JAMS

Certification of Discontinuous Composite Material Forms for Aircraft Structures

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Cert of Discontinuous Composite Material Forms for Aircraft Structures

Outline:

- -Research Introduction
- -HexMC Angle Component Bending Tests
- -Elastic Stiffness and Analysis Results
- -Buckling Analysis Results
- -Discussion

Cert of Discontinuous Composite Material Forms for Aircraft Structures

- 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

Cert of Discontinuous Composite Material Forms for Aircraft Structures

- 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)

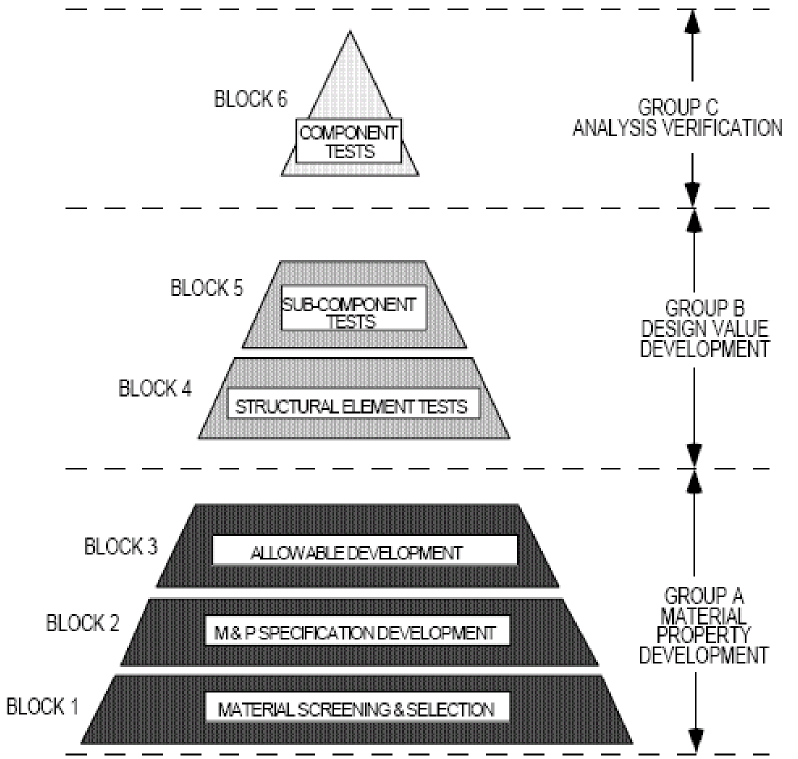

FIGURE 4.4.3.2 *Building block approach.*

Feraboli Group

Tuttle Group

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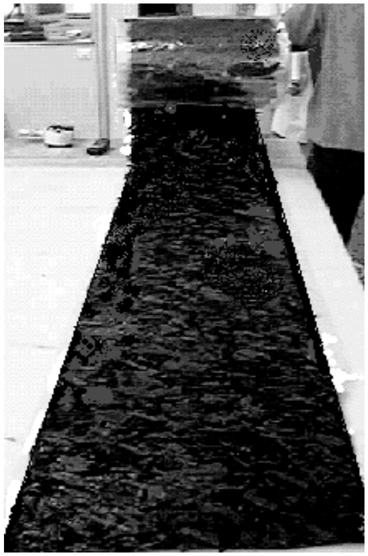
- HexMC® parts are produced using compression molding
- Industrial grade HexMC®:
  Available from Hexcel in pre-preg form
- Aerospace grade HexMC®:
  Exclusively provided by Hexcel as manufactured and finished parts



HexMC Angle Bend Testing Overview

- Testing Objective: Compare beam theory and FEA analyses using coupon level isotropic material properties to 4 point bending test results
- Research Results (preliminary)
  - Static 4 point bend tests to obtain elastic stiffness properties with beam theory analysis
  - Bending failure tests for buckling loads with finite element buckling analysis

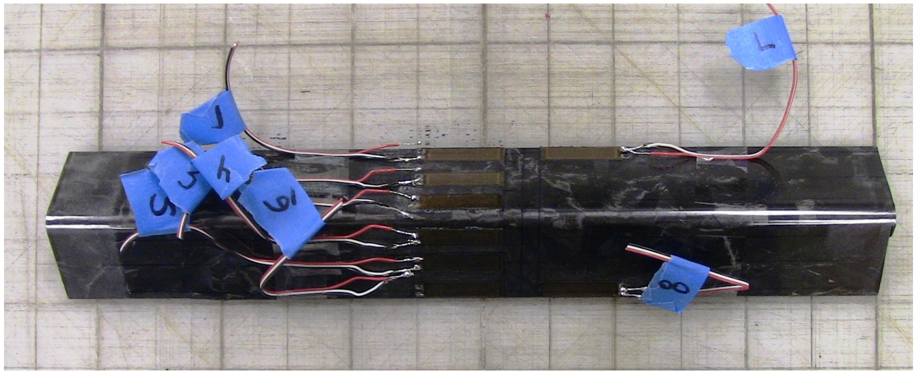
HexMC Compression Molded Angle Beam Specifics

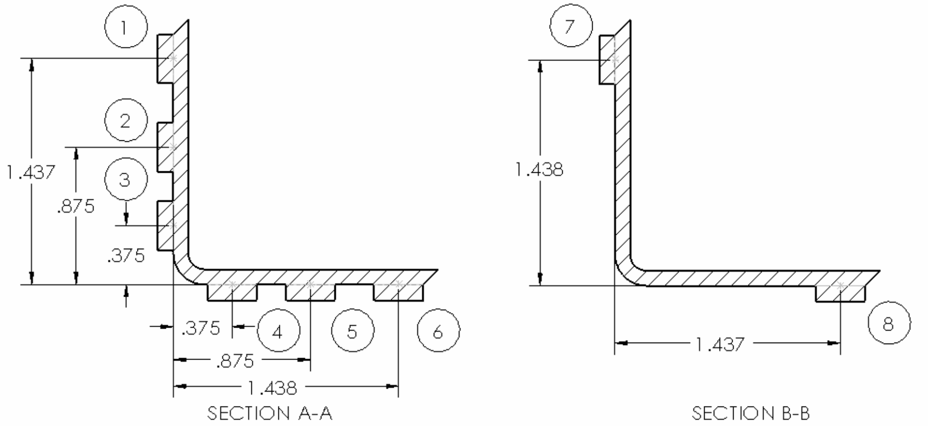
- Manufactured by Hexcel Corporation
  - 0.188 x 3.5 in (Large)
  - 0.188 x 2.5 in (Medium)
  - 0.097 x 1.7 in (Small)

  - Beam length: 14 inches (final cut length)

Testing Apparatus/Procedure

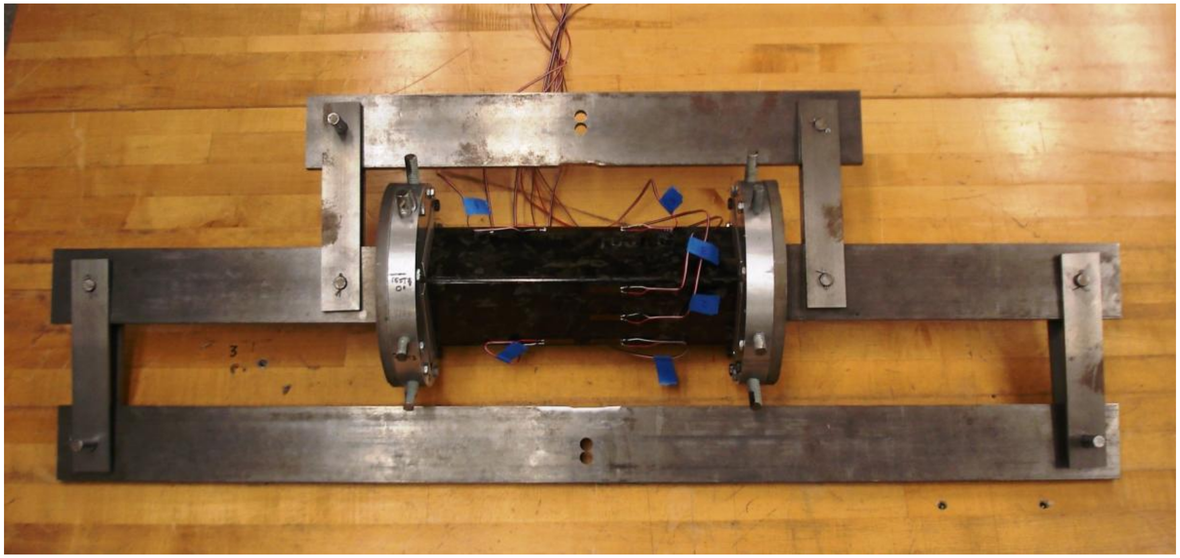
- Instrumentation included 8 strain gages located among 2 cross sections along angle length, aligned axially
- 1 inch length strain gages were used to obtain an average axial strain measurement at each strain gage location

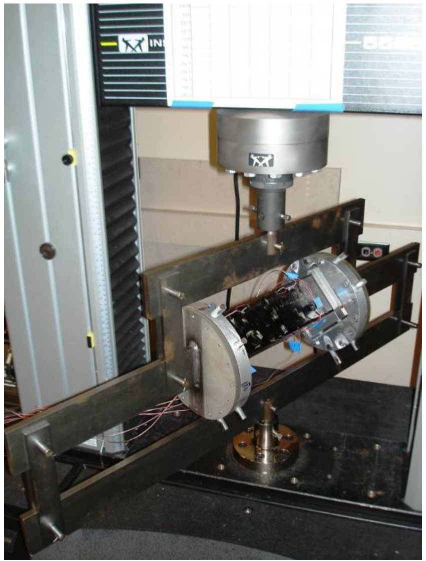




Testing Apparatus/Procedure

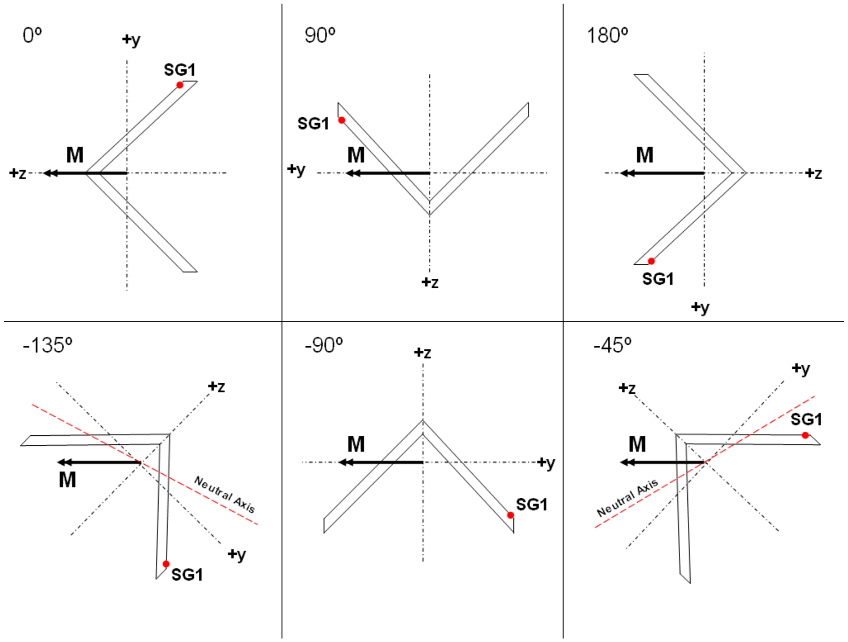
- 4 point bending fixture manufactured at UW
- Rotatable grips on fixture allowed for rotation of beam bending orientation
- Bending fixture was loaded using Instron 5585H Universal Test Frame
- Strain and load data was recorded at a rate of 1/sec





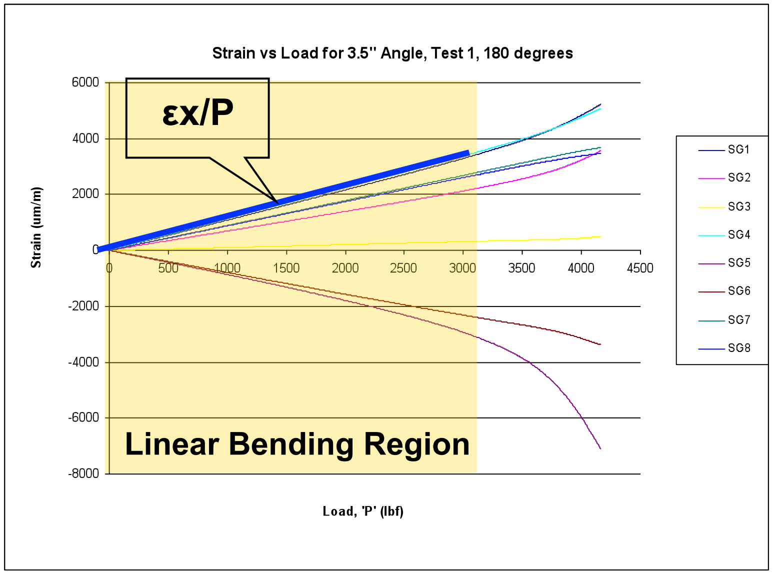
Testing Apparatus/Procedure

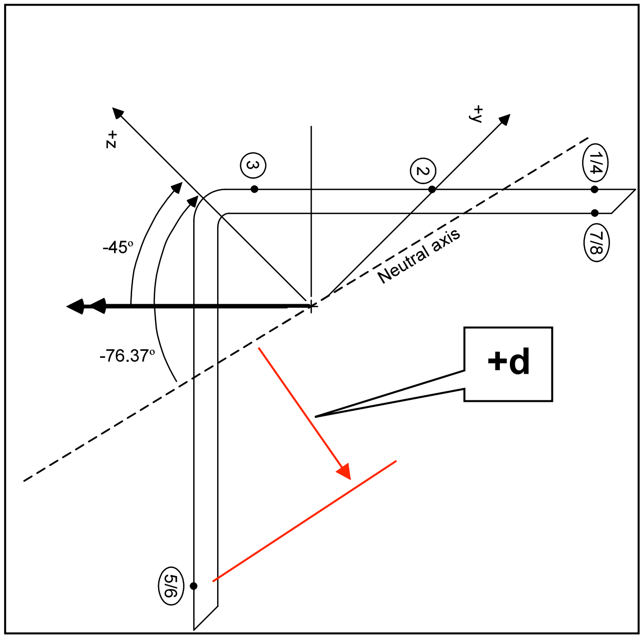
- 6 Bending orientations were chosen to test each angle size at
- Bending limits were to |3000 με| maximum strain measured at the gage with the highest strain value (orientation dependent)



Testing Results – Elastic Bending Stiffness

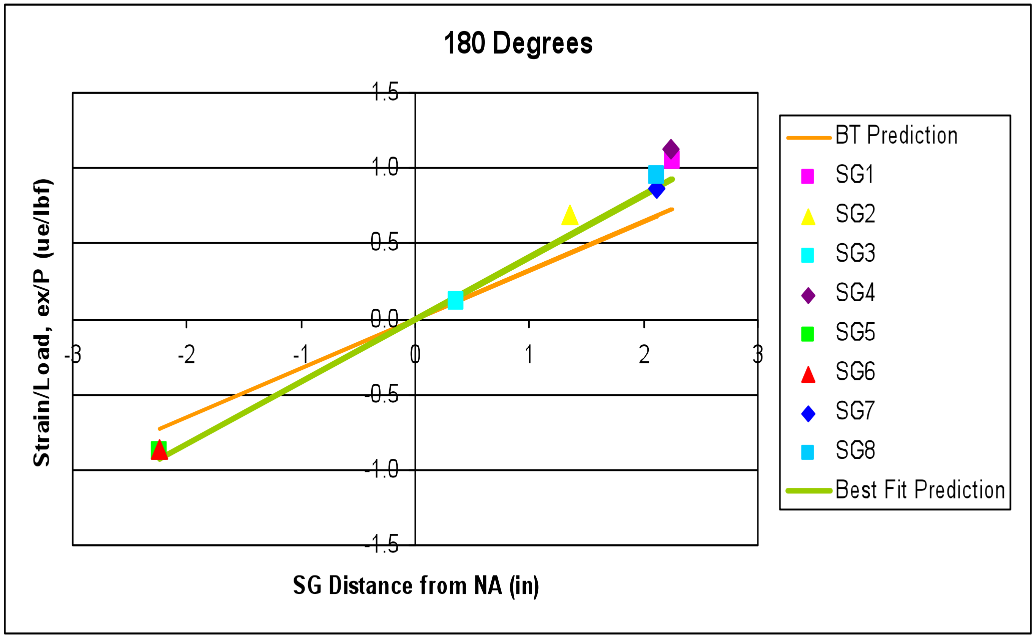
- Linear region of strain versus bending load curves was reduced to slope values to be compared with beam theory predictions
- These strain/load slope values (με/P) were plotted for each gage with respect to strain gage distance (d) from neutral axis of bending





Testing Results – Elastic Bending Stiffness

- Beam theory predictions were obtained based on
  - tensile modulus of elasticity as averaged from a Hexcel allowables study, E = 6.64 msi (“BT Prediction” in plots)
  - Linear regressions were performed to best fit experimental data for each angle size (using all bending orientation data per angle size for regression) (“Best Fit Prediction” in plots)



$$\varepsilon x/P = \frac{lz\sin\theta}{2EI_y} - \frac{ly\cos\theta}{2EI_z}$$

***l* = lever arm length for bend fixture (10 in)**

***z, y* = strain gage cartesian position along z or y centroidal axis**

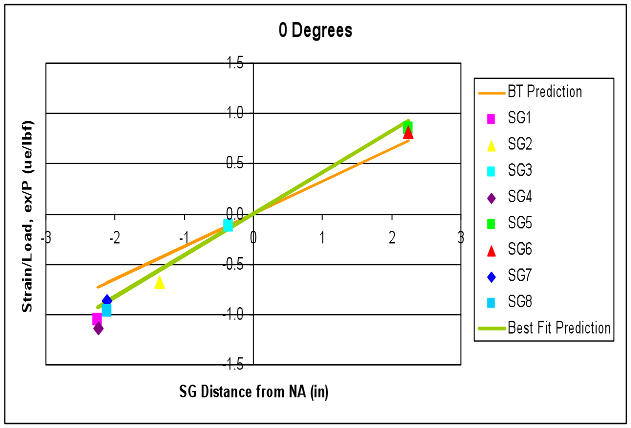
***θ* = bending moment orientation**

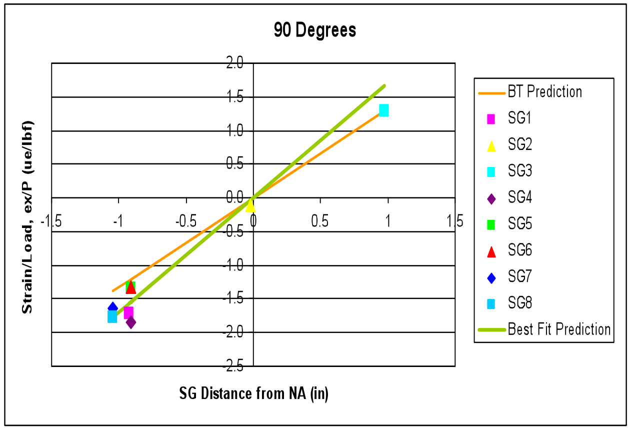
***E* = axial modulus of elasticity**

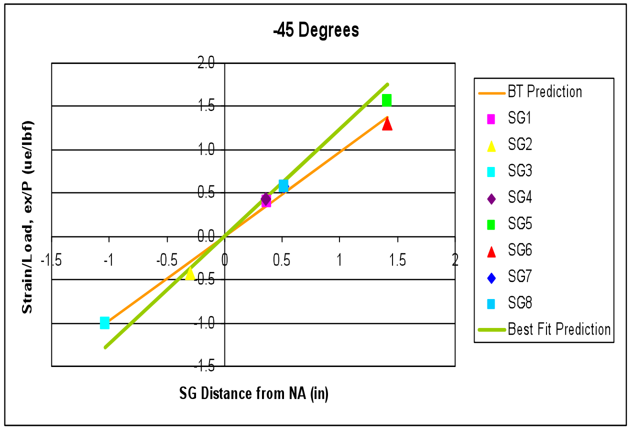
***Iy, Iz* = area moment of inertia about beam centroid**

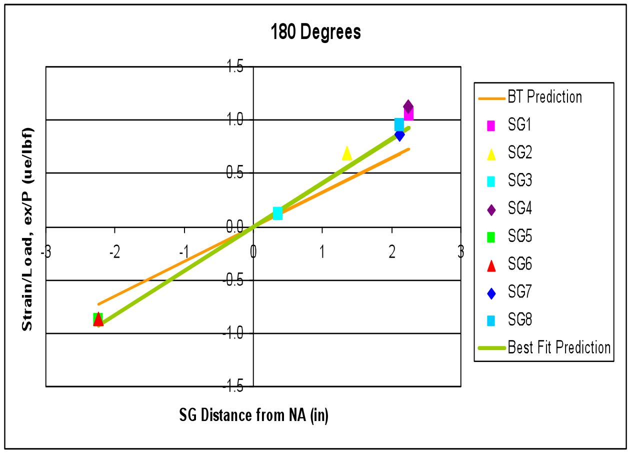
Testing Results – Elastic Bending Stiffness

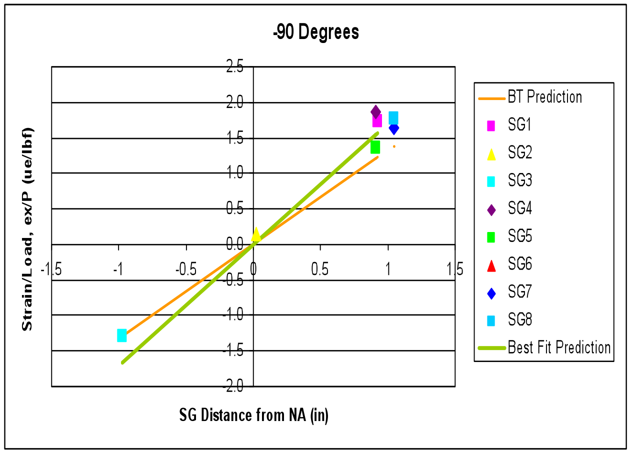
- Large Angle - BT Prediction (allowables): E = 6.64 msi, Best Fit Prediction: E = 5.19 msi

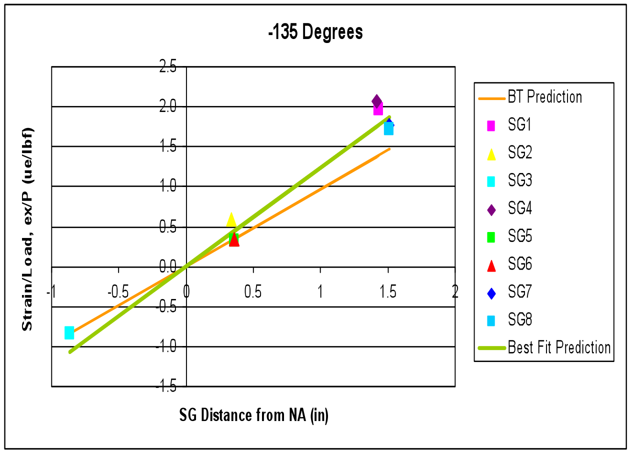






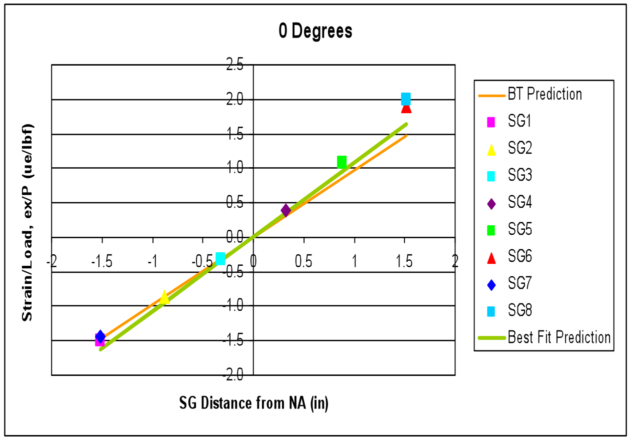


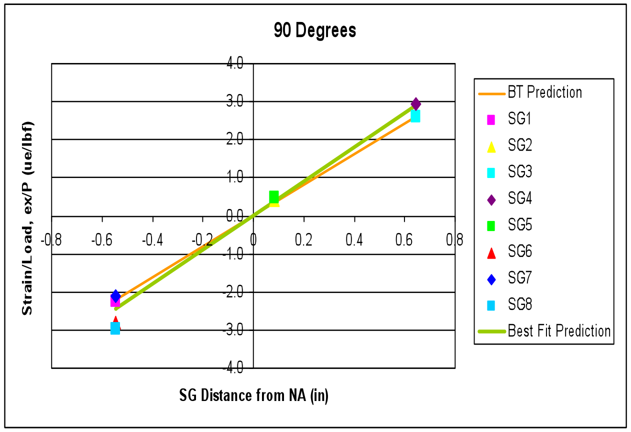


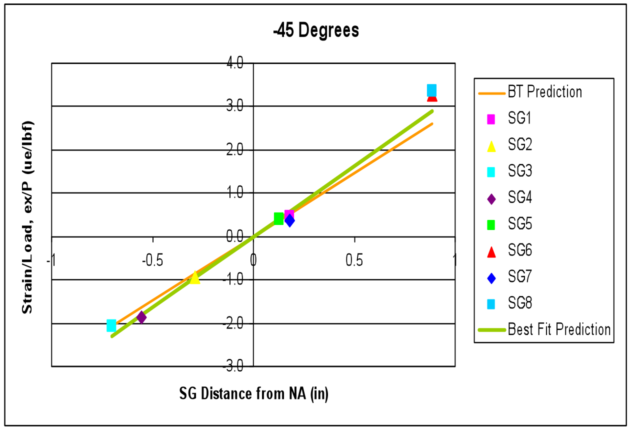


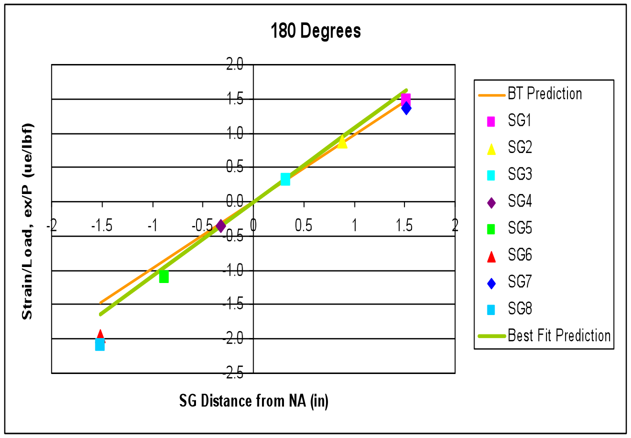
Testing Results – Elastic Bending Stiffness

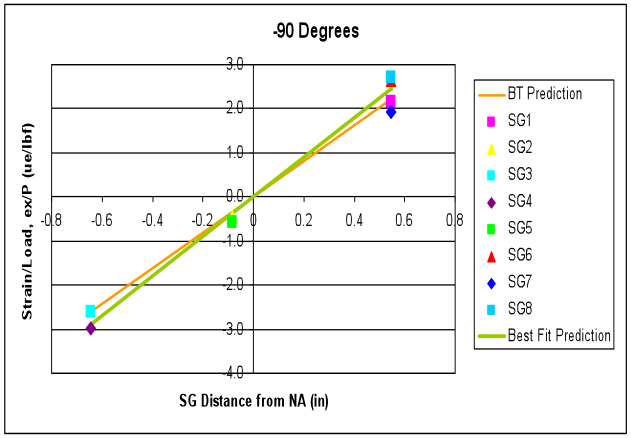
- Medium Angle - BT Prediction (allowables): E = 6.64 msi, Best Fit Prediction: E = 6.00 msi

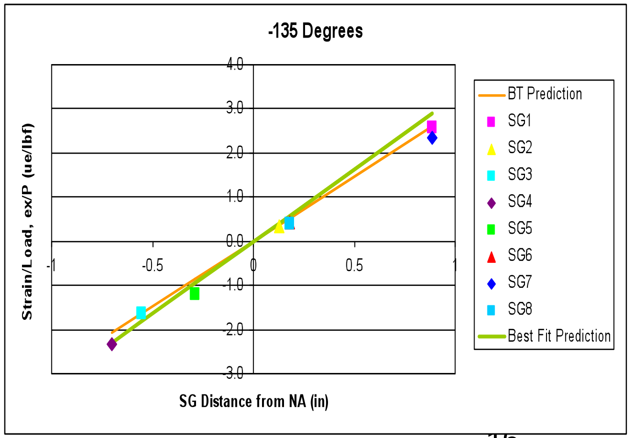






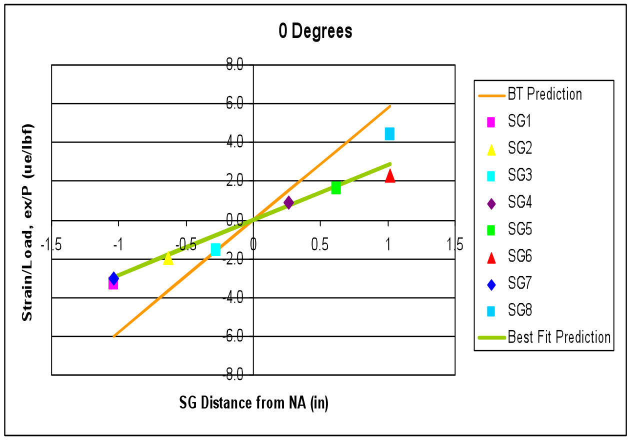


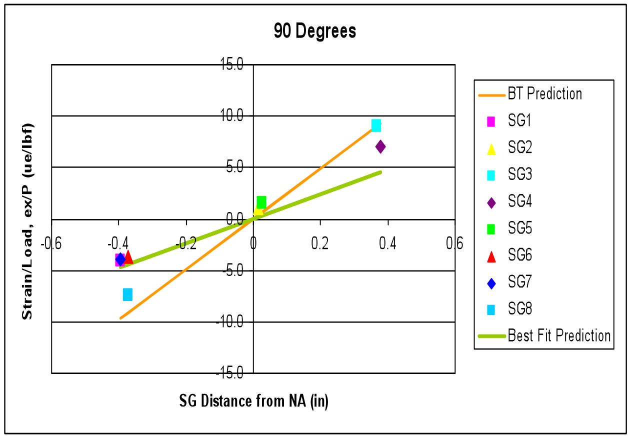


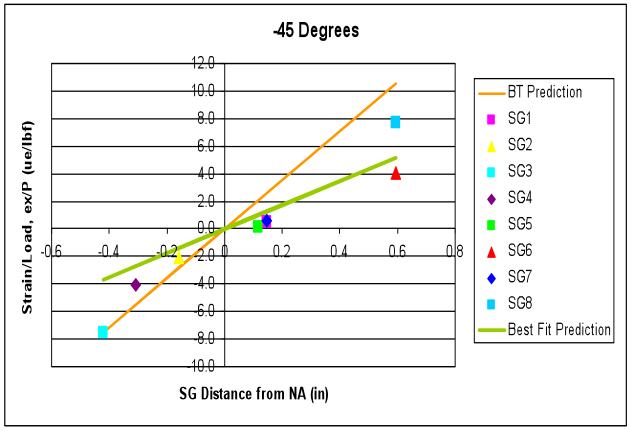


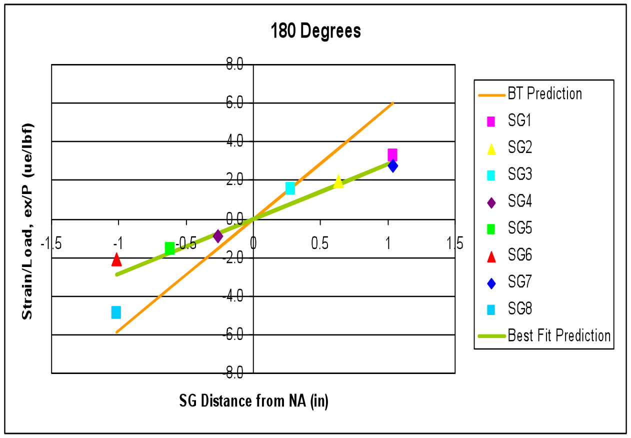
Testing Results – Elastic Bending Stiffness

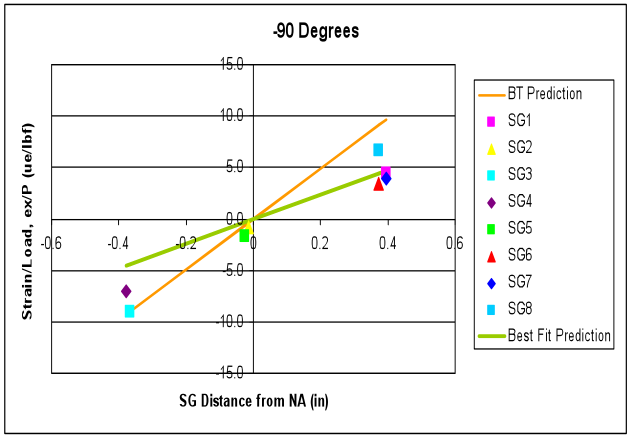
- Small Angle - BT Prediction (allowables): E = 6.64 msi, Best Fit Prediction: E = 13.6 msi

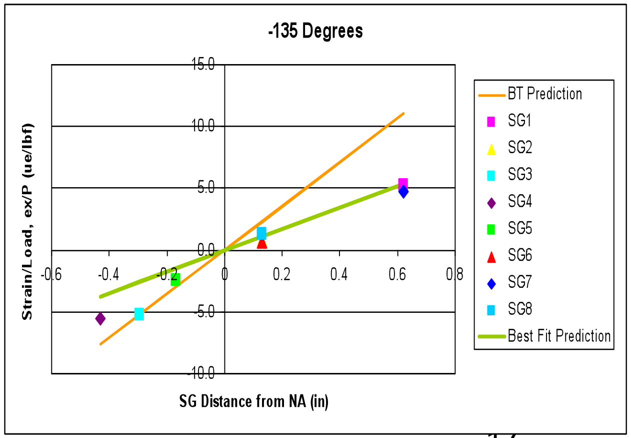

0 Degrees


90 Degrees


-45 Degrees

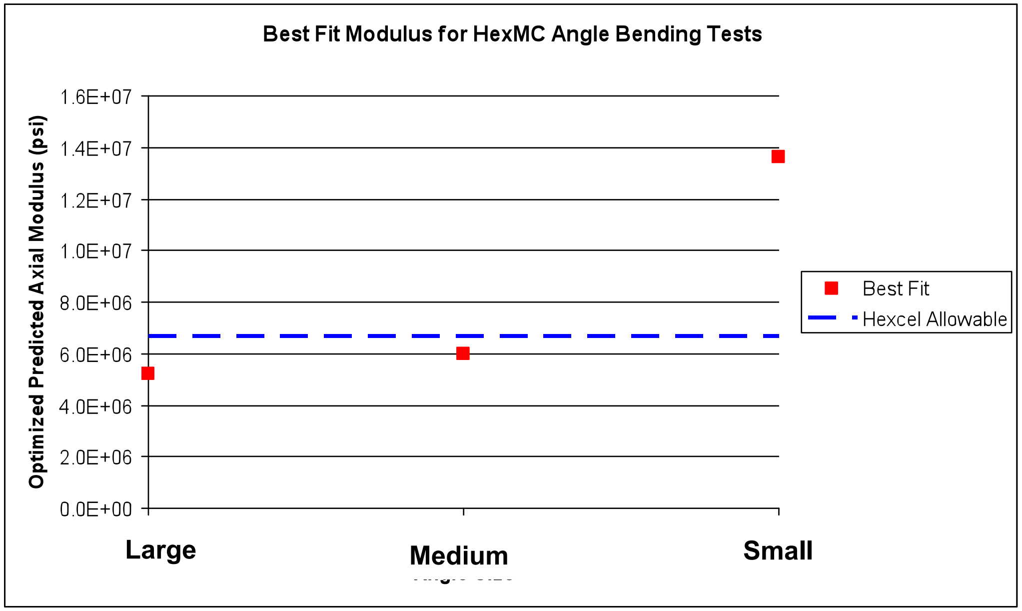

180 Degrees


-90 Degrees


-135 Degrees

Testing Results – Elastic Bending Stiffness

- Best fit modulus predictions for angles seem to vary with size
- Microscopy results confirm that flow effects are present in beams from molding and fiber alignment accounts for modulus variations from Hexcel Allowable modulus



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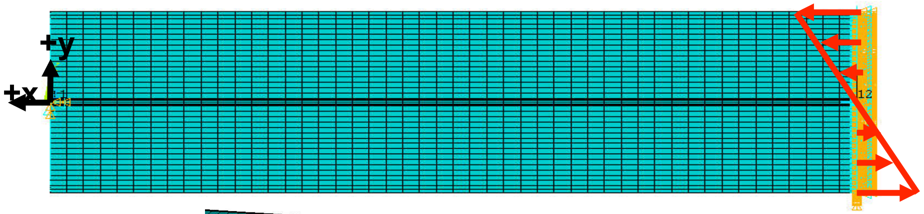
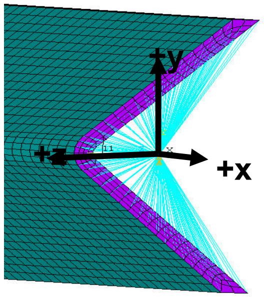
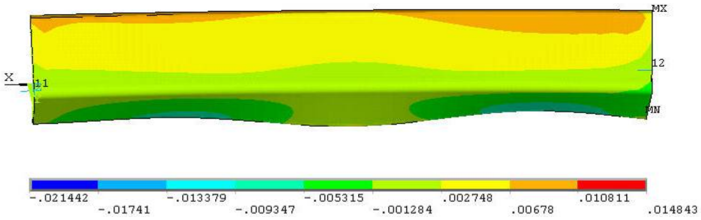
Testing Results – Buckling Analysis/Failure Results

- Nonlinear finite element analysis performed in ANSYS 12.0 using 3 angle size geometries
- Fixed face rotation was applied to free end of model while fixed end was constrained to a point located at the centroid of the face
- Element Type: Solid45

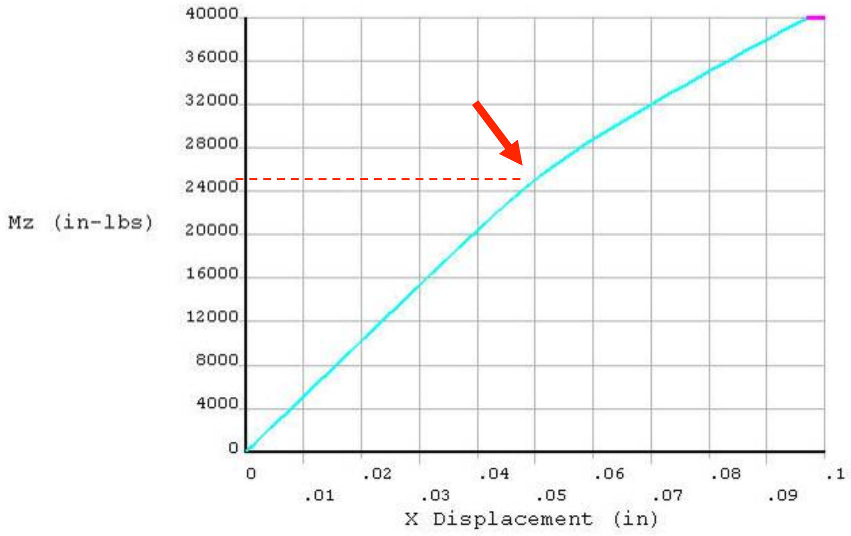






Testing Results – Buckling Analysis/Failure Results

- Reaction moments were plotted against axial (x) displacement at model free end (displacement controlled)
- Buckling predictions were estimated at the inflection point of moment/displacement plots where linear region becomes non linear

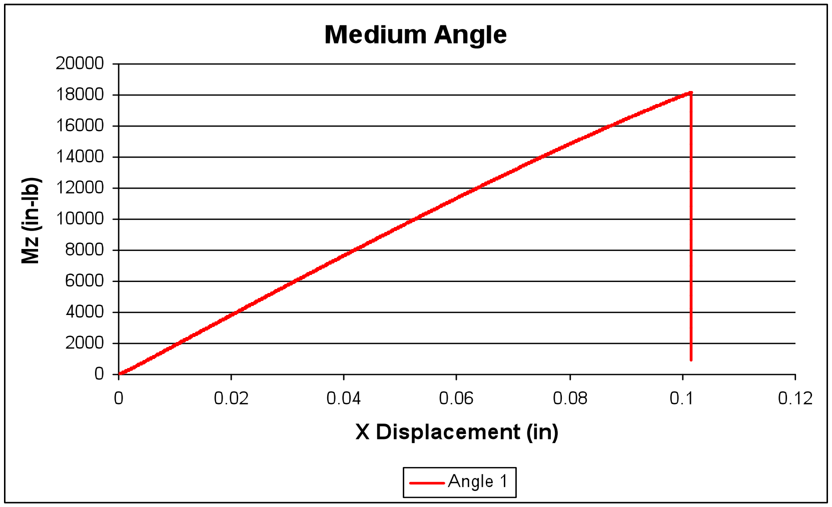


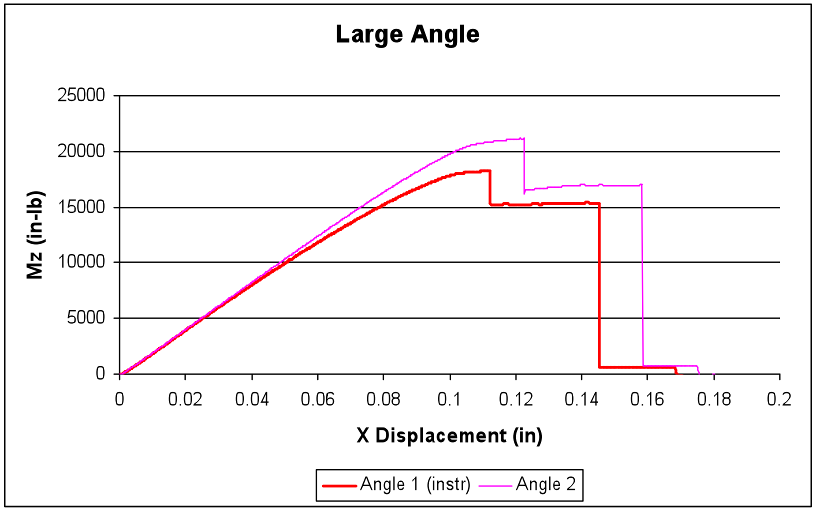
Angle Size	Orientation [degrees]	FEA Buckling Moment Prediction (in lb)	Experimental Observed Buckling Moment (in-lb)	% Difference (p-e)/e
Large	0	25000	18750	33.3
	90	17600	7800*	N/A
Medium	0	26400	18131*	N/A
	90	6875	1000*	N/A
Small	0	3400	2550	33.3
	90	1300	340*	N/A

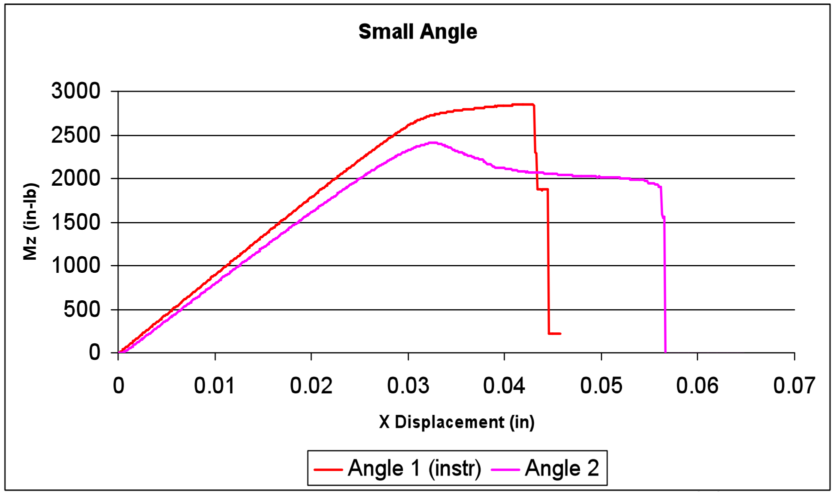
*** Denotes maximum load recorded before test ended (i.e. maximum strain was reached or failure occurred) where buckling was not experienced**

Testing Results – Buckling Analysis/Failure Results

- 2 Beams at each angle size were tested to failure using the 0 degree bending orientation
- 3 specific loads of interest were noticed on Large and Small angle failure tests, buckling load, peak load, and fracture load
- Medium angle failed before buckling occurred, due to geometry
- Medium angle failure data was lost so only 1 of the 2 beams data is shown







Summary

- Beam Theory analyses using isotropic properties appears to match experimental data well for larger flange thickness angles
- Using an allowables modulus to predict bending behavior in angles might not be appropriate for parts with flow effects in the material structure (fiber alignment)
- Modeling buckling behavior needs further study, though preliminary results are reasonable

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QUESTIONS ?