DAMAGE TOLERANCE TEST METHOD DEVELOPMENT FOR SANDWICH COMPOSITES

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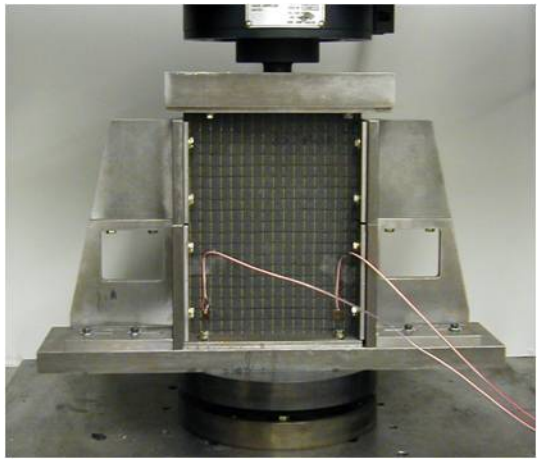
Outline

- ***Review*: Damage Tolerance Test Method Development for Sandwich Composites**
- ***Introduction*: Notch Sensitivity of Sandwich Composites**
- ***Summary*: Development and Evaluation of Fracture Mechanics Test Methods for Sandwich Composites**

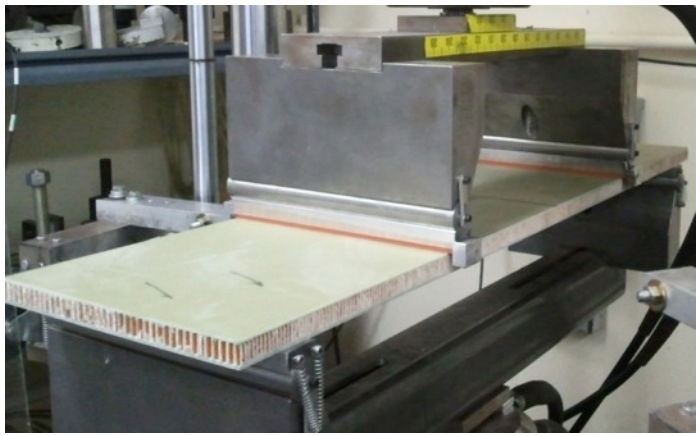
RESEARCH OBJECTIVES:

Damage Tolerance Test Methods for Sandwich Composites

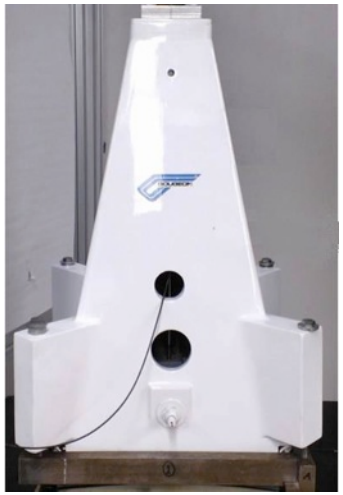
- Identify and evaluate candidate test methodologies
- Compare residual strengths of impact damaged sandwich panels using proposed test methods
- Develop standardized ASTM test method(s)
- Investigate scaling of test results



Edgewise Compression



Four-Point Flexure



Hydromat
Pressure Loading

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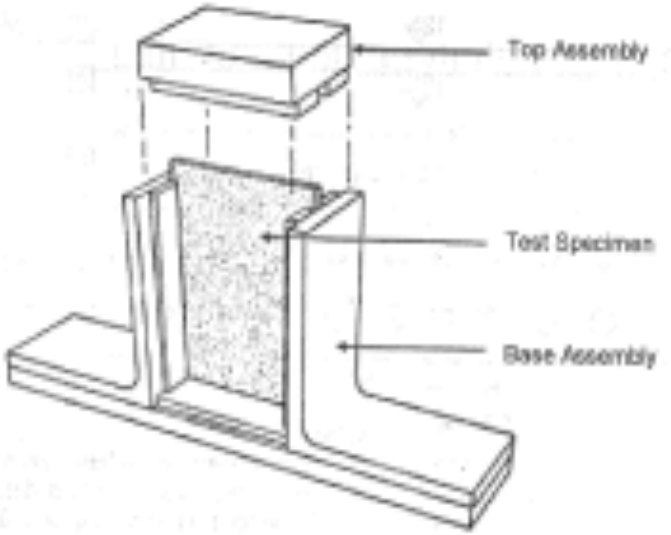
Considerations for Test Method Development:

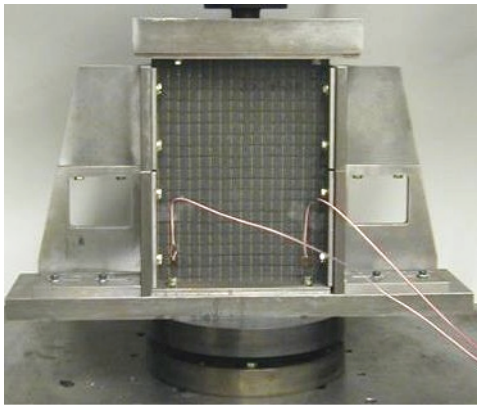
Damage Tolerance of Sandwich Composites

- Identify intended usage(s)
  - Quality Assurance
  - Material ranking/selection/specification
  - Establishing design properties/allowables
  - Research and development activities
  - Product development
- Ensure compatibility with existing ASTM Standard for Damage Resistance Testing of Sandwich Composites (ASTM D7766, 2011)
- Establish suitable range of sandwich configurations
  - Facesheet and core parameters
  - Specimen size relative to damage size
  - Desired degree of strength reduction

Edgewise Compression Testing For Damage Tolerance: Considerations For Test Method Development

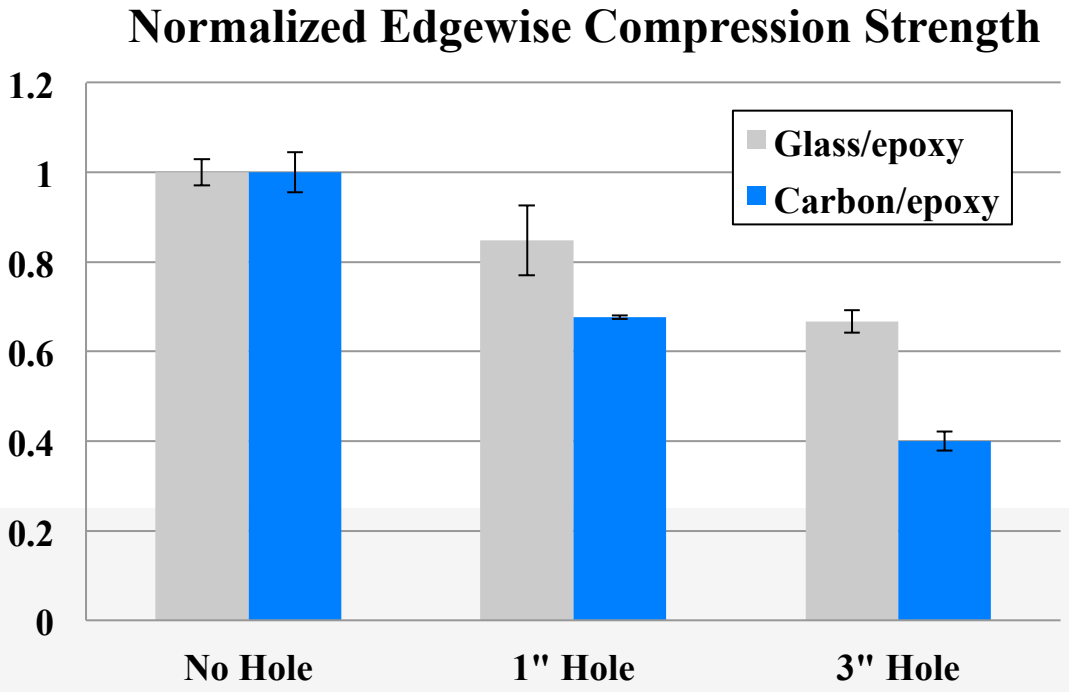
- **Test fixture/Specimen support**
  - **"Clamped" at top & bottom**
  - **Potting of sandwich specimen ends**
    - **Internal potting: removal of core**
    - **External potting ???**
  - **Side supports**
    - **Knife edge (pinned)**
    - **Clamped (reduce rotation)**
- **Specimen size**
  - **Separation of damage and boundary effects**
  - **Production of acceptable strength reductions**

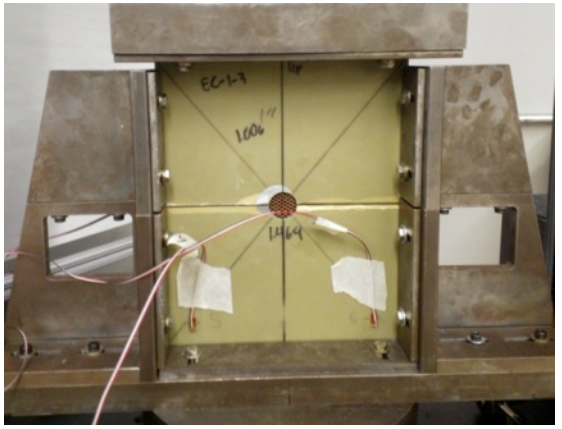


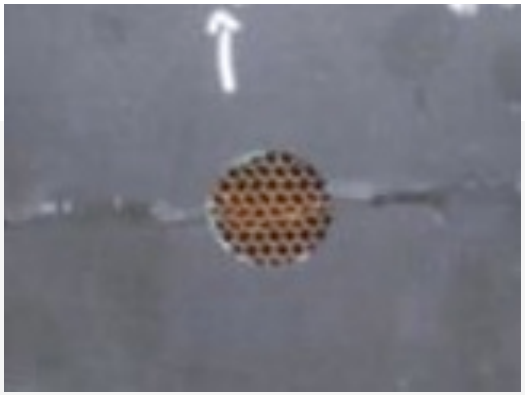


Edgewise Compression Testing For Damage Tolerance: Initial Evaluations Using Idealized Impact Damage

- Glass/epoxy & carbon/epoxy facesheets, Nomex honeycomb core
- "Idealized" damage: 1 in. & 3 in. thru-hole in one facesheet
- Strength reductions relative to baseline (no damage) condition

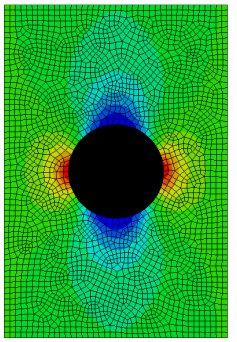




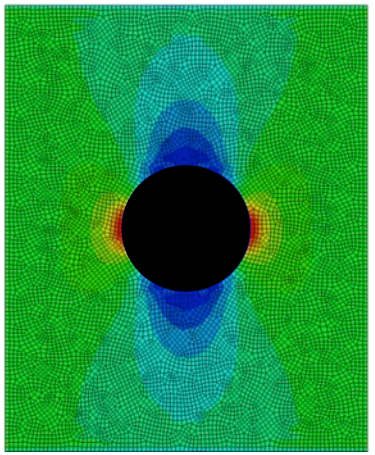


Edgewise Compression Testing For Damage Tolerance: Investigating Required Specimen Dimensions

- **Comparison with laminate Compression After Impact (CAI) test method (ASTM D 7137)**
  - Damage size limited to half unsupported specimen width (1.7 in.)
- **Analysis of laminate and sandwich specimens modeled with idealized damage**
  - Thru and partial thickness holes
  - 4 x 6 in. cross-ply and quasi-isotropic laminates
  - 8.5 x 10.5 in. sandwich specimens
    - Carbon-epoxy laminate/facesheets
    - Nomex honeycomb core



Laminate

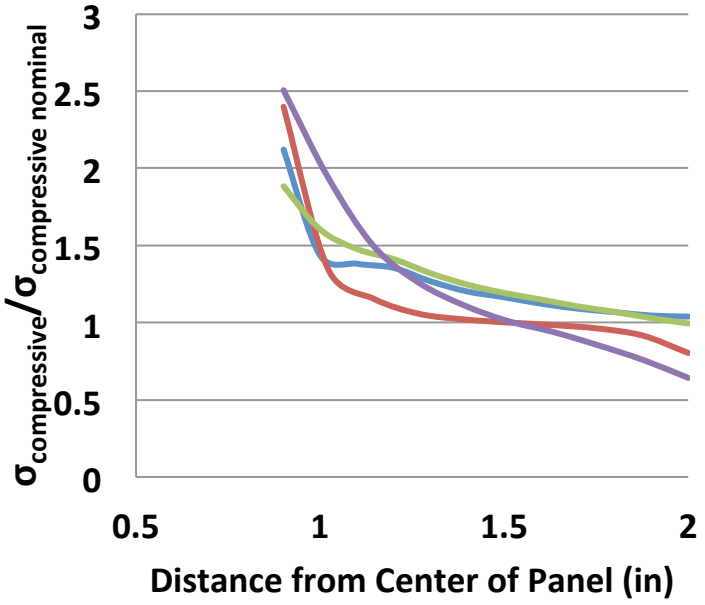


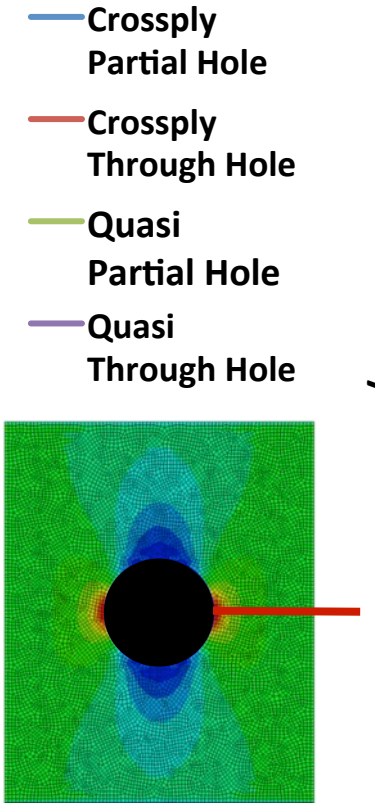
Sandwich

Investigating Required Specimen Dimensions:

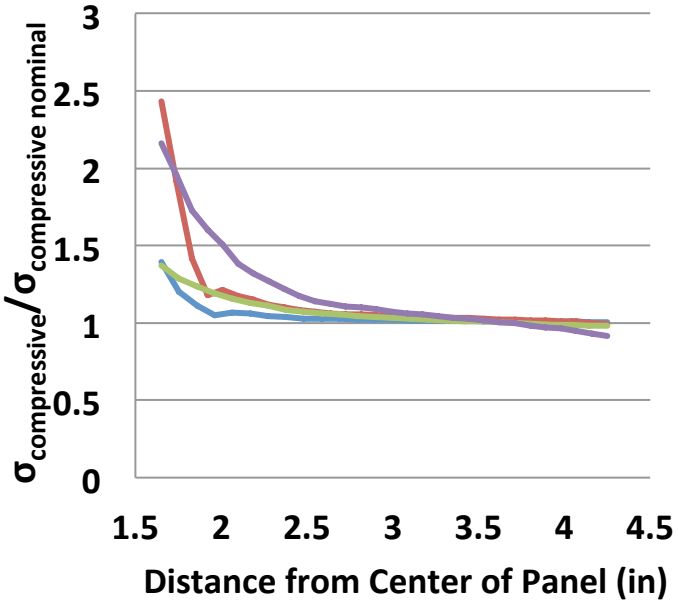
Comparison of Laminate and Sandwich Stress Distributions

4 x 6 in. Laminate
1.7 in. damage dia.





8.5 in. x 10.5 in. Sandwich
3 in. damage dia.



Similar compressive stress distributions across specimen widths

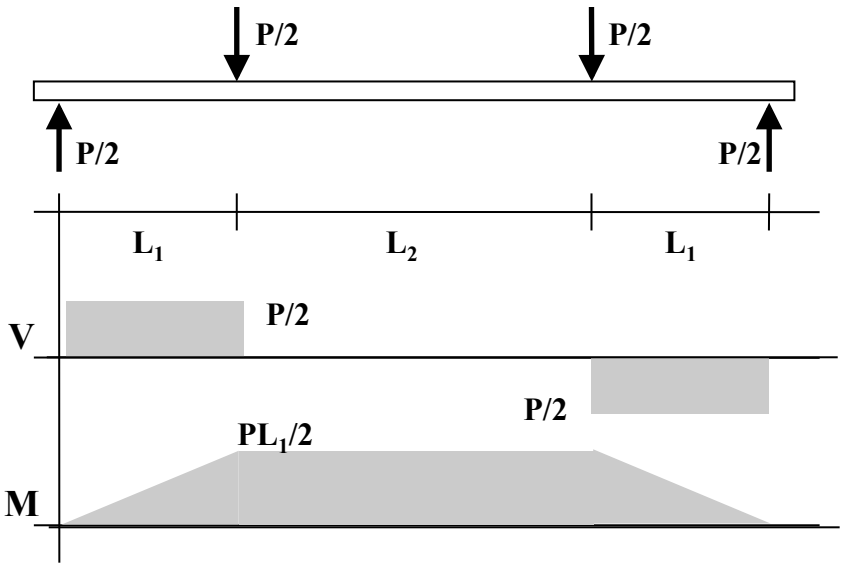
Edgewise Compression Testing For Damage Tolerance:

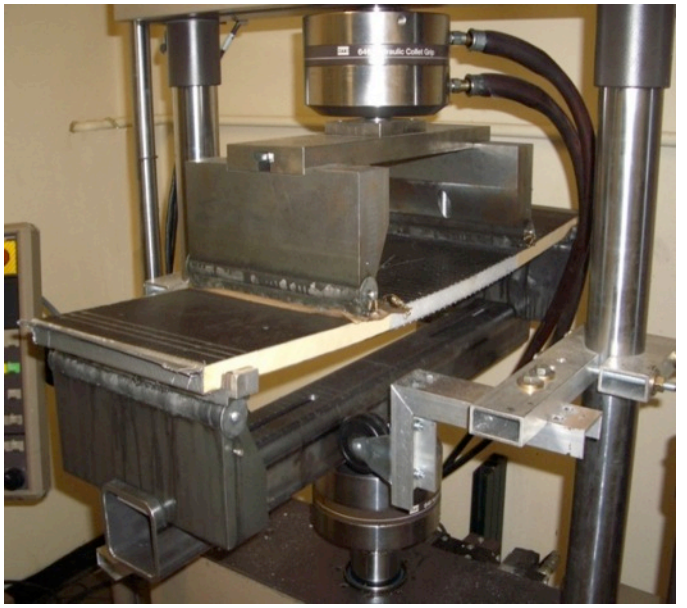
Current Focus

- **Testing with actual impact damage**
  - **Impact procedure defined in ASTM D7766**
  - **Strain distributions via Digital Impact Correlation**
  - **Numerical modeling: prediction of residual strength**
- **Addressing suggestions provided by ASTM Committee D30 (October 23, Wichita, KS)**
  - **Harmonize with existing ASTM standard for Damage Resistance of Sandwich Composites, ASTM D7766 (2011)**
  - **Determine/specify default sandwich specimen dimensions**
  - **Provide guidance for selection of alternate specimen dimensions**
    - **Thickness of sandwich configuration**
    - **Damage area**

Four-Point Flexure Testing For Damage Tolerance: Considerations For Test Method Development

- **Required specimen dimensions for central test section**
  - Separation of damage and loading point/boundary effects
- **Required length of outer regions of sandwich specimen**
  - Sufficient length to develop bending moment
  - Core requirements for shear stress
- **Facesheet /core requirements at loading points**





Four-Point Flexure Testing For Damage Tolerance: Initial Evaluations

- **<u>First Round:</u> Undesirable failures in non-damaged sandwich specimens without modification**
- Shear failure of honeycomb core in outer regions
- Localized failure at loading point
- Excessive deflection
- **<u>Second Round:</u> Utilized spliced cores for higher shear strength and reduced stress concentrations at loading points**
  - "Idealized" damage: 1 in. & 3 in. thru-hole in one facesheet

Four-Point Flexure Testing For Damage Tolerance:

Current Focus

- **Testing with actual impact damage**
  - **Impact procedure defined in ASTM D7766**
  - **Strain distributions via Digital Impact Correlation**
  - **Numerical modeling: prediction of residual strength**
- **Addressing suggestions provided by ASTM Committee D30 (October 23, Wichita, KS)**
  - **Harmonize with existing ASTM standard for Damage Resistance of Sandwich Composites, ASTM D7766 (2011)**

➡ **Determine/specify default sandwich specimen core thickness**

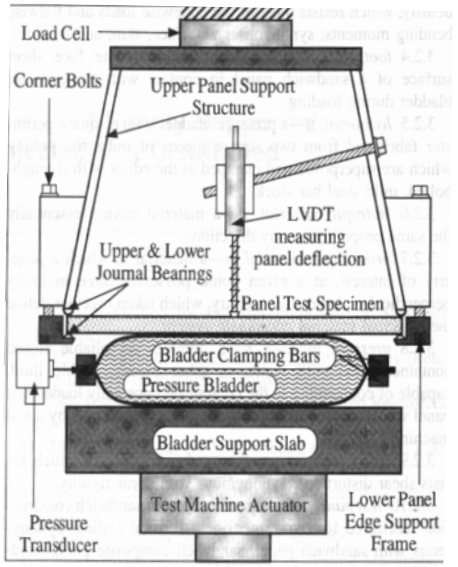
- **Reduce/eliminate problems with core shear failure, localized failure at loading points, excessive deflection**
- **Utilize facesheet material/layup/thickness of interest**

"Hydromat" Pressure Testing For Damage Tolerance: Based on Existing Standard: ASTM D 6146

- Simulates hydrostatic pressure loading
- Pressure loading of sandwich panel using test machine & pressure bladder
- Used primarily in marine industry

Undesirable results using specimens with "idealized damage"

- Core shear failures in glass/epoxy specimens
- No failure at deflection limits for undamaged and 1 in. hole carbon/epoxy specimens



Not pursuing further for sandwich damage tolerance testing

Outline

- **Review: Damage Tolerance Test Method Development for Sandwich Composites**

- **Introduction: Notch Sensitivity of Sandwich Composites**

- **Summary: Development and Evaluation of Fracture Mechanics Test Methods for Sandwich Composites**

Background:
Notch Sensitivity of Sandwich Composites

- **Notch sensitivity test methods for monolithic composites are reaching relatively high levels of maturity**

  In-plane loading: open hole tension, open hole compression

  Out-of-plane loading: bending, out -of -plane shear (Parmigiani)

- **Less attention to notch sensitivity tests methods of sandwich composites**
  - Currently no standardized tests for notch sensitivity
- **Failure prediction of notched monolithic composites is receiving considerable attention**
  - Reduced focus on analysis of notched sandwich composites

RESEARCH OBJECTIVES:
Notch Sensitivity of Sandwich Composites

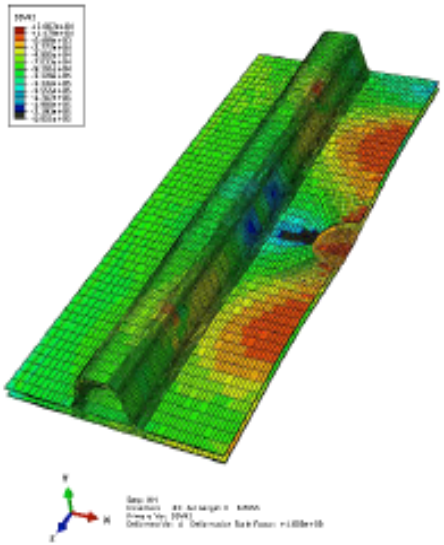
- **Initial development of notched test methods and associated analysis methodology for composite sandwich panels**
- **Assist in documenting notched testing and analysis protocols in Composite Materials Handbook (CMH-17) with Parmigiani group (OSU)**
- **Explore development of new ASTM standards:**
  - **Notched laminate tests under out-of-plane loading (with Parmigiani group,OSU)**
  - **Notch sensitivity tests for sandwich composites**

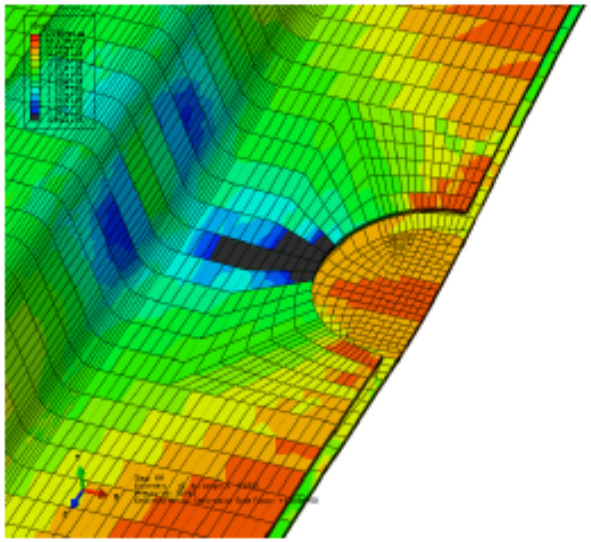
Initial Focus:
Notch Sensitivity of Sandwich Composites

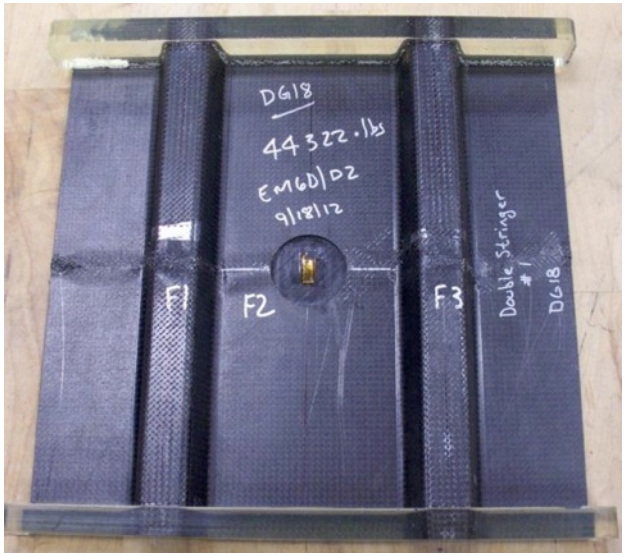
- **Recruit graduate student!**
  - Mr. Marcus Stanfield, Ph.D. candidate
- **Literature review**
  - Notch sensitivity test methods for sandwich composites
  - Numerical simulations: notched sandwich composites
- **Initial investigation: Notched sandwich testing and analysis**
  - Open-hole compression test of sandwich composite
  - Progressive failure analysis using ABAQUS with NDBILIN progressive damage model (Materials Sciences Corp)

Previous Analyses using ABAQUS with NDBILIN:

Failure Analysis of Stiffened Composite Panel







Progressive failure analysis of stiffened panel with idealized impact damage

-ABAQUS finite element code

- NDBILIN progressive damage user material subroutine

Experimental validation using idealized impact damage

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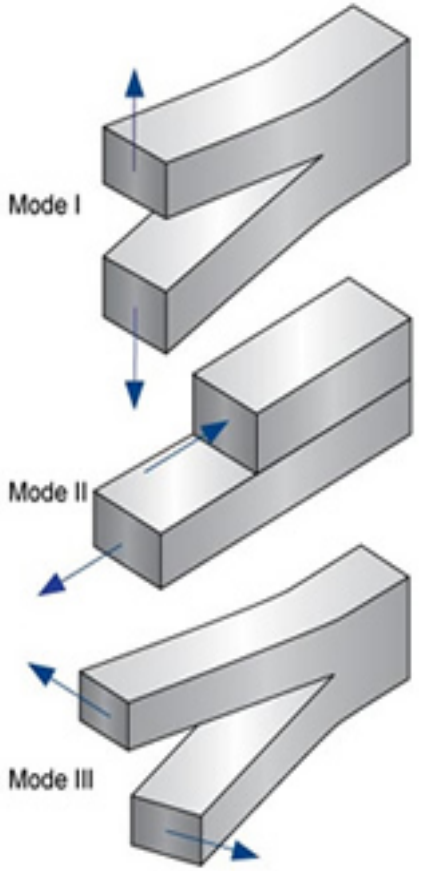
- **Introduction: Notch Sensitivity of Sandwich Composites**

- **Summary: Development and Evaluation of Fracture Mechanics Test Methods for Sandwich Composites**

RESEARCH OBJECTIVES:

Fracture Mechanics Test Methods for Sandwich Composites

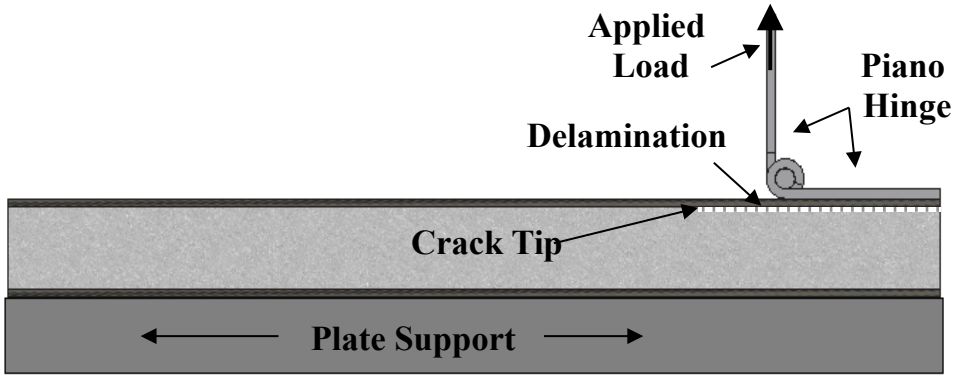
- **Focus on facesheet-core debonding**
- **Mode I and Mode II**
  - **Identification and initial assessment of candidate test methodologies**
  - **Selection and optimization of best suited Mode I and Mode II test methods**
  - **Development of draft ASTM standards**

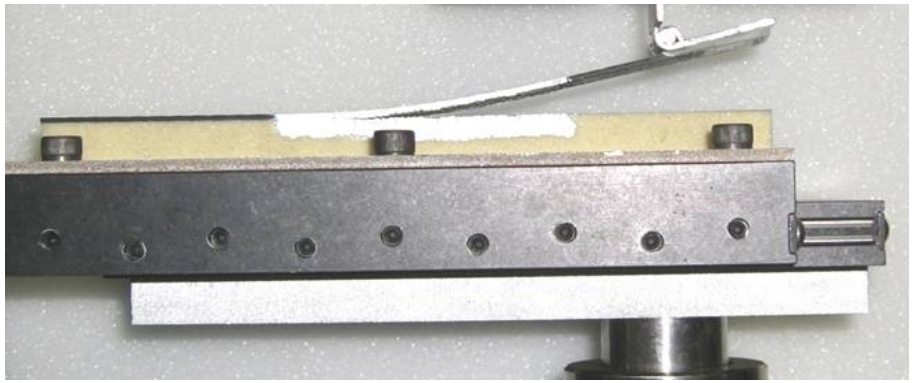


MODE I TEST CONFIGURATION:

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***

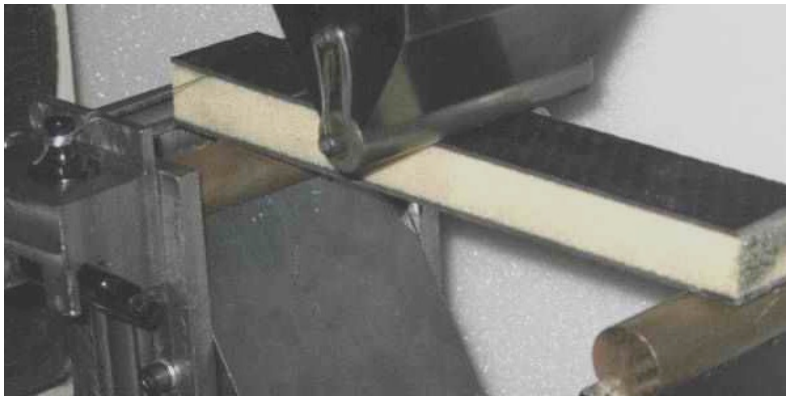


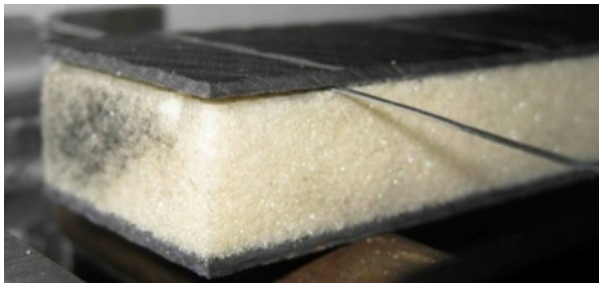


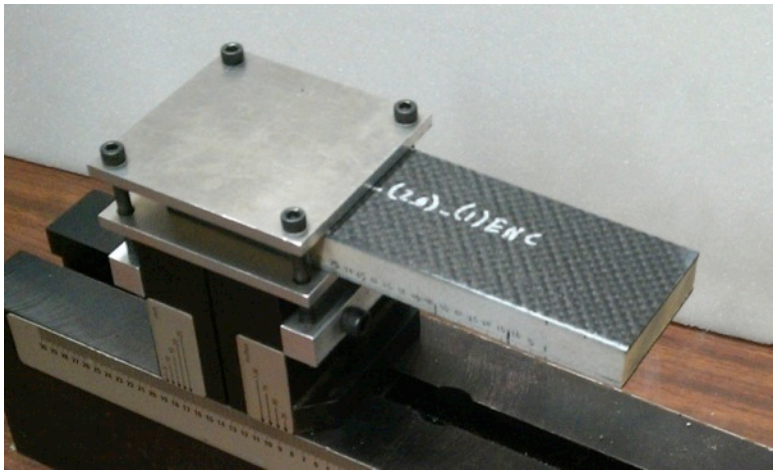
MODE II TEST CONFIGURATION:

End-Notched Sandwich Bend Test

- **Three-point flexure and cantilever beam configurations**
- **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***







CURRENT STATUS:

Fracture Mechanics Test Methods for Sandwich Composites

- **Participation/Support of CMH-17 Sandwich Disbond Technical Committee**
  - **European meeting in Cologne Germany (EASA), July 2013**
  - **U.S. meeting next week in Hampton, VA Nov 20-21**
- **Completion of initial draft of Mode I SCB test method for ASTM standardization**
- **Documentation of findings**
  - **FAA Report**
  - **Journal publications**

Thank you for your attention!

Questions?