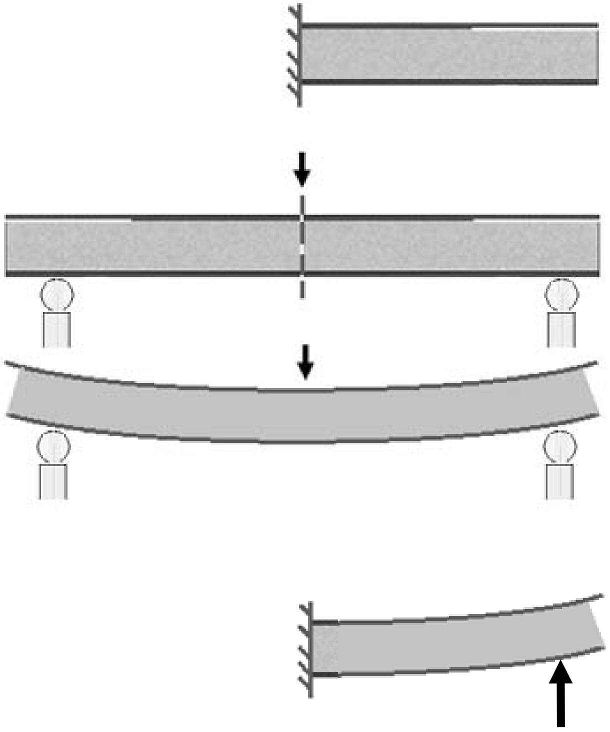
End Notched Flexure

(Unsymmetric bending)



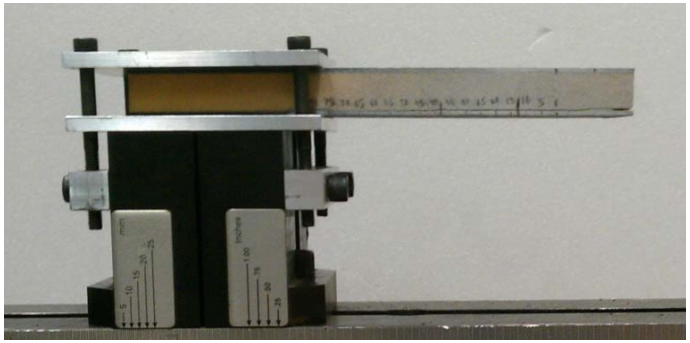
End Notched Cantilever

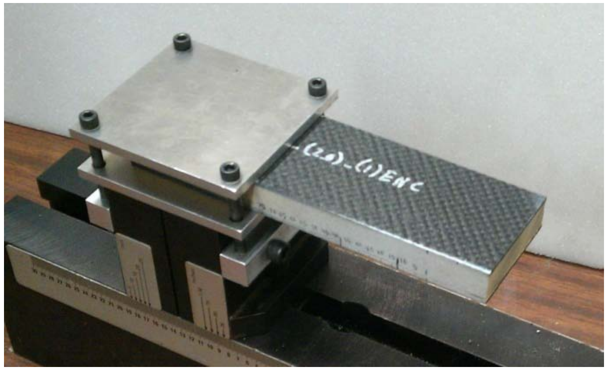
(Symmetric bending)



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***





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 D30**
- **Summary of findings at European Honeycomb Sandwich Disbond Growth Workshop (EASA, Cologne, June 2013)**

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