Certification of Discontinuous Composite Material Forms for Aircraft Structures

Presented at the:

AMTAS Spring Meeting

March 16, 2010

The Joint Advanced Materials and Structures Center of Excellence

Cert of Discontinuous Composite Material Forms for Aircraft Structures

Outline:

- -Introduction
- -Research Goals/Tasks
- -Current Research Summary
  - -Tensile Testing
  - -Microscopy
- -Future Research
- -Discussion

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- Key Issues
  - Rigorous structural analyses difficult:
    - rel high variability in all mechanical properties
    - lack of material allowables
    - lack of standard design or analysis methods
  - Consequently certification of DFC parts currently requires testing large numbers of parts (“point design”)…issues:
    - Time-consuming
    - Expensive for all (material producer, part manufacturer, aircraft manufacturer, FAA)
    - Leads to suboptimal (e.g., overweight) parts

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- Overall objective: Simplify certification of discontinuous fiber composite aircraft parts

Project Information

- Personnel Involved:

  University of Washington (principally):
    Paolo Feraboli, Marco Ciccu (A&A Dept)
    Mark Tuttle, Tory Shifman (ME Dept),
  Hexcel (principally):
    Bruno Boursier (Dublin, CA)
    Dave Barr (Kent, WA)
  Boeing (principally):
    Bill Avery (Seattle, WA)
  FAA (principally):
    Larry Ilcewicz (Renton, WA)

- FAA Technical Monitor:
    Curt Davies (Atlantic City, NJ)

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- Objective:
  - Simplify certification of DFC parts/structures
- Technical Approach:
  - Use HexMC as model material
  - 4-year study envisioned (began Aut '08)
  - Funding and specific technical tasks reviewed and (re)defined annually
  - All specific technical tasks defined with reference to the "building block philosophy" (CMH-17)

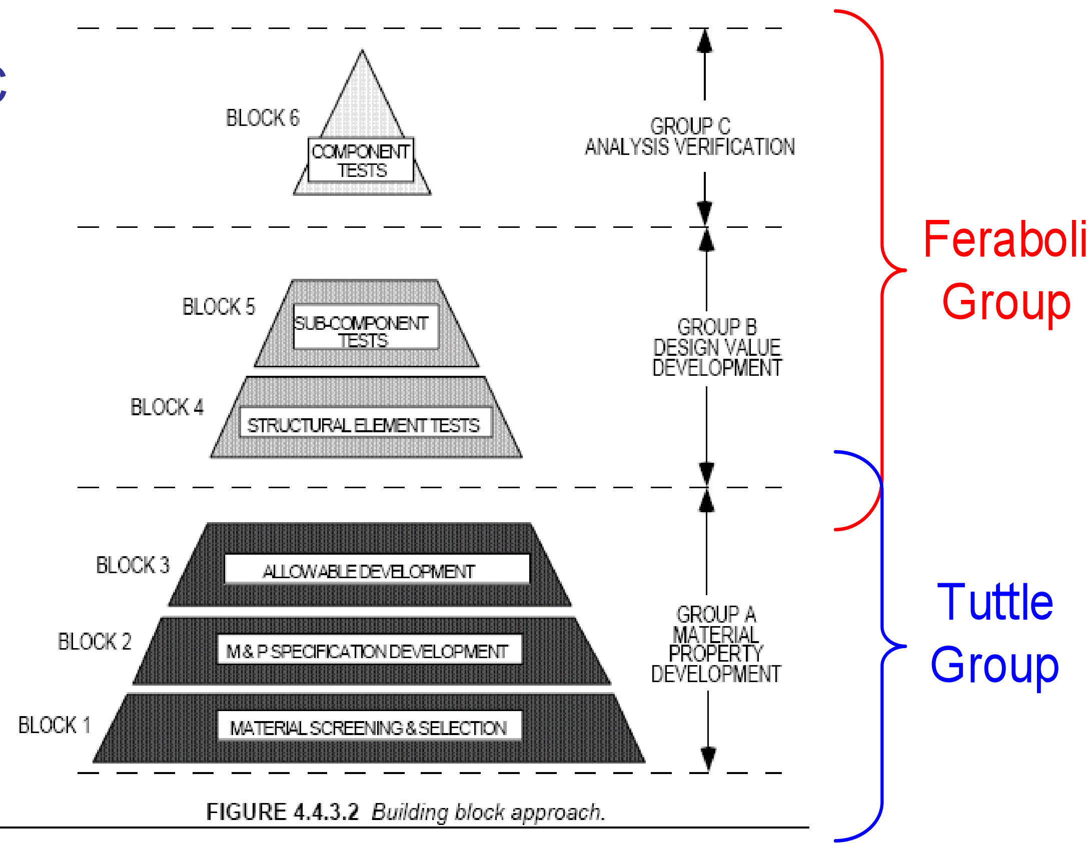

FIGURE 4.4.3.2 *Building block approach.*

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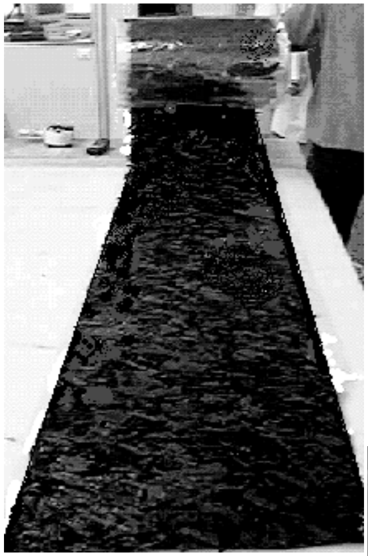
- HexMC® parts are produced using compression molding
- Industrial grade HexMC®:
  - Available from Hexcel in pre-preg form
- Aerospace grade HexMC®:
  - Exclusively provided by Hexcel as manufactured and finished parts



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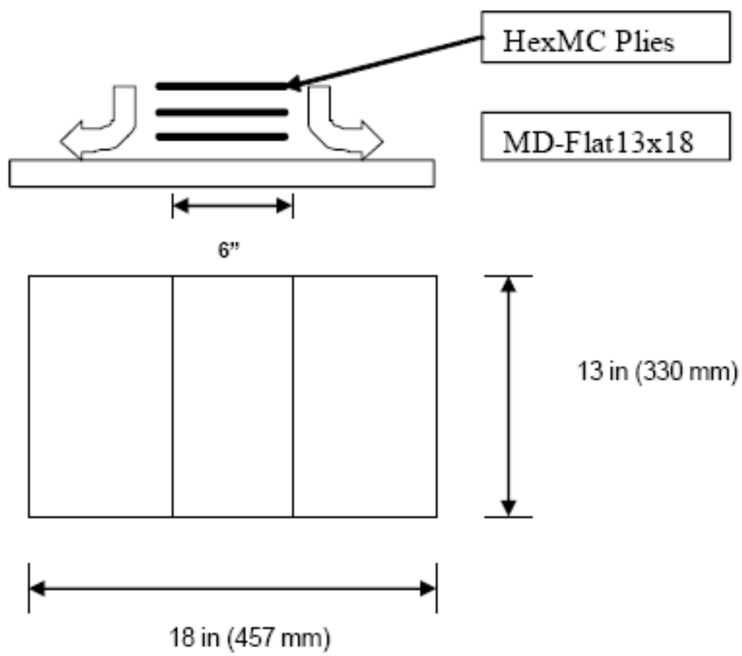
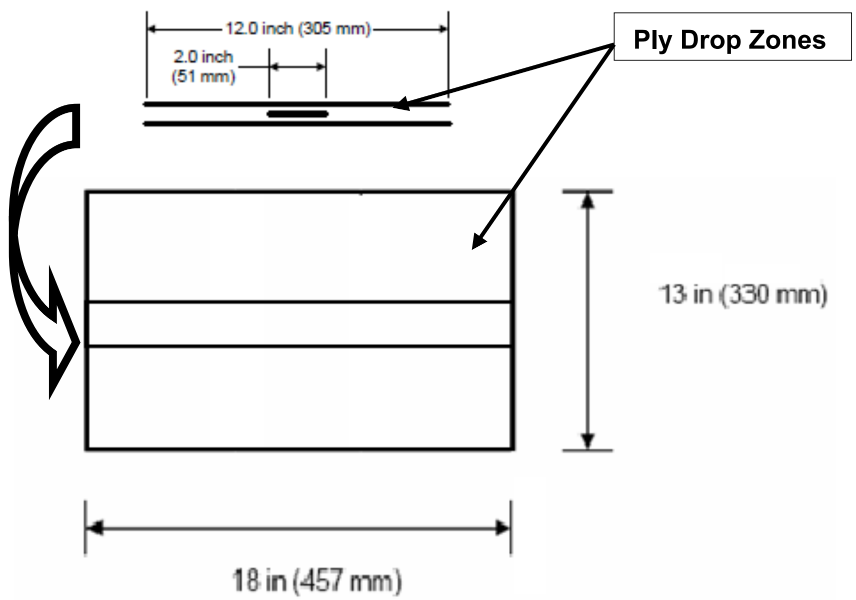
Panel Testing:

- 2 Types: High Flow Panels, Ply Drop Panels
- 3 Approximate Thicknesses: 0.09, 0.14, 0.23 in



High Flow Panel Layup



Ply Drop Panel Layup

Project Tasks 2010

Tasks for 2010:

(Task, Expected Completion)

1. Tensile Testing of High Flow and Ply Drop Panels, April 1
2. Optical Microscopy/Analysis of Microstructure, April 1
3. Bending Tests of HexMC Angles with Analysis/FE Modeling, July 1
5. Develop Empirical Rules of Flow Behavior and Effects on Material Properties, October 1
6. Apply Halpin Analysis, November 20
7. Measure Thermal Stresses, November 20

Current Research Results and Methods

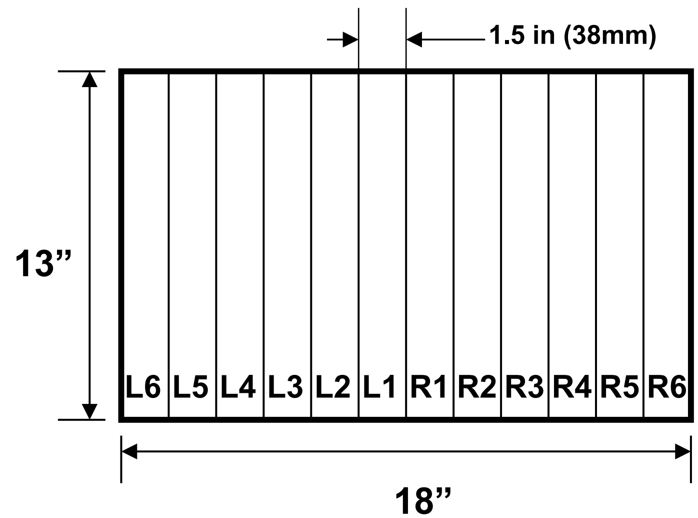
(A sampling of current activities & preliminary results):

– Tensile testing in High Flow panels

– Microscopy analysis of composite structure

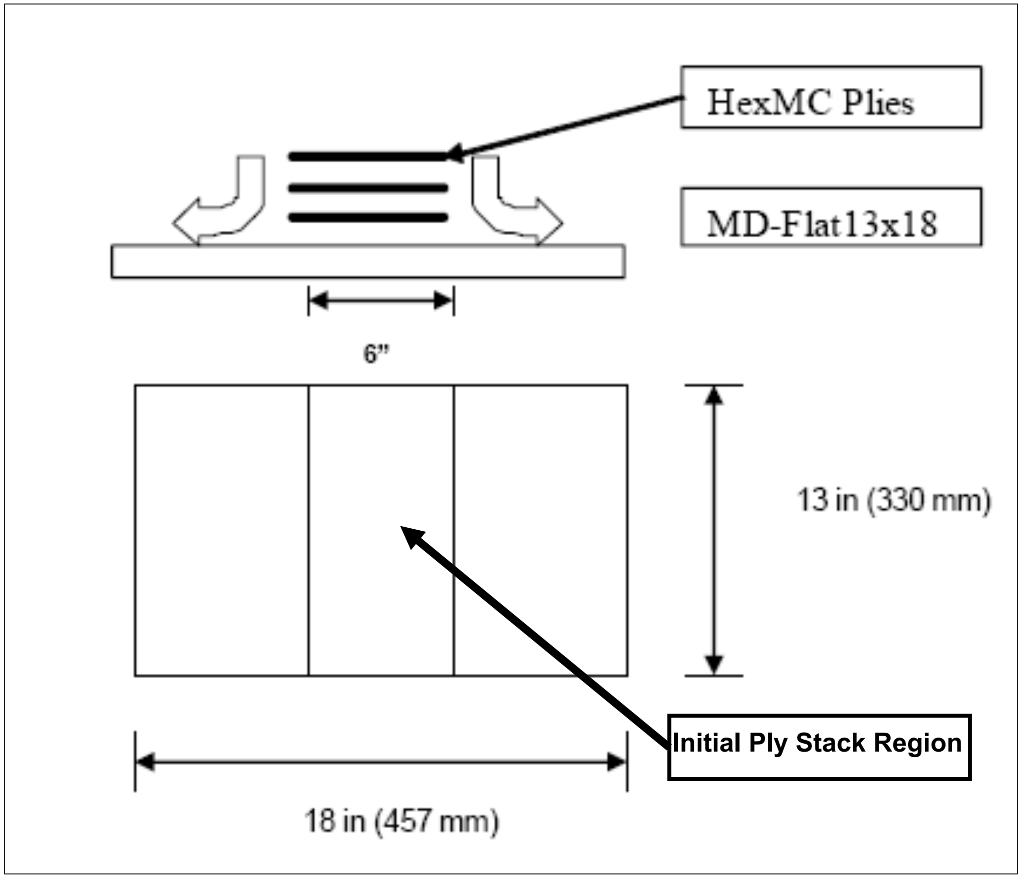
Tensile Testing

Panels fabricated by Hexcel:
- in-plane dimensions 13x18 in
- 2 Panel Lay-up Types: High Flow, Ply Drop
- Target thicknesses:
  0.090 in
  0.140 in
  0.230 in



Tensile Specimen:
- 12 specimen machined per plate
- Specimen dimensions: 1.5 x 13 in
- Modulus measured using 2” extensometer

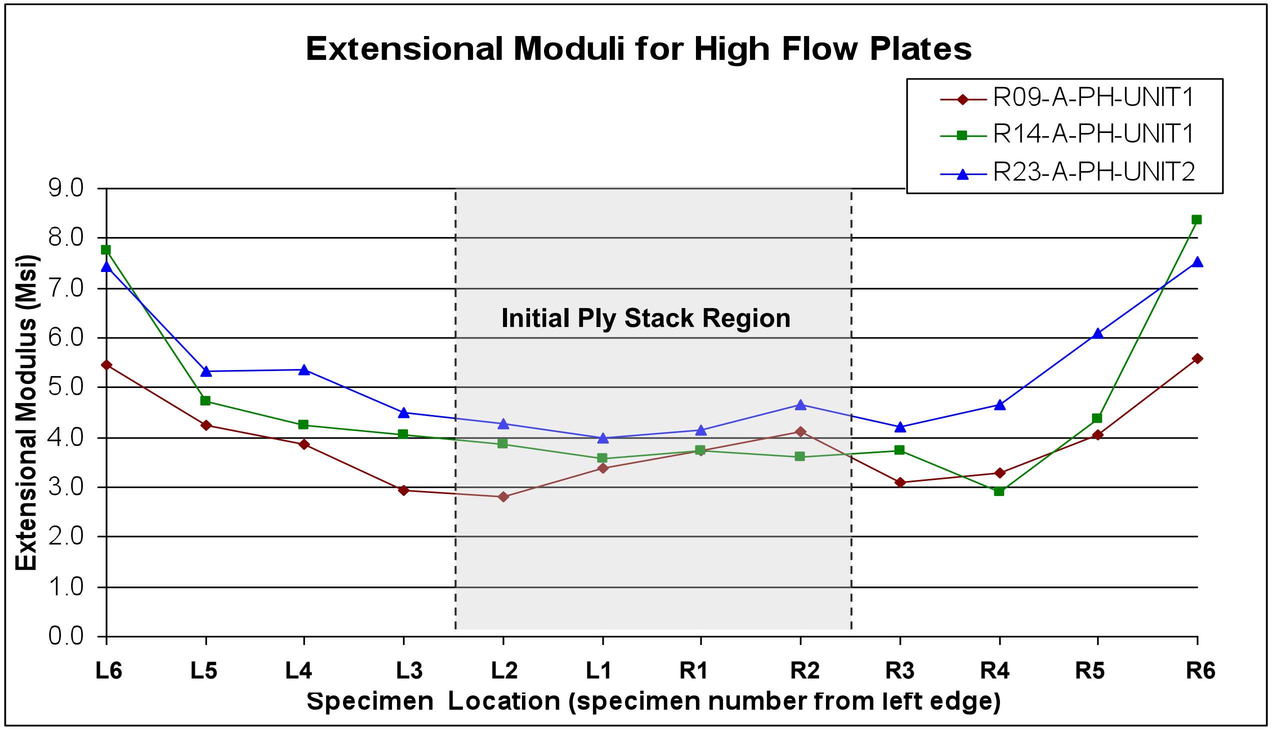
Tensile Testing - High Flow Plates



High Flow Panel Tensile Testing

Tensile Testing – High Flow Plates

High Flow Plates - Extensional Moduli



E_{ax} GPa (Msi):

Min: 19.4, (2.8)
Max: 57.6, (8.4)
(Max = 3 x Min)

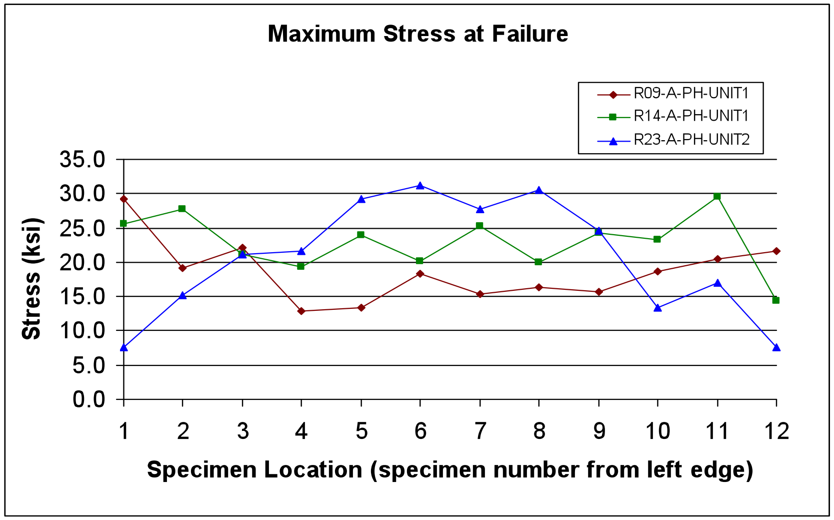
•For specimens 4L→4R (only):

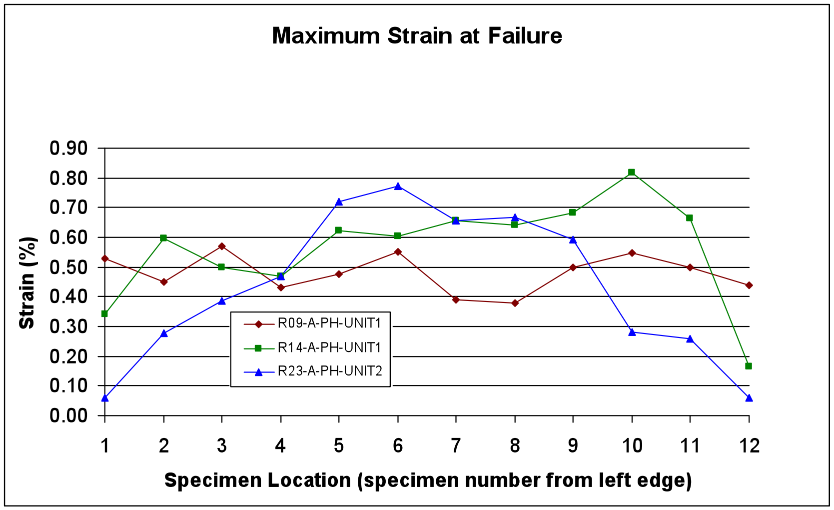
E_{ax} = 28.2 ± 8.81 GPa (4.09 ± 1.28 Msi)

-“Tub” shaped modulus profile shows flow effects on material properties

-Higher modulus at outsides of plate show fiber alignment toward axial direction of tensile specimen

Tensile Testing – High Flow Plates





σ_{fail}, MPa (ksi)

Min: 52.9(2.81)

Max: 215 (31.2)

(Max = 4 x Min)

Specimens 4L→4R (only):

σ_{fail} = 152 ± 63.1 MPa

(22.1 ± 9.15 ksi)

- Significant scatter in stress/strain to failure

ε_{fail}, %

Min: 0.060

Max: 0.816

(Max = 13.6 x Min)

Specimens 4L→4R (only):

ε_{fail} = 0.549 ± 0.268%

Microscopy

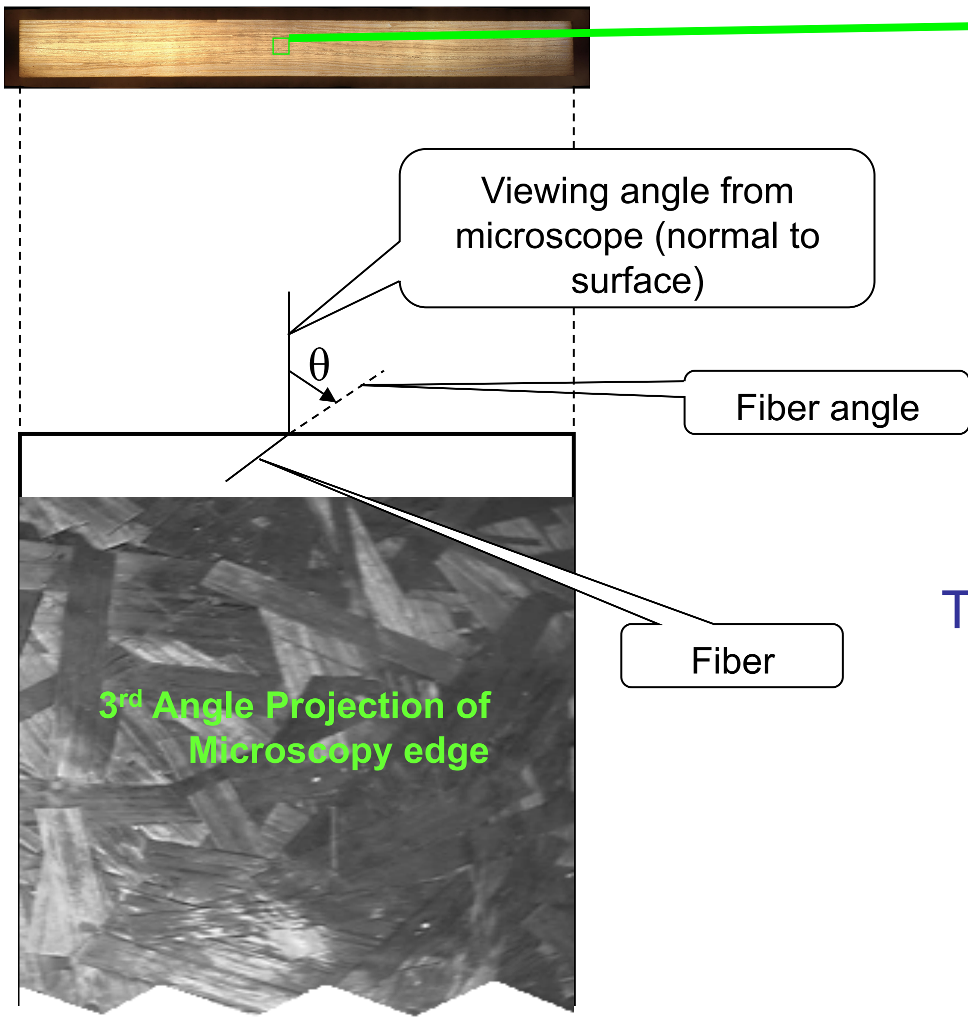
- Microscopy is performed on inter-panel surfaces normal to axial loading direction
- Objectives:
  - Classify level of “Randomness” in fiber orientation structure
  - Determine from fiber orientations, level of flow and flow directions
  - Determine fiber volume fractions
- Microscopy results discussed include High Flow plate data only, no Ply Drop plate microscopy will be discussed

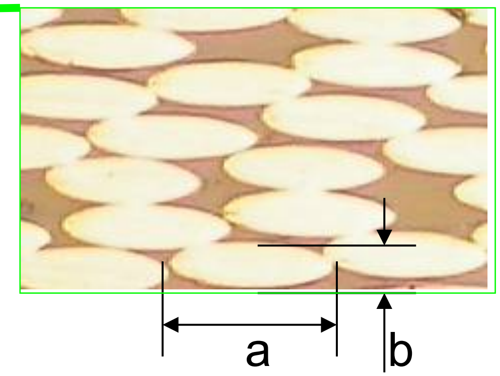
Microscopy - Method

Specimen are polished on polishing wheel to 0.4μm abrasive

Images of surface are taken using a microscope with a digital camera attachment

Microscopy – Fiber Angle Convention Defined





Fiber angle: $$\theta = \cos\left(\frac{b}{a}\right)$$

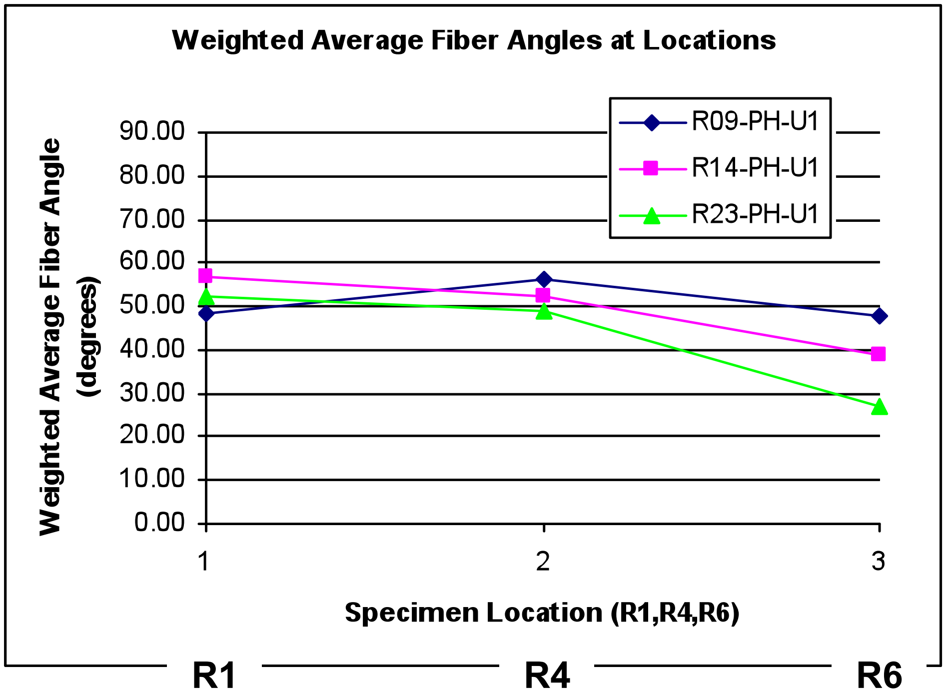
There are many chips through the thickness of a panel. To determine the weighted average fiber angle of these chips:

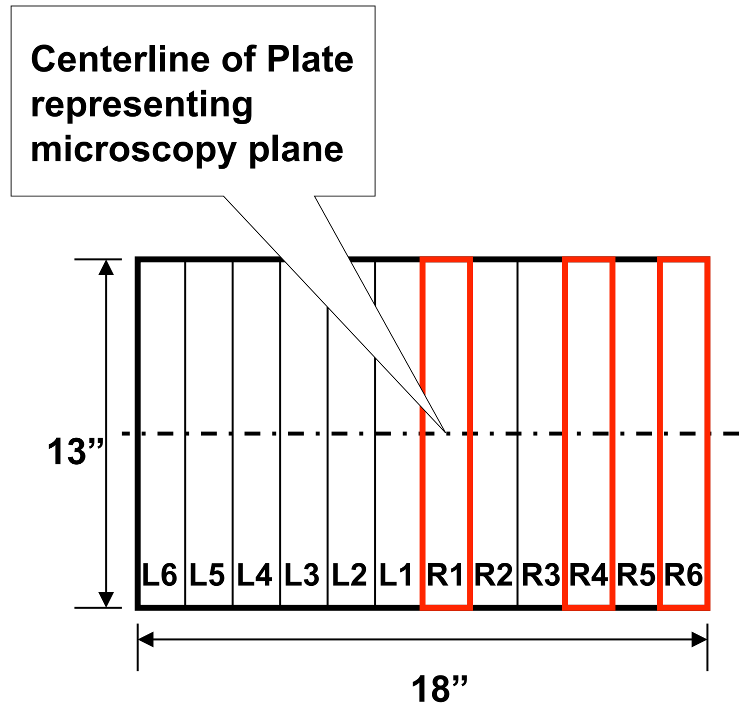
$$\theta_{Avg} = \frac{\sum_{i=1}^{n} \theta_i t_i}{t_{tot}}$$

Microscopy

- Since weighted average fiber angle (WAF) is measured using the aspect ratio of a fiber end, it is an absolute value of the fiber angle
- Absolute value of WAF lies between 0-90º. A perfectly random fiber orientation would occur at a WAF of 45º
- Due to fiber angle convention, lower angles represent fiber alignment towards axial direction (normal to microscopy surface), while higher angles are oriented parallel to surface

Microscopy Results





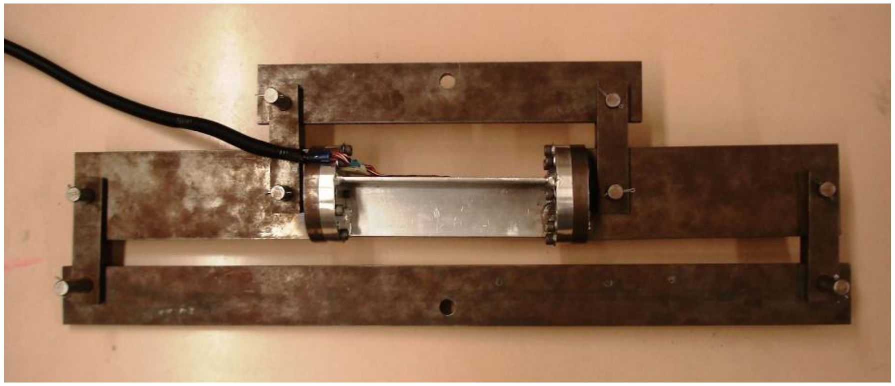
- Weighted Average Fiber Angles (WAF) at a point decreases when moving from center of plate to edge (R1->R6), as fibers begin to align parallel to panel edge

Microscopy Results

- Fiber Volume Fractions (FVF) at each microscopy location were taken to determine trends in FVF with plate location
- No trends were determined in FVF from location to location, though there was a range of FVF's found
- It appears that FVF is independent of material flow during molding.

Future work

- Bending Test Objectives:
  - Measure bending material modulus and compare to beam theory predictions
  - FE model using material bending properties
- Bending tests on HexMC angles:
  - 3 different thicknesses with corresponding flange lengths
  - 4 point bending
  - Strain gage measurements for strain, 1” gage lengths
  - Projection Moiré technique for measuring out of plane deflection/ buckling



Four-Point Bending Fixture for Angle Beams

Summary

- 2 types of HexMC panels researched: High Flow, Ply Drop, each representing a special case of material flow
- High modulus variations in High Flow plates shows effect of material flow during panel manufacturing on properties
- Microscopy shows weighted average fiber angles at locations in a panel allowing for a measurement of flow in a panel at a location
- Microcopy will be used to corroborate modulus and strength trends seen in these plate tests.

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QUESTIONS ?