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Advanced Materials in Transport Aircraft Structures

Certification of Discontinuous Composite Material Forms for Aircraft Structures

Presented by

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Certification of Discontinuous Composite Material Forms for Aircraft Structures

- Objective: Simplify certification of DFC aircraft parts
- Technical Approach: HexMC (a DFC being used on the B787) selected as a model material. For this material, perform:
  - Experimental studies of HexMC mechanical behaviors, starting with simple coupon-level specimens and progressing towards "complex" parts
  - Study effects of processing (e.g., impact of material flow during molding on stiffness and strength)
  - Develop stochastic modeling approaches
  - Compare measurements with analytical-numerical predictions

Certification of Discontinuous Composite Material Forms for Aircraft Structures

Principal Investigators & Researchers (UW):

- PI: Mark Tuttle
- Grad Students: Brian Head and Tory Shifman (MSME ‘11)
- (Prior to 2011 Prof. Paolo Feraboli and his grad students also participated)

FAA Technical Monitor

- Lynn Pham

Other FAA Personnel Involved

- Larry Ilcewicz

Industry Participation

- Boeing: Bill Avery
- Hexcel: Bruno Boursier, David Barr, and Marcin Rabiega

Certification of Discontinuous Composite Material Forms for Aircraft Structures

Previous work has shown:

- HexMC coupon tests exhibit relatively high levels of scatter
- HexMC is notch insensitive
- Material flow causes modest chip/fiber alignment and a measureable change in stiffness and strength
- A modeling approach called the “Stochastic Laminate Analogy” (SLA) was developed
- Elastic bending stiffness of HexMC angle beams exhibits scatter equivalent to that encountered in coupon tests

Certification of Discontinuous Composite Material Forms for Aircraft Structures

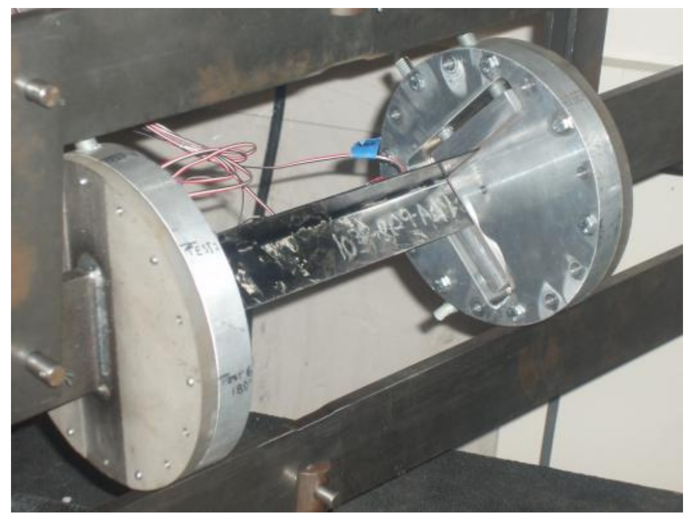
Focus of this presentation:

- Predicting buckling/fracture of HexMC angle beams
  - Predictions using isotropic material properties
  - Causes of errors in predictions
  - Future work to address errors
- Ongoing work
  - Angle beams
  - Intercostals

Angle Buckling

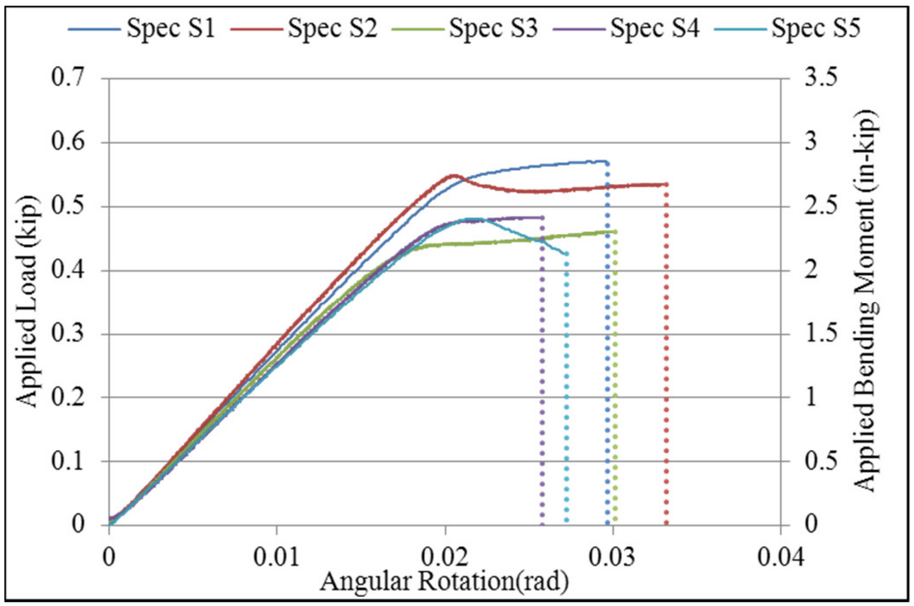
Experimental Testing

- Three sizes of angle beams compression molded from HexMC were tested in a four point bending fixture

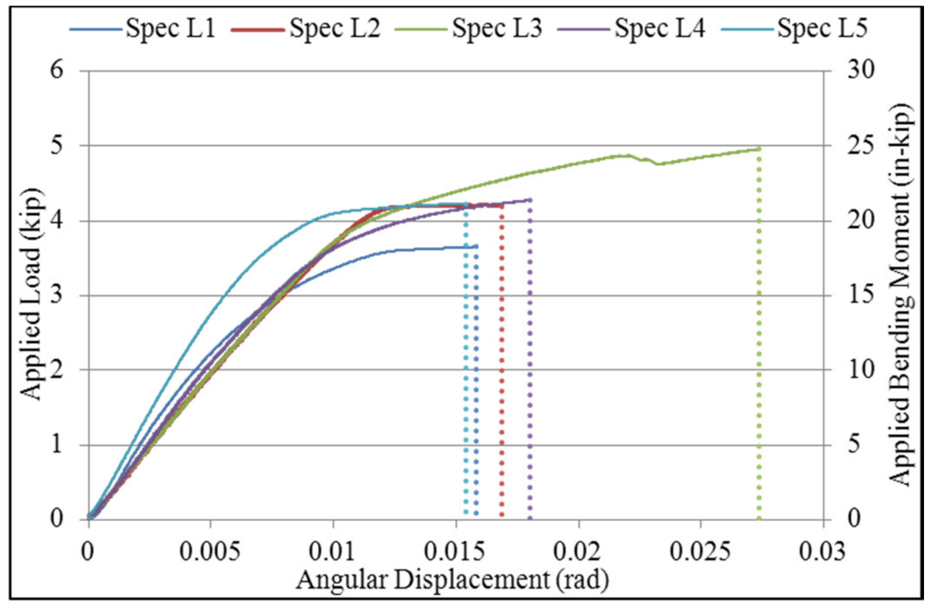


Angle Buckling
Experimental Results

- Both small and large angle sizes buckled/crippled well before fracture



Small Specimens

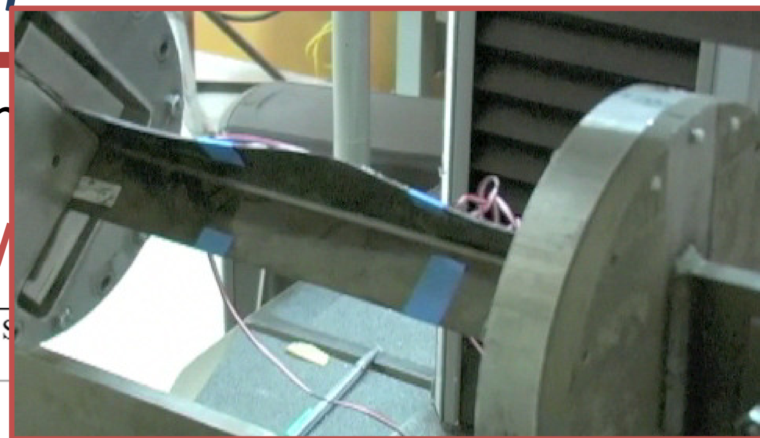


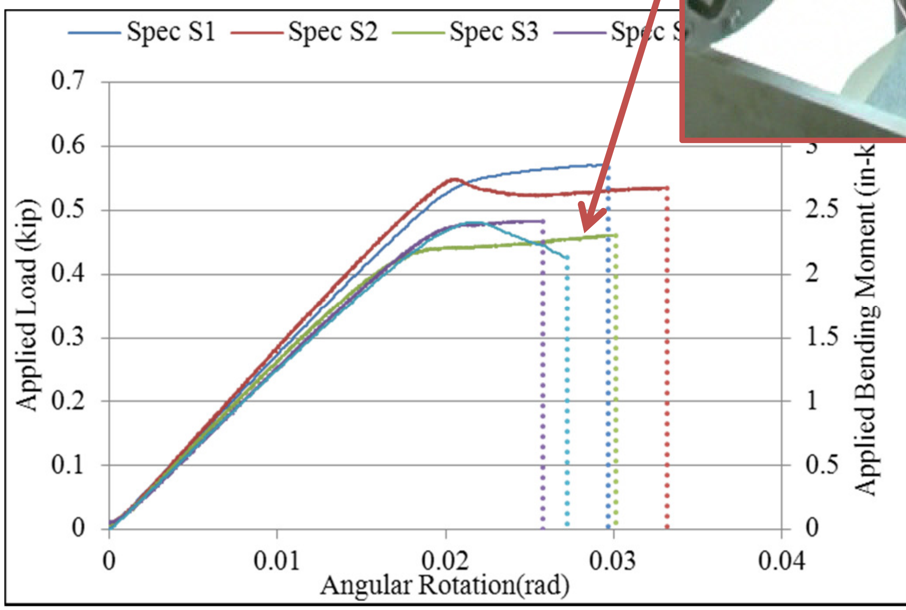
Large Specimens

Angle Buckling

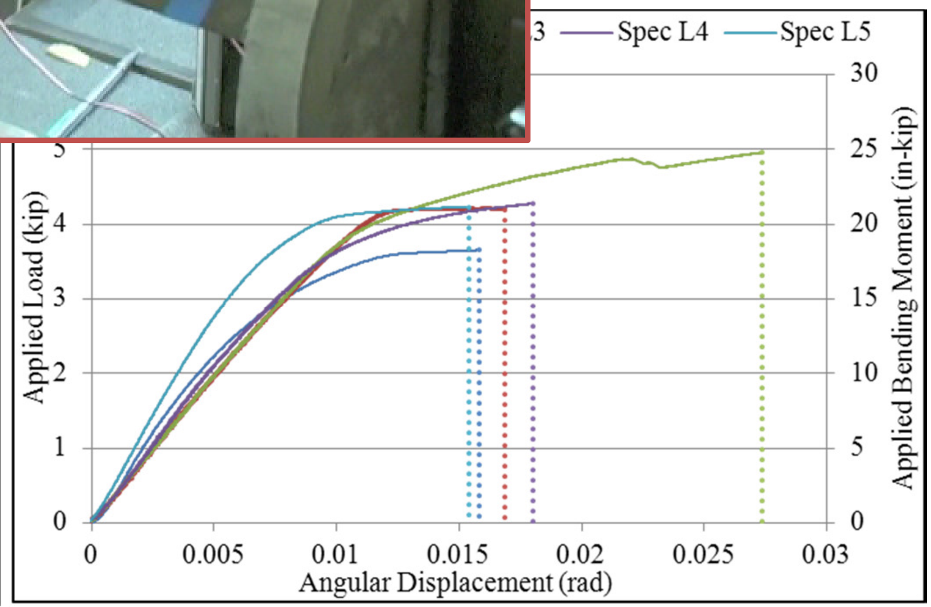
Experimental Results

- Both small and large an ell before fracture





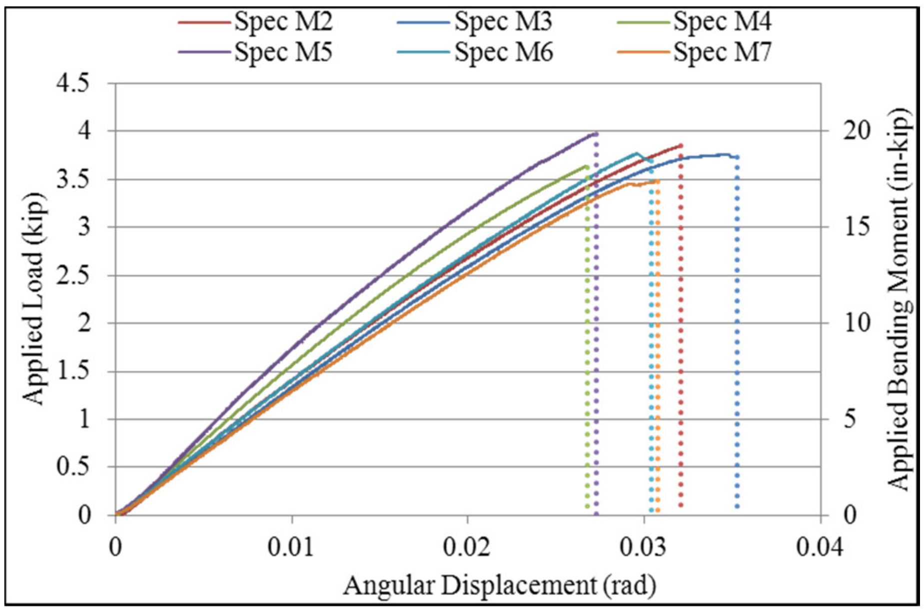
Small Specimens



Large Specimens

Angle Buckling
Experimental Results

- Medium size angles fractured prior to (or simultaneously with) the onset of buckling



Medium Specimens

Angle Buckling

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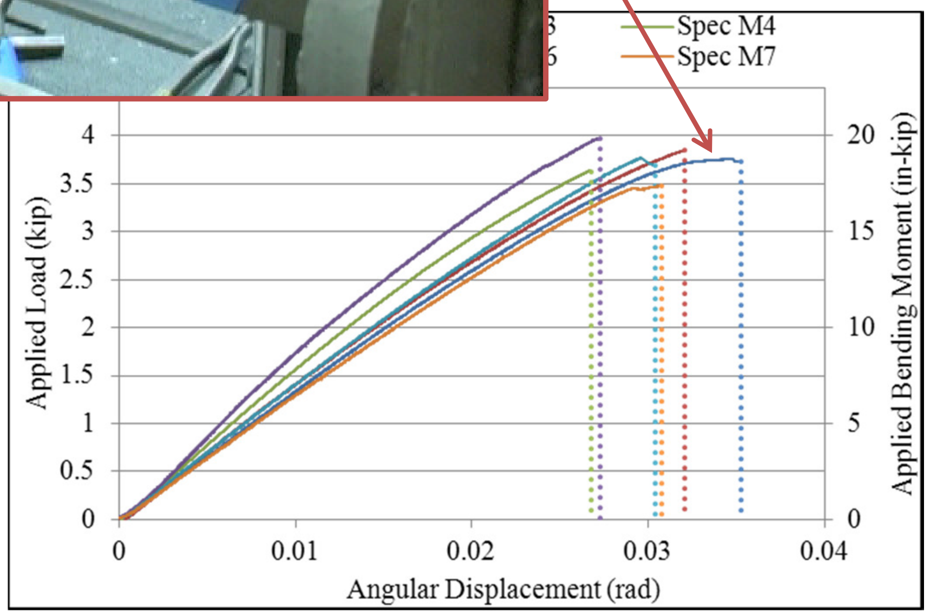
- M… r to (or simultaneously with) the c…



Medium Specimens

B-Basis Material Properties
Used in FE Analyses

- Calculated B-Basis and B-Max moduli based on experimental data
  - Calculated following Mil17 HDBK v. 1 ch. 8
  - B-Max is the modulus under which 90% of samples should fall 95% of the time

Moduli (Msi)

	B-Basis	Average	B-Max
Compression	5.36	6.31	7.27
Tension	5.58	6.62	7.65

- Predicted failure using B-Basis and average strengths

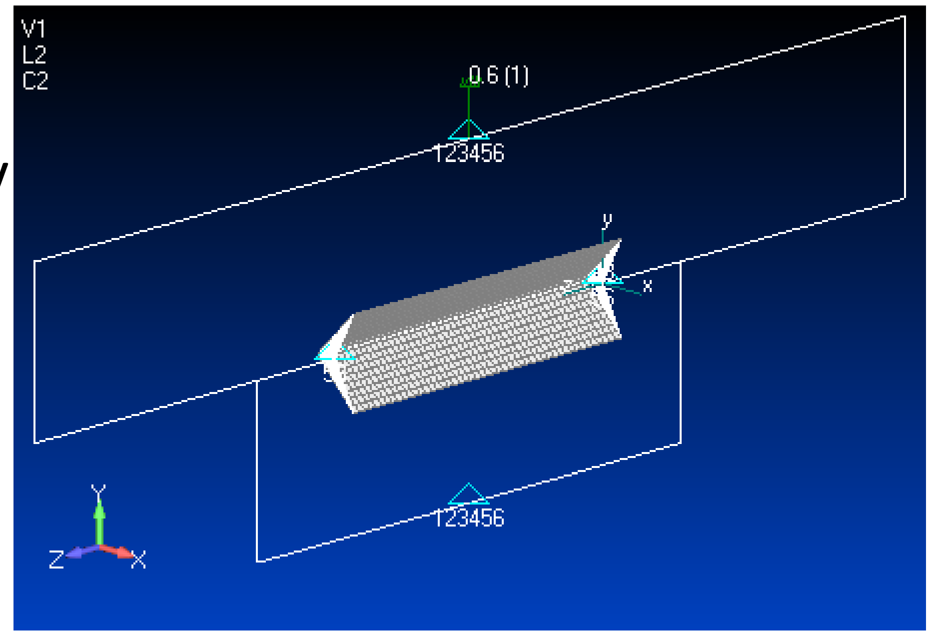
Strengths (ksi)

	B-Basis	Average
Compression	50.2	57.0
Tension	40.2	49.9

Angle Modeling

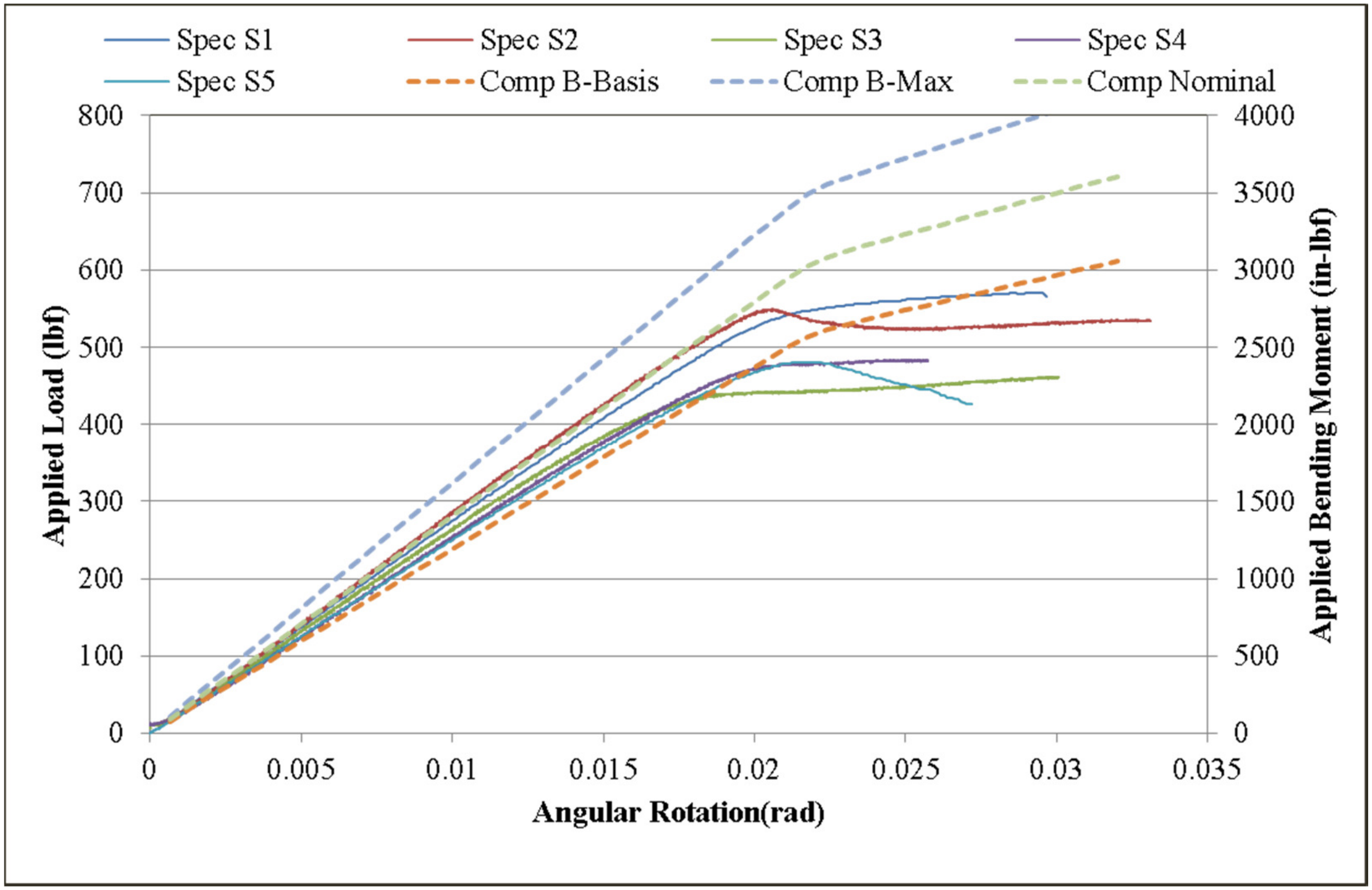
Mesh and Convergence Study

- Both solid and shell elements used (equivalent results obtained)
- Element size convergence study performed
- Modeled over range of linearly elastic moduli
- Effects of flange thickness variations studied



Medium Angle Modeled with Frame

Small Angle Predictions
Based on design thickness



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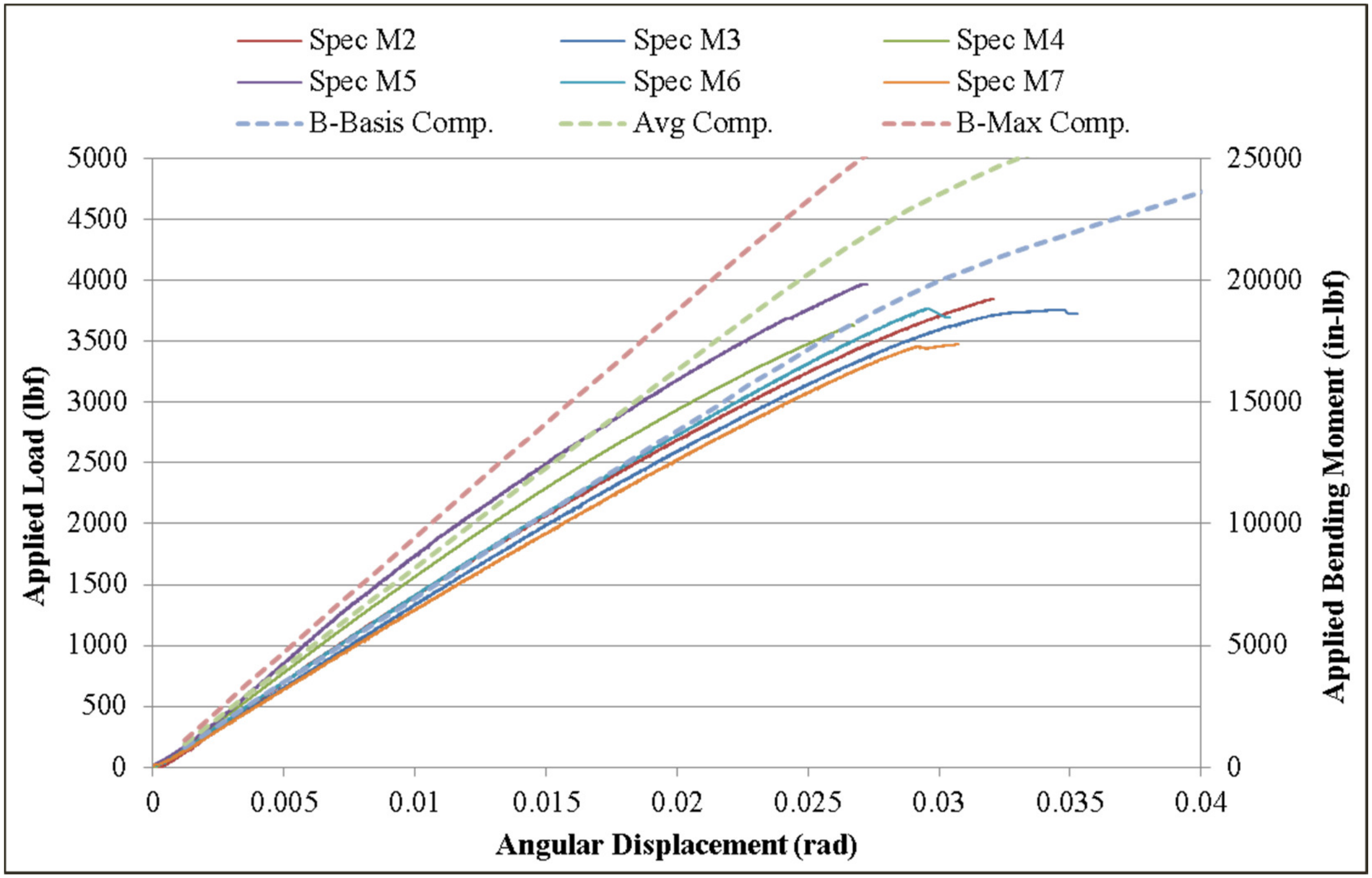
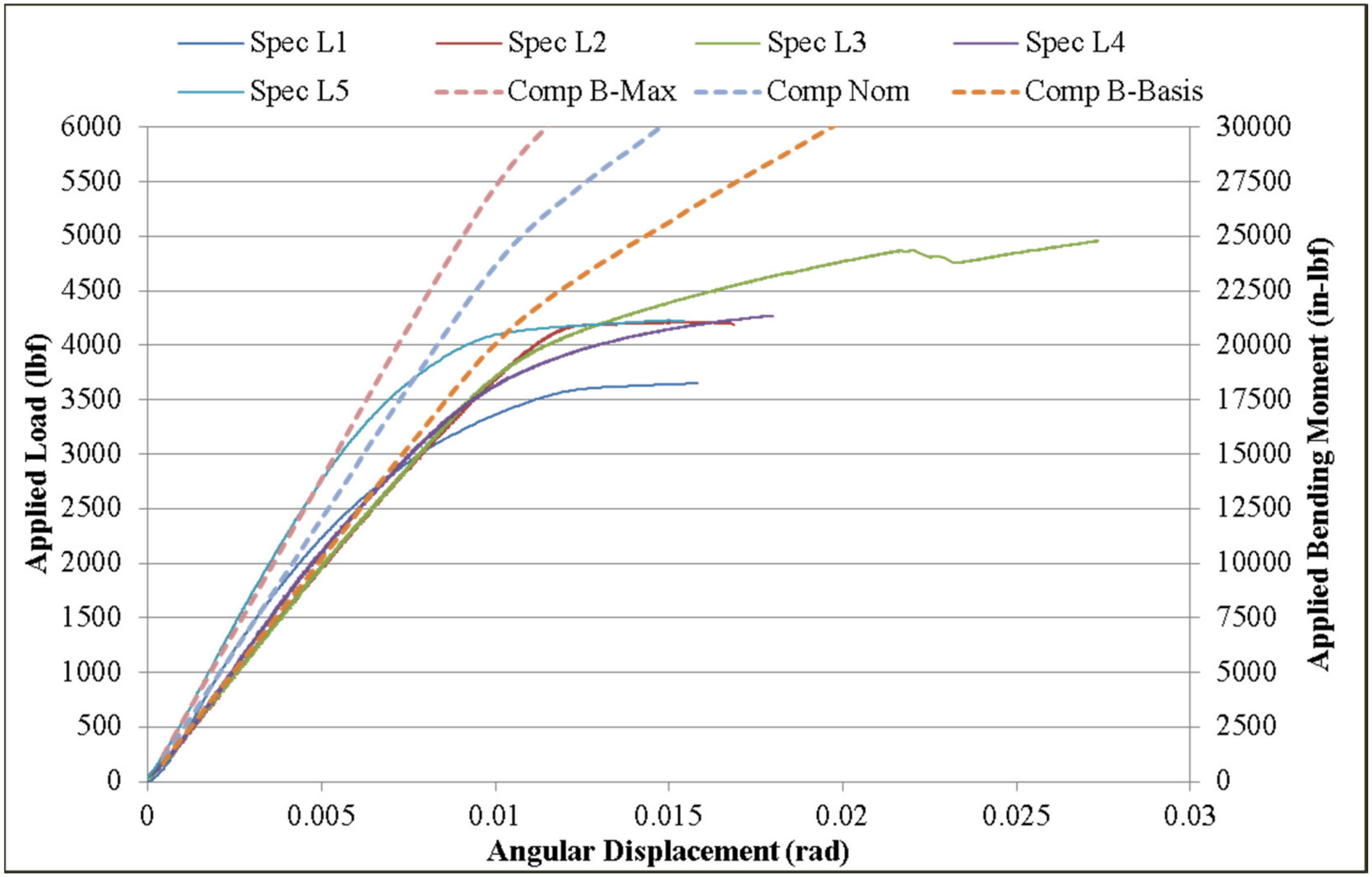
Medium Angle Predictions

Based on design thickness



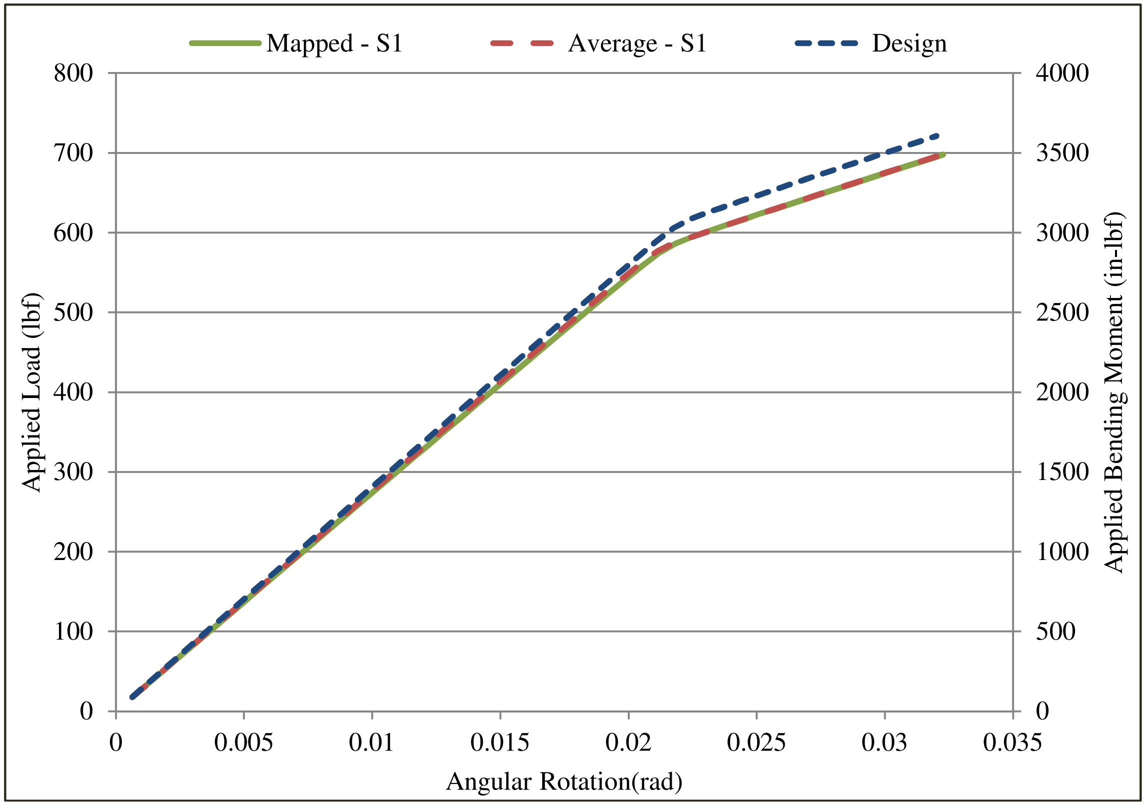
Large Angle Predictions
Based on design thickness



Effect of Thickness Variations

For small angle

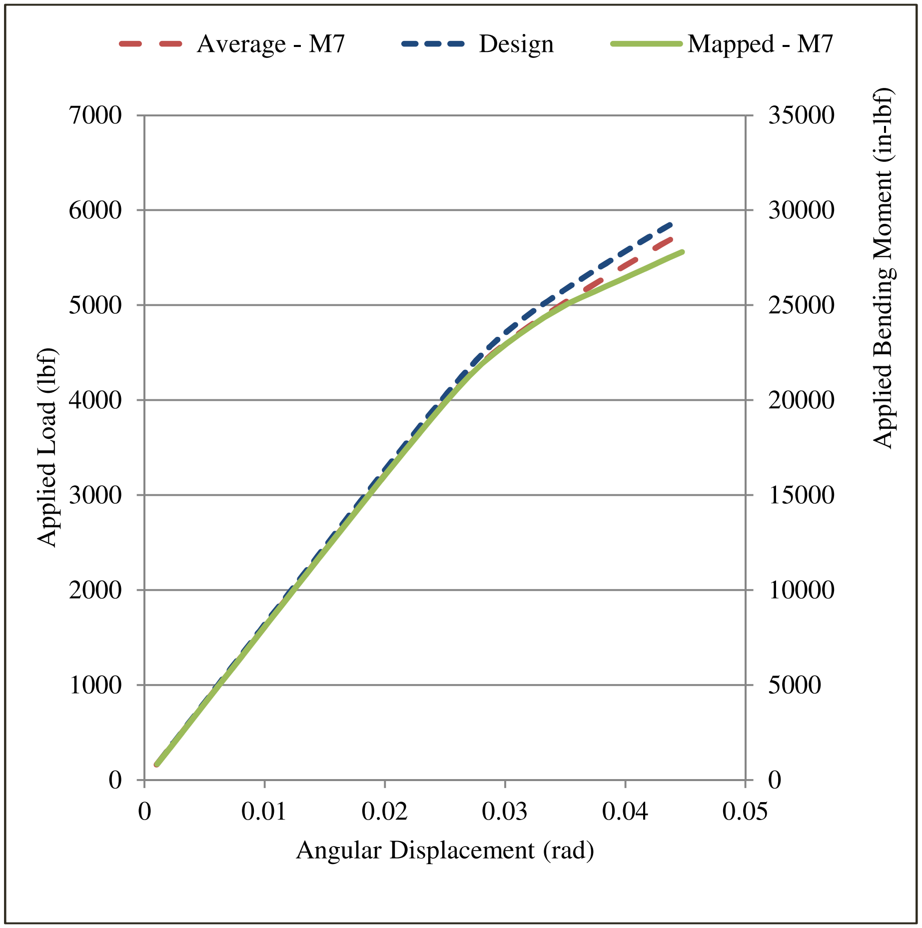
- Measured thickness of two angles of each specimen size in 36 locations
- Modeled with three different thicknesses
  1. Design thickness
  2. Measured thickness mapped to 36 locations
  3. Average of 36 measured thicknesses



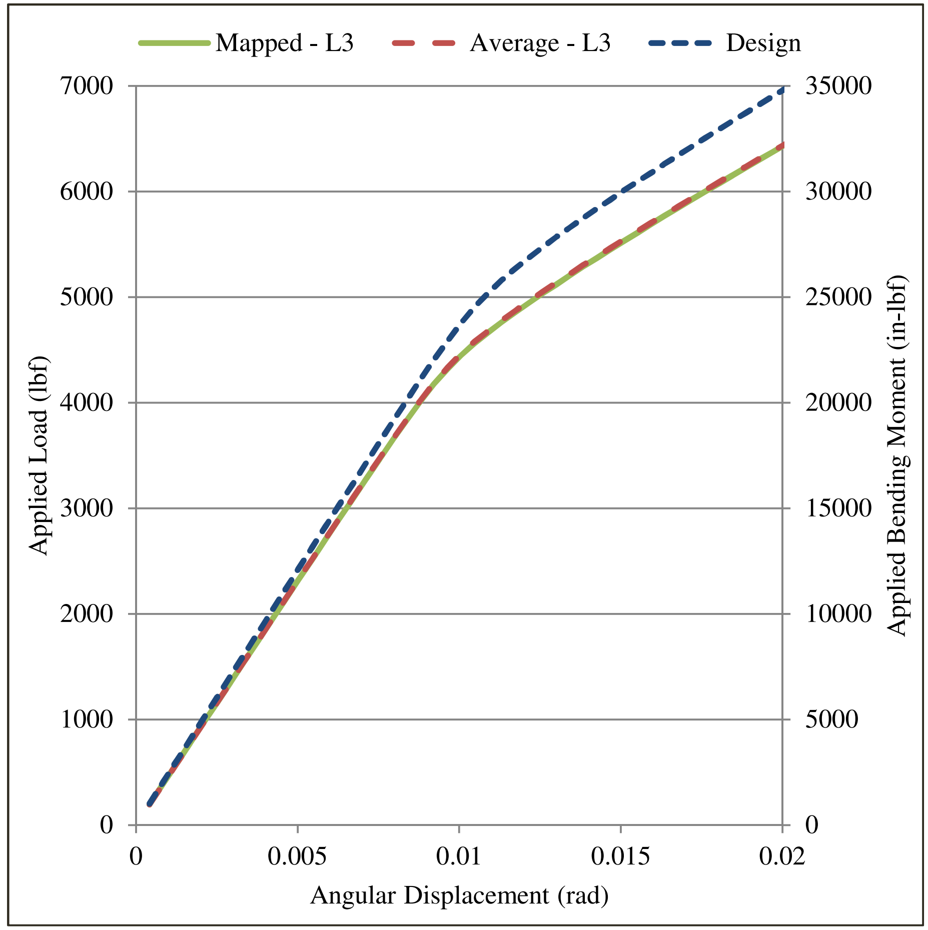
Small Angle

Effect of Thickness Variations

For medium and large angles



Medium Angle



Large Angle

Effect of Thickness Variations
Conclusions

- For all three angle sizes, predictions based on mapped thicknesses were nearly identical to those based on average thicknesses.

- For both small and large angles, using measured thicknesses decreased the predicted buckling and failure loads (resulting in an improved comparison between measurement and prediction).

Measured vs Predicted Buckling Loads

		Low		Average		High	
		Moment (in-lbf)	Error	Moment (in-lbf)	Error	Moment (in-lbf)	Error
Small Angle	Experiment	2112	--	2451	--	2747	--
	Design	2675	**26.7%**	3155	**28.7%**	3634	**32.3%**
	Measured Average*	2546	**20.5%**	3002	**22.4%**	3458	**25.9%**
Med. Angle	Experiment	--	--	--	--	--	--
	Design	20298	--	23934	--	27535	--
	Measured Average*	20128	--	23733	--	27303	--
Large Angle	Experiment	15550	--	19256	--	20949	--
	Design	21685	**39.5%**	25569	**32.8%**	29457	**40.6%**
	Measured Average*	19448	**25.1%**	22931	**19.1%**	26418	**26.1%**

*Average measured thickness of all specimens of that size

Measured vs Predicted Failure Loads

		Low		Average	
		Moment (in-lbf)	Error	Moment (in-lbf)	Error
Small Angle	Experiment	2307	--	2546	--
	Design	2880	**24.8%**	3358	**31.9%**
	Measured Average	2706	**17.3%**	3158	**24.0%**
Med. Angle	Experiment	17350	--	18707	--
	Design	18094	**4.3%**	22111	**18.2%**
	Measured Average	17293	**-0.3%**	21149	**13.1%**
Large Angle	Experiment	18260	--	21330	--
	Design	25820	**41.4%**	29776	**39.6%**
	Measured Average	24017	**31.5%**	27568	**29.2%**

*Average measured thickness of all specimens of that size

Possible Source of Remaining Errors

- Buckling and fracture loads were over-predicted by ~20% and ~25%, respectively
- Cause is suspected to be partially due to local "modulus" variations

Ongoing Work

Analysis

- A stochastic analysis (similar to the Feraboli SLA approach) which includes coupling effects is being developed and implemented
  - Will be applied to HexMC angles
  - Will be applied to HexMC Intercostals

Experimental

- Failure loads and modes of a cantilevered HexMC intercostals being measured using digital image correlation (DIC)

[1] Feraboli et. Al. Comp. Pt. A 41 (2010) 557-570

Future Work

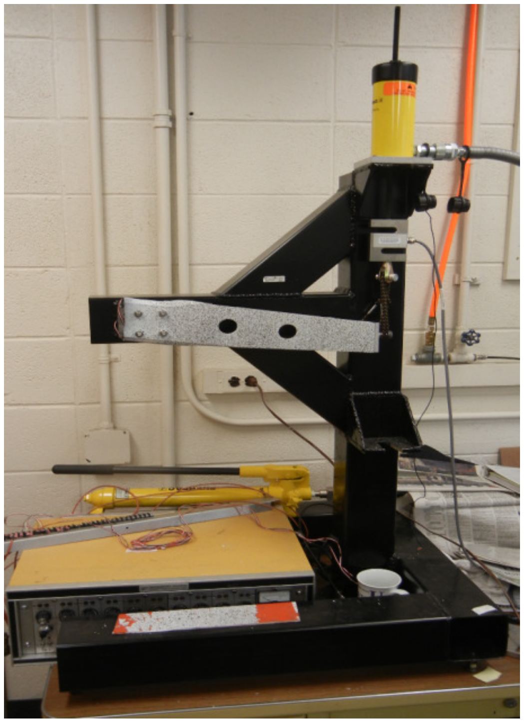
Thank you for your attention!

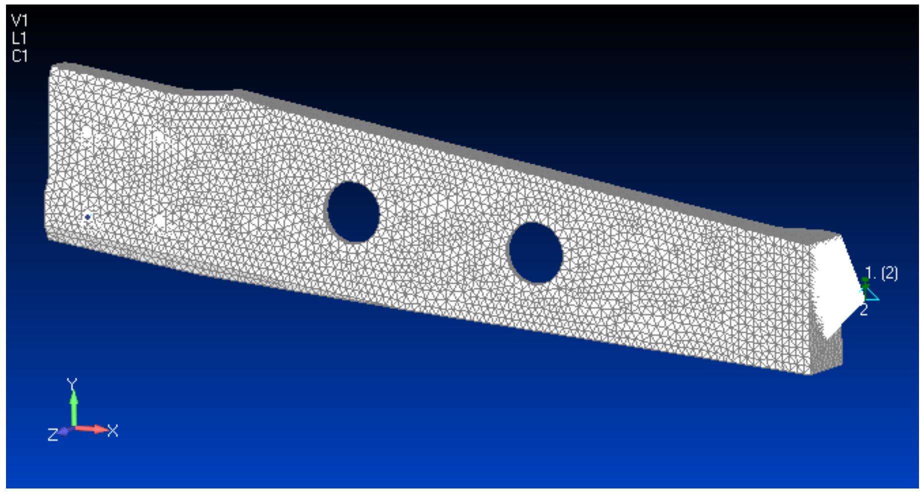
Questions?

Backup Slides

HexMC Intercostals

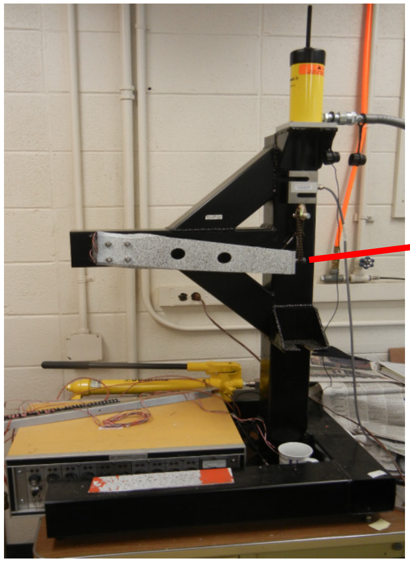
- Testing of intercostals to failure in cantilevered configuration
- FEA modeling of intercostal using isotropic properties

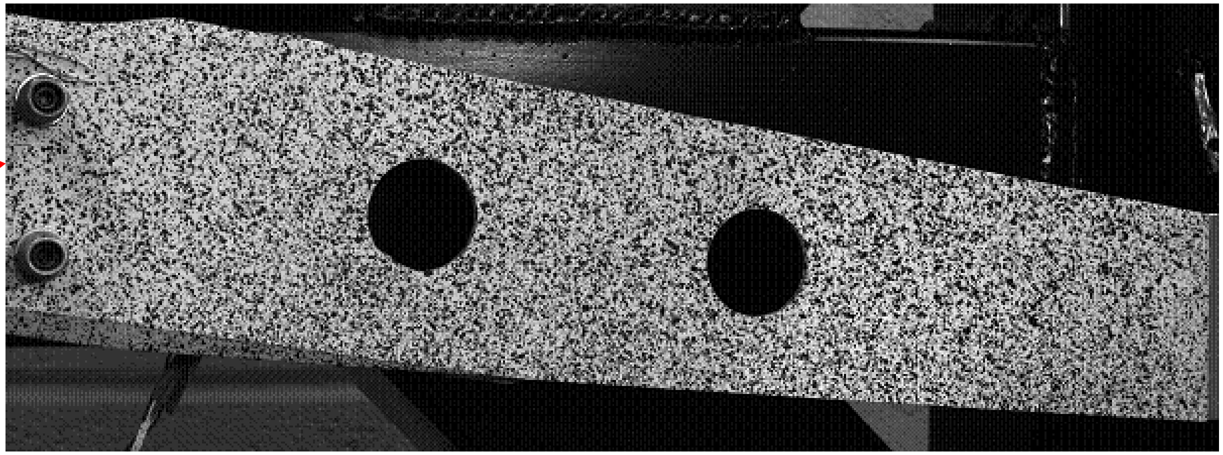




Intercostal Testing

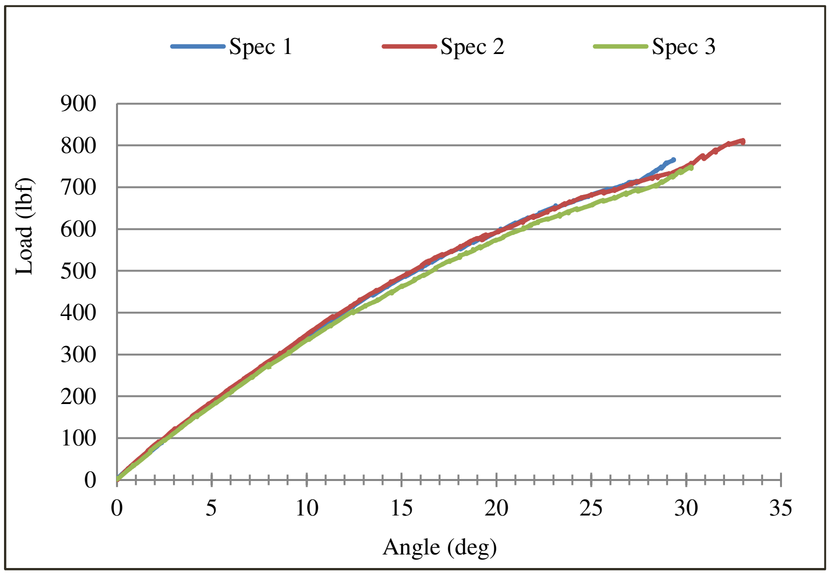
- Intercostals tested in a cantilevered configuration, allowing the loaded end to rotate freely.
- Three specimens were tested to failure initially
- Strains were measured with Digital Image Correlation (DIC) on the front face of the intercostal



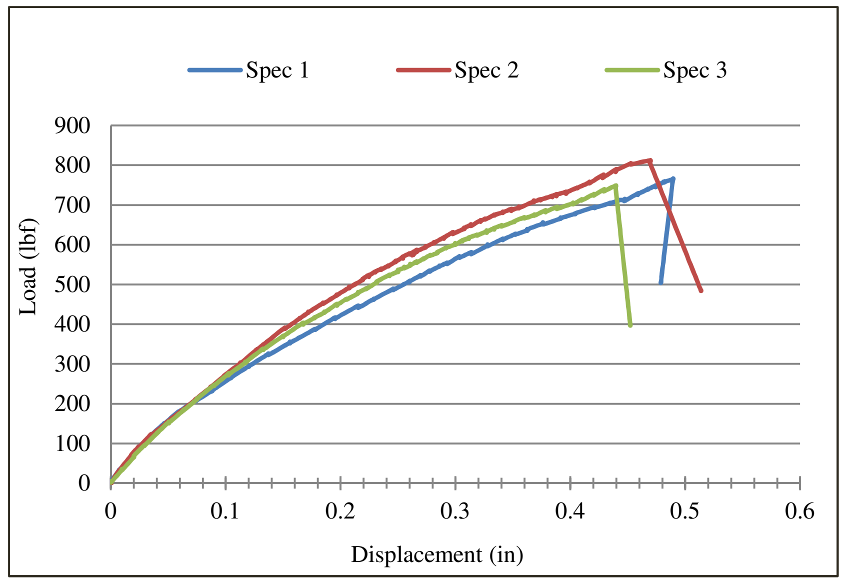


Intercostal Testing
-Clip Displacements

- Intercostals tested in a cantilevered configuration, allowing the loaded end to rotate freely.
- Three specimens were tested to failure initially



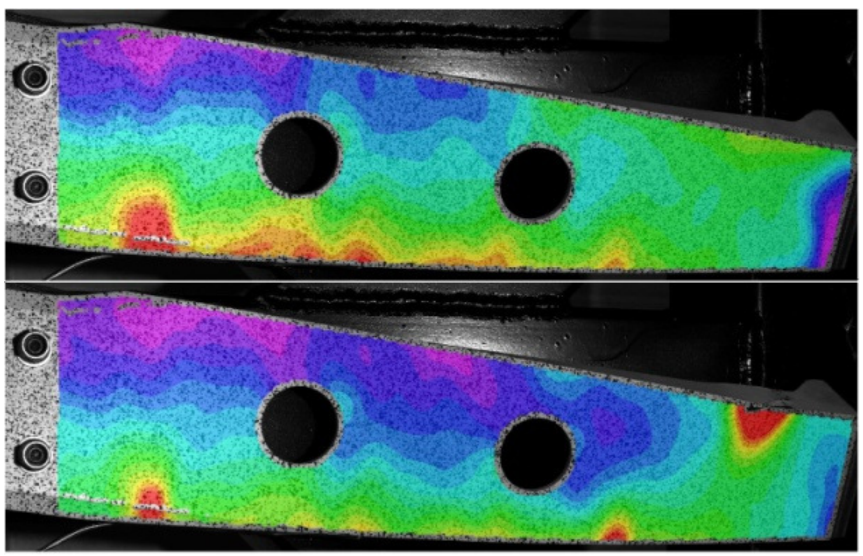
Clip End Total Rotation



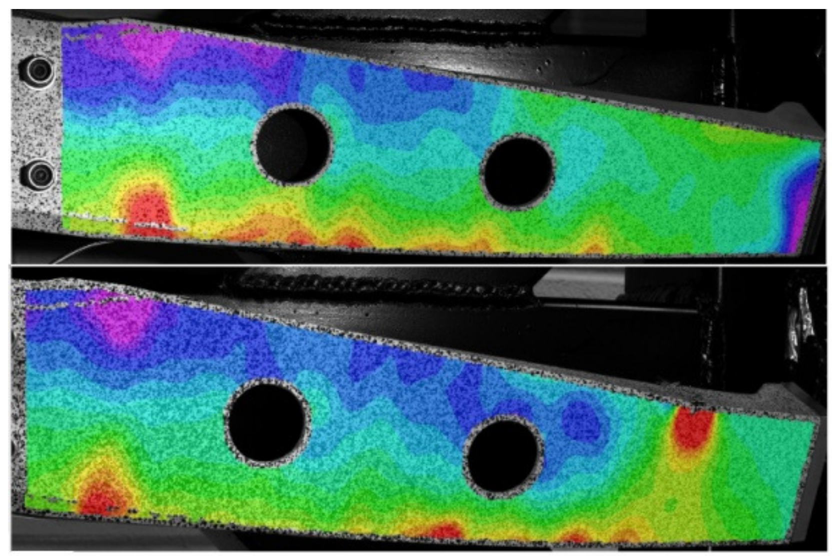
Clip End Vertical Displacement

Intercostal Testing -Strain Fields

- Strain in the horizontal direction measured using DIC
  - Immediately pre and post failure
  - Failure occurs near clip end, far away from max and min stresses



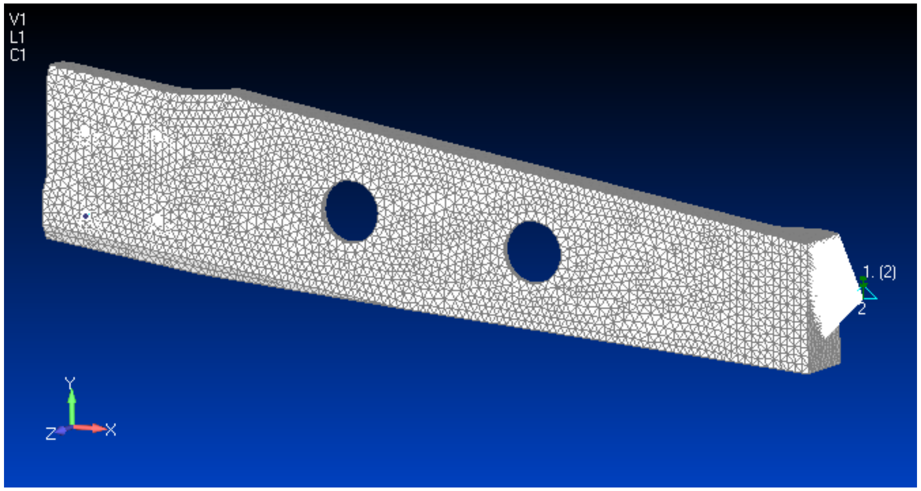
Specimen 1 – 765 lbs



Specimen 3 – 739 lbs

Intercostal Modeling -Model

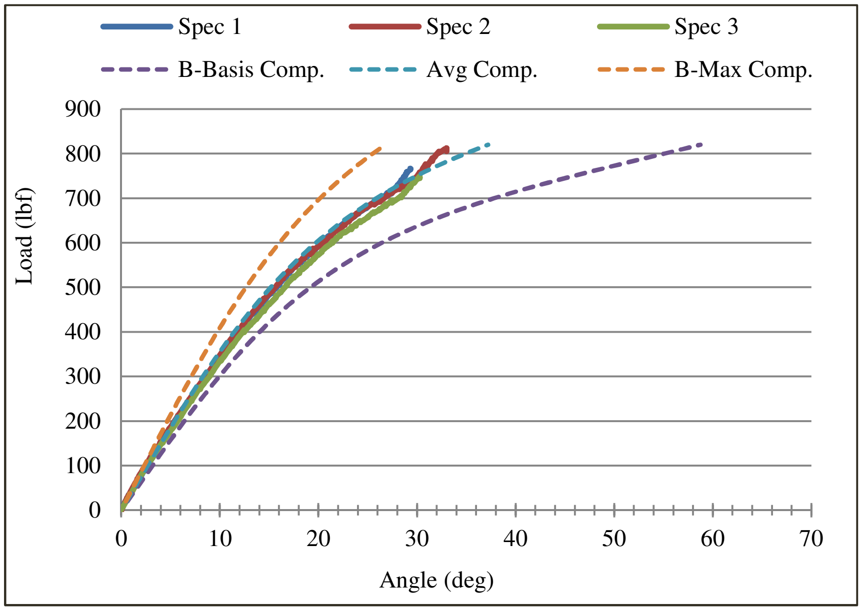
- Modeled with 10 noded tetrahedral solid elements
- Modeled over same range in moduli as angles
  - B-Basis in Compression - 5.36 Msi
  - Average in Compression - 6.31 Msi
  - B-Max in Compression – 7.27 Msi



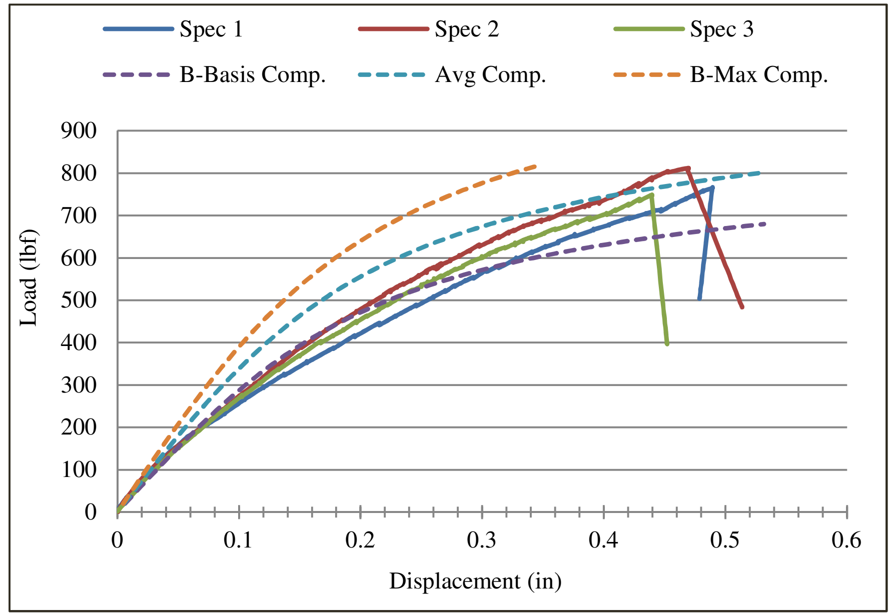
Intercostal Model

- Compared predicted to measured clip end displacements and rotations

Angle Modeling -Model



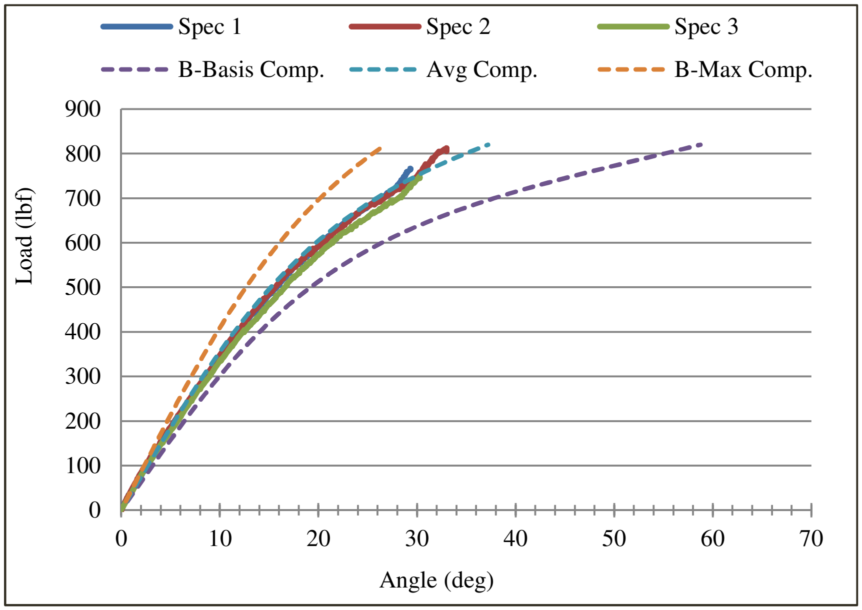
Clip End Rotation



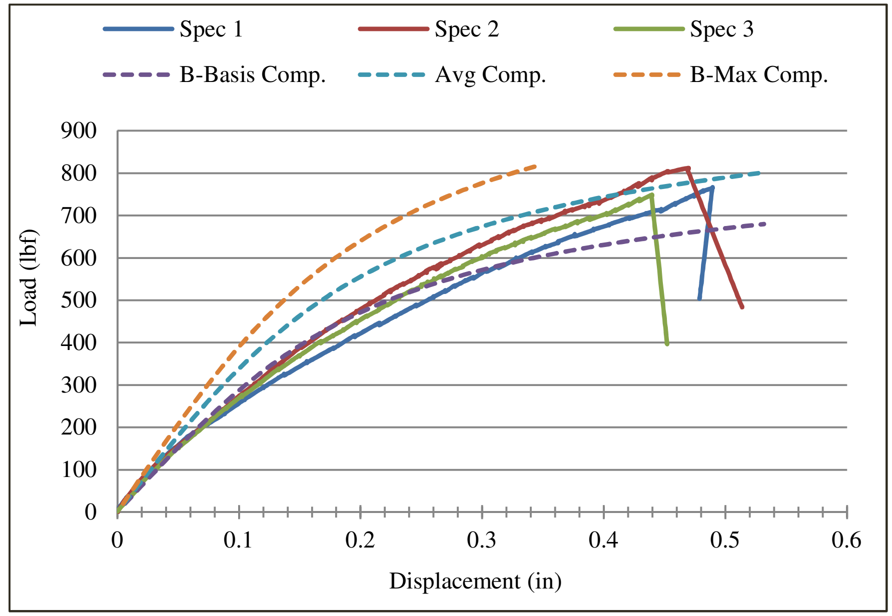
Clip End Vertical Displacement

- Displacements fairly well modeled

Angle Modeling -Model



Clip End Rotation

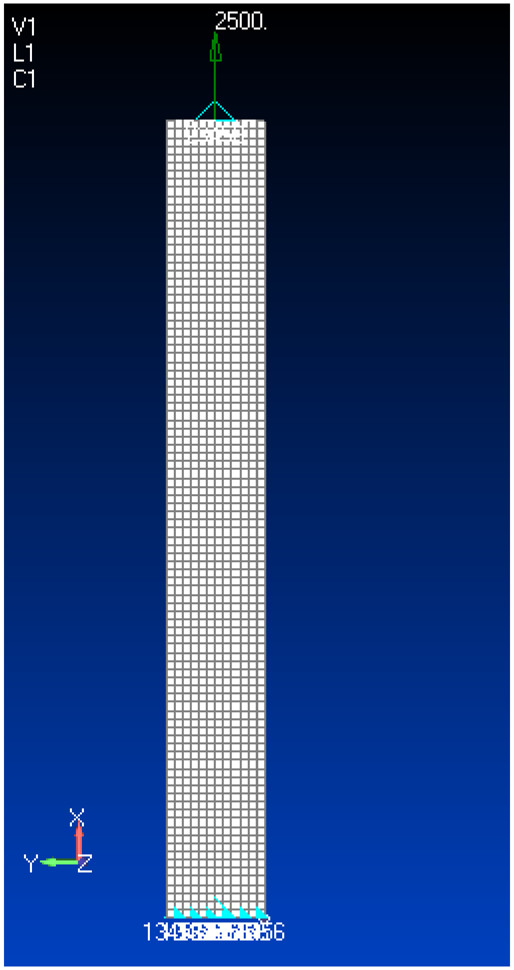


Clip End Vertical Displacement

- Displacements fairly well modeled

Stochastic Modeling -Model

- Assigns random stacking sequence to fixed size Random Representative Volume Element (RRVE)
- Uses “Chip Properties”
- Meshes FEA elements with assigned layup to each RRVE
- Analyzes model, and starts with new sequence of layups

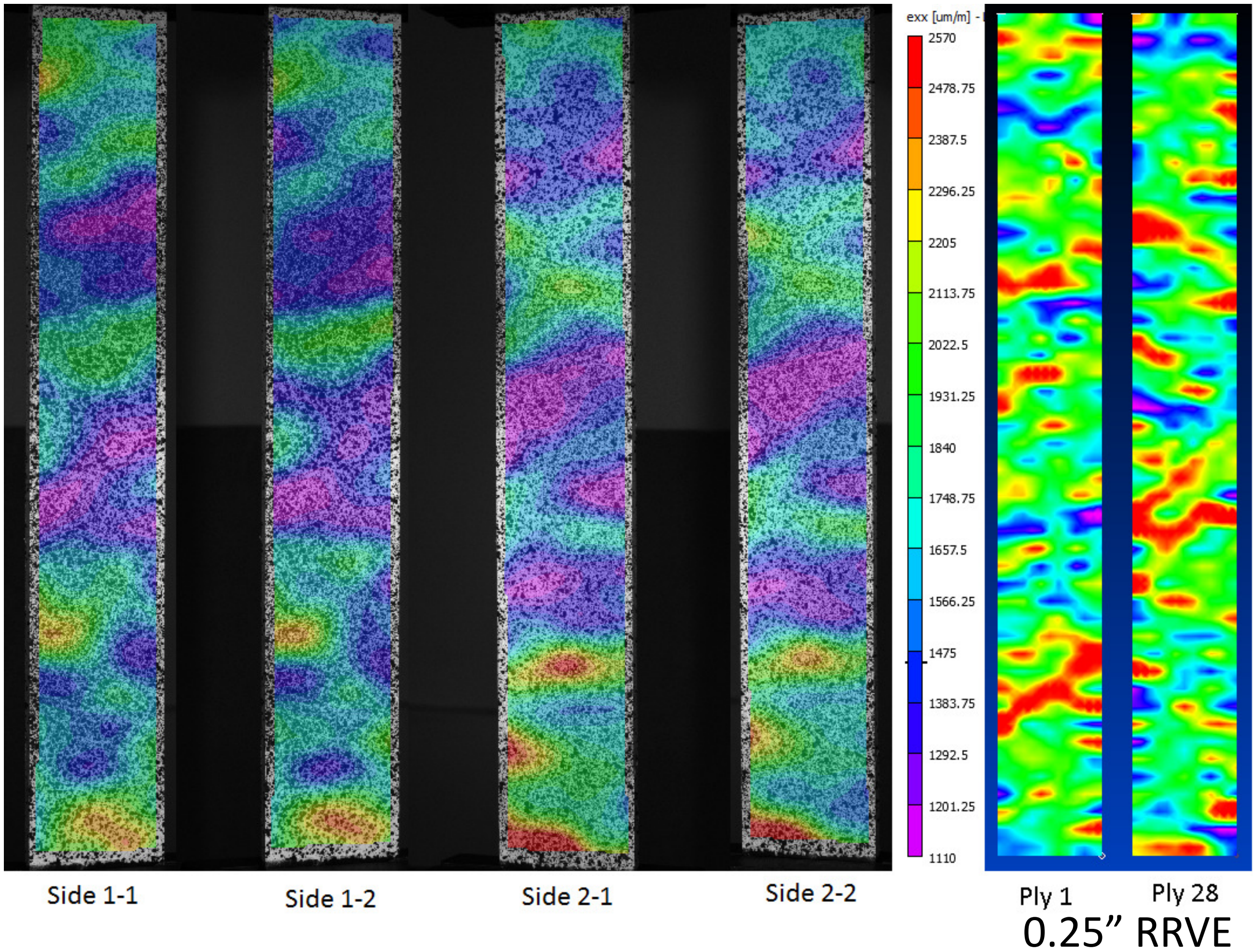


Stochastic Modeling -Comparison to Coupon Test

- 1.5” x 12” specimens cut from low flow HexMC plates left over from previous work
  - 0.140” thick
  - 0.090” thick
- Displacements measured using DIC and used to calculate strain
- Comparison of strain distributions and out of plane displacements being used to determine RRVE size

Stochastic Modeling -Strain

- Strain variation regions are too small for 0.25” RRVE
- Strain are not the same through the thickness



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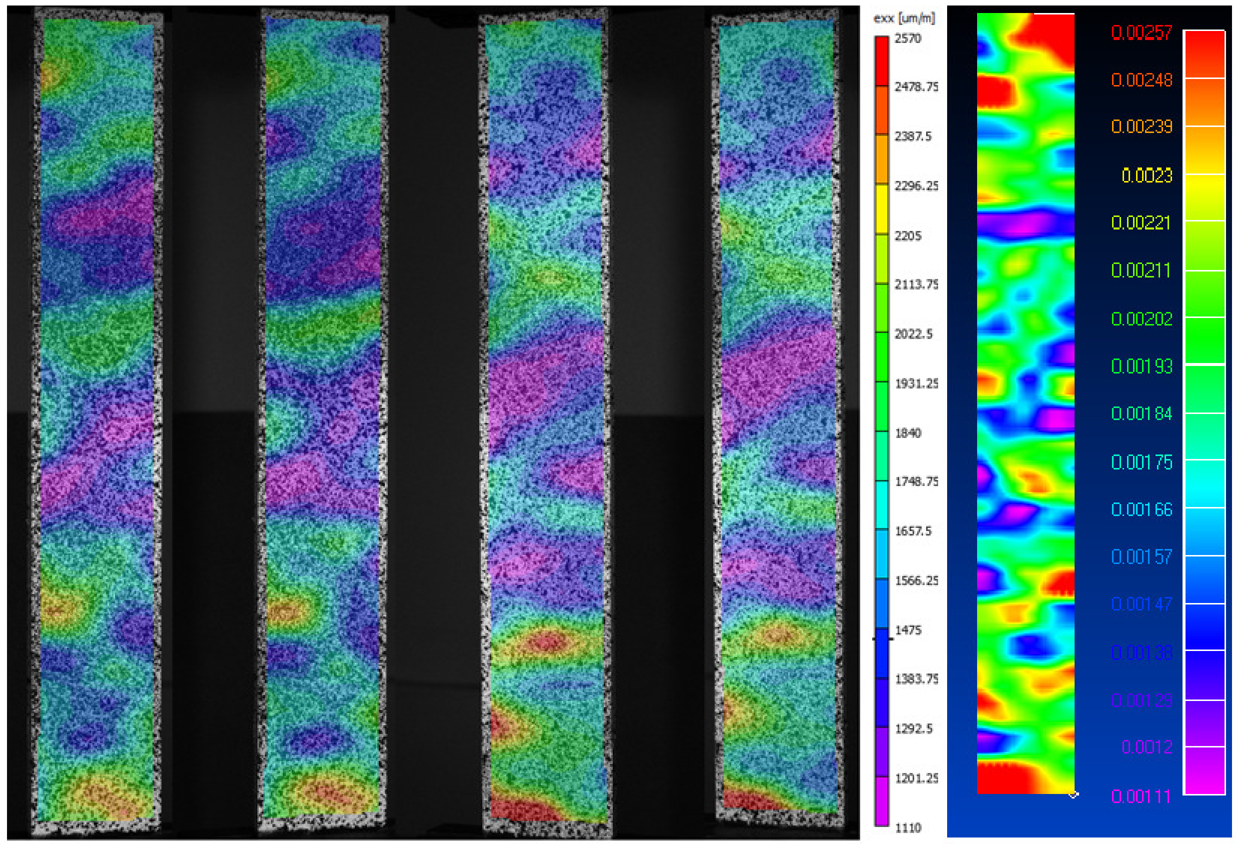
Stochastic Modeling -Strain

- Strain variation regions are more accurate for 0.5” RRVE

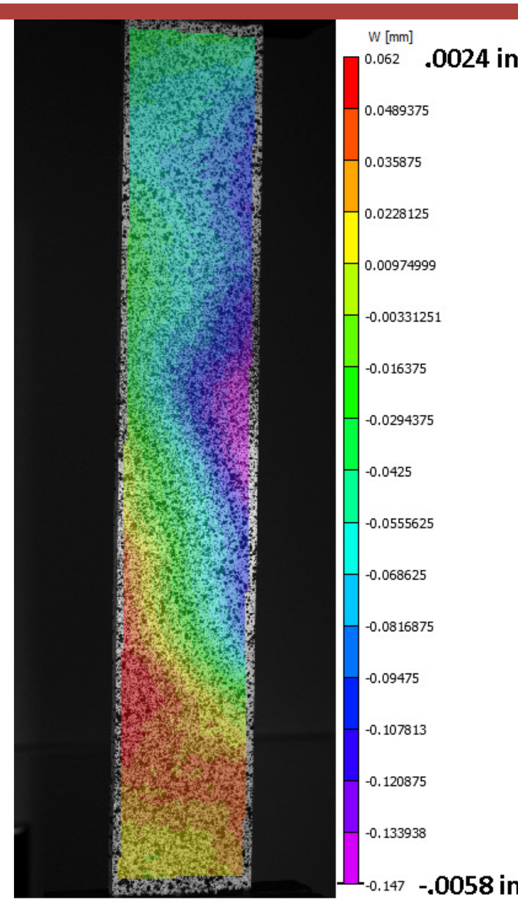


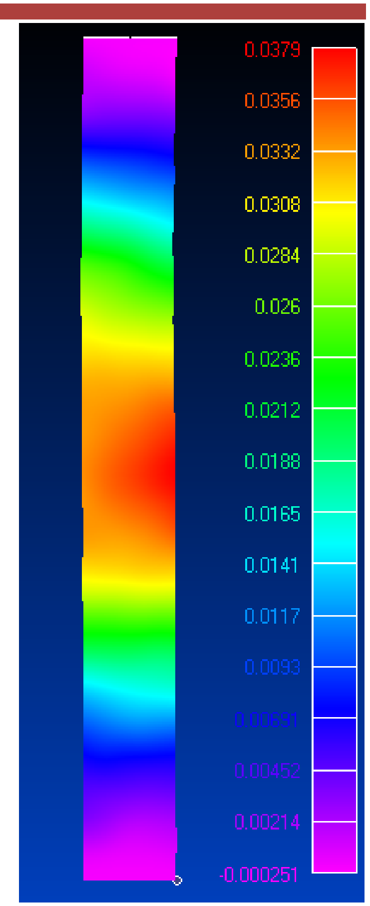
Side 1-1 Side 1-2 Side 2-1 Side 2-2

0.5” RRVE

Stochastic Modeling -W Comparison

- 0.25” RRVE over predicts W
- 0.5” RRVE under predicts W
- Further testing will reveal if proper RRVE size is dependent on thickness of specimen





0.5” RRVE Max w (600 Runs)

0.5 RRVE

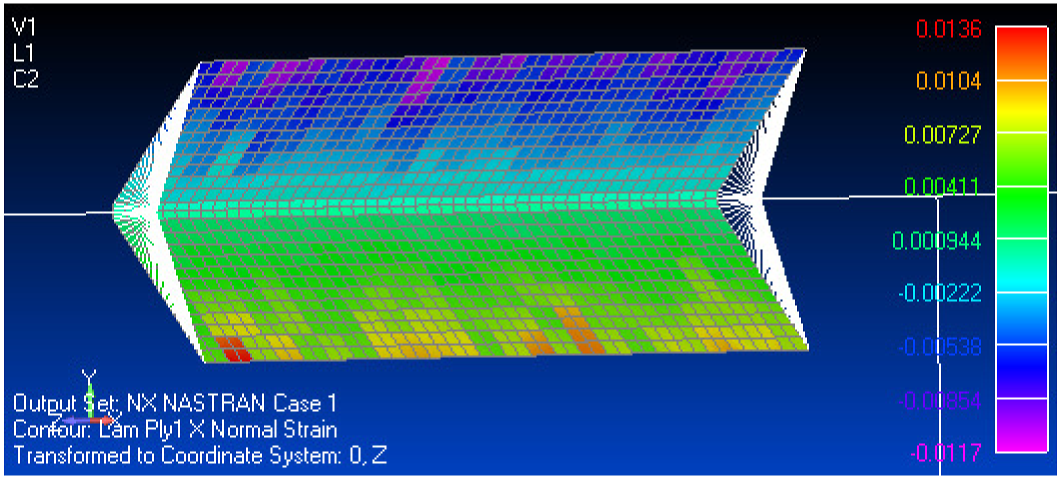
Max=	0.036337	in
Avg=	0.013419	in
Min=	0.003197	in

0.25 RRVE

Max=	0.022789	in
Avg=	0.006426	in
Min=	0.001719	in

Stochastic Modeling -Angles

- Method is being extended to angles to hopefully improve buckling predictions



Static Analysis