Framework for the Calibration and Validation of Multiscale Material Models

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Outline

Rationale

- Multi-scale material models are used to simulate behavior of composite materials.
- It is possible to predict:
  - performance of layups from single layer properties
  - performance of these composites under complex loadings

Work Plan

- Multi-scale MDS model is calibrated for UD composites
- MDS is used to simulate different kinds of layups.
- Manufactured layups are tested and compared to simulation in a validation step which provides a measure of the solution accuracy.

What do we mean by Multiscale?

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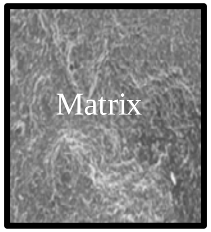
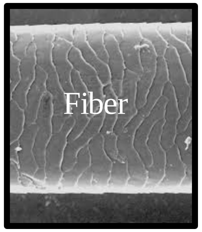
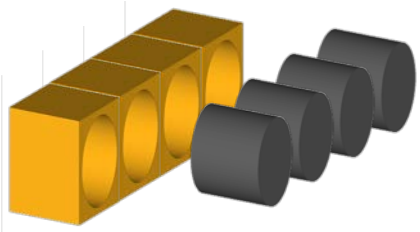
Example Unidirectional Carbon Fiber Reinforced Plastics (CFRP)

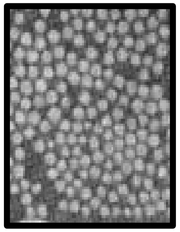
Scale0 ($\sigma^{MicroStructure}$)



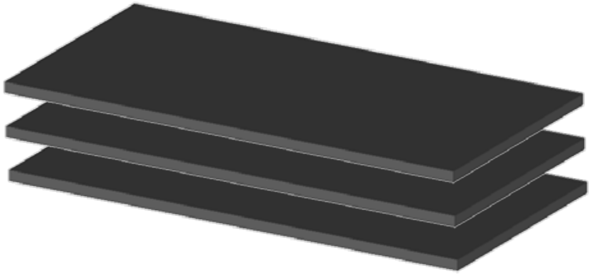


Scale1 ($\sigma^{Fiber/Matrix}$)

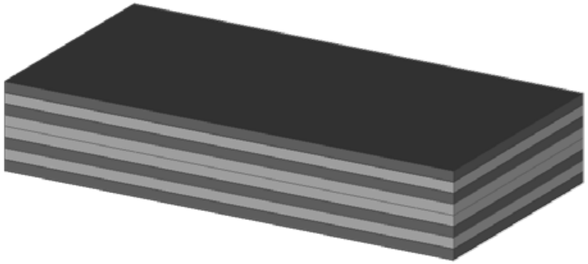




Scale2 (σ^{Ply})



Scale3 ($\sigma^{Laminate}$)



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Forward Homogenization

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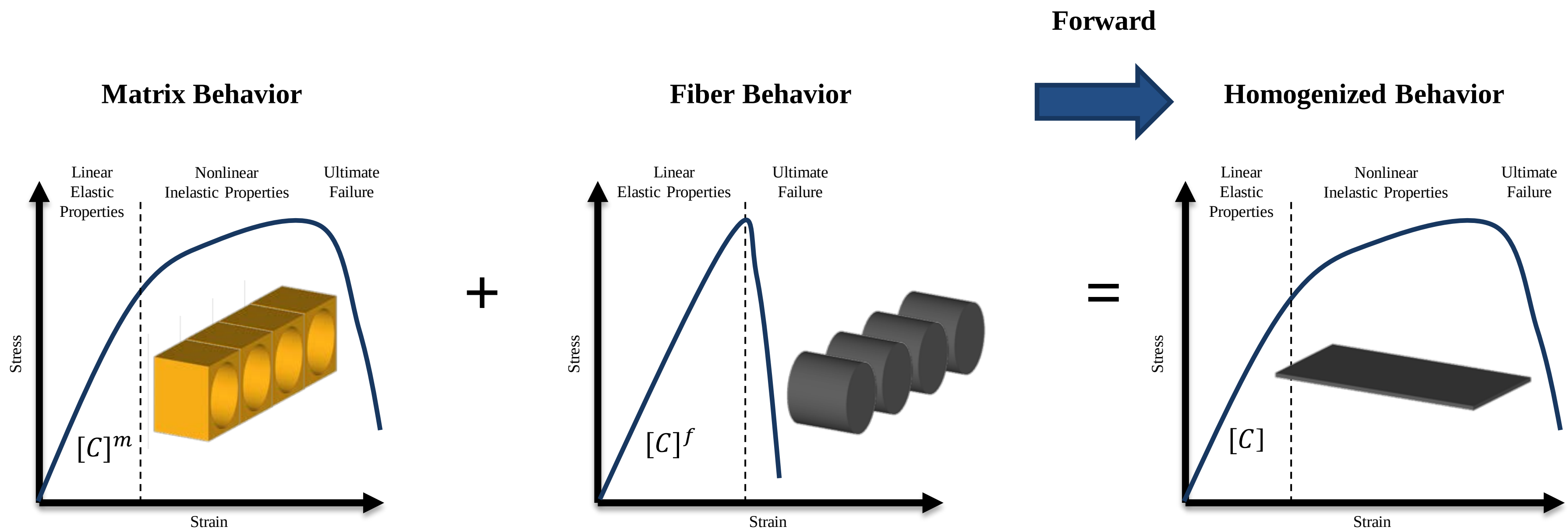
Given Matrix Linear Properties (E^m, ν^m, …) and Fiber Linear Properties (E_1^f, E_2^f, …)
Calculate the Homogenized Linear Properties (E_1, E_2, …)

$$E_1 = E_1^f V^f + E^m V^m$$

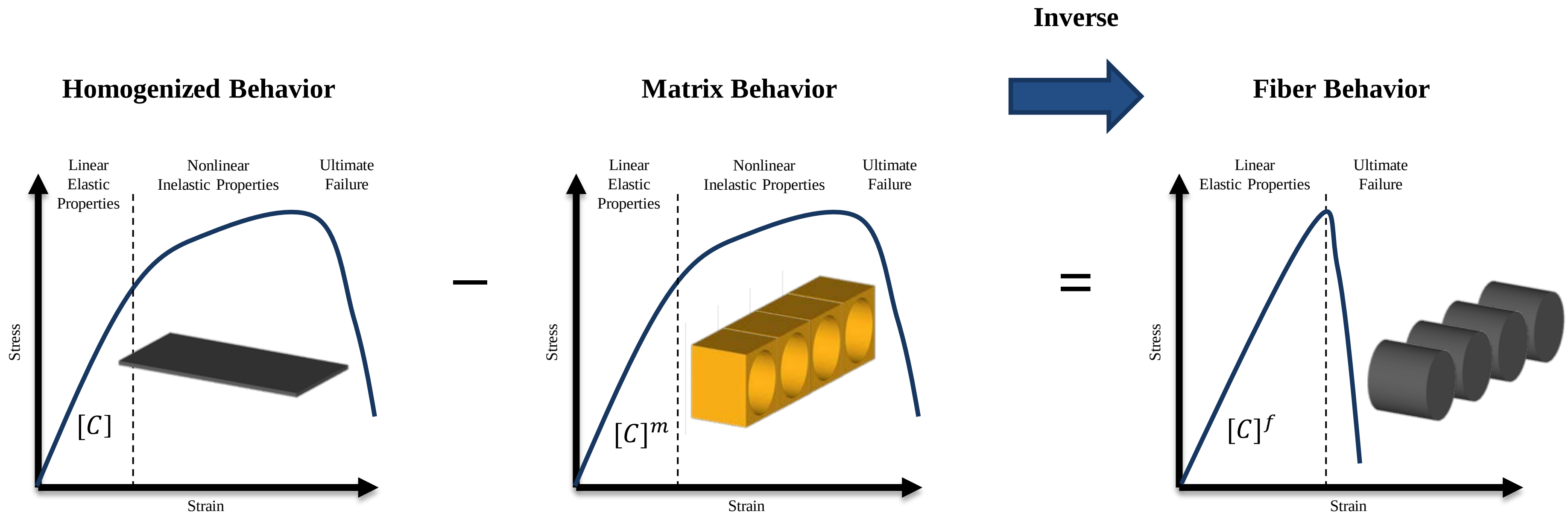


courtesy of Jeff Wollschlager/Altair Engineering

Inverse Characterization

Given Homogenized Linear Properties (E_1, E_2, …) and the Matrix Linear Properties (E^m, ν^m, …)
Calculate the Fiber Linear Properties (E_1^f, E_2^f, …)

$$E_1^f = \frac{E_1 - E^m V^m}{V^f}$$



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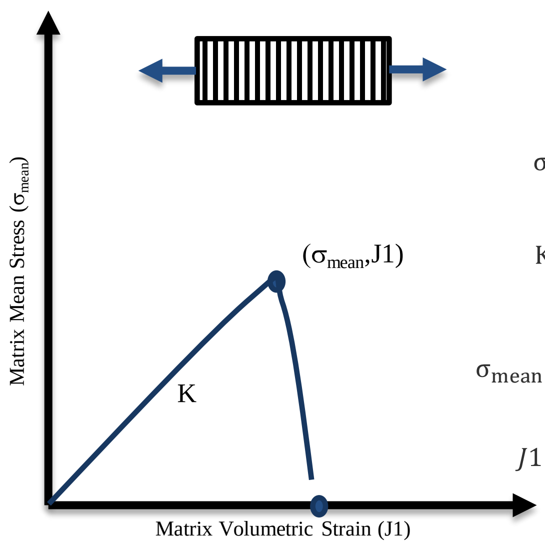
Polymer Matrix Material Behavior

Two critical modes of polymer matrix behavior need to be characterized for Unidirectional Product Form

1. Matrix Brittle Behavior [90] Tension σ_{mean}, J1
2. Matrix Ductile Behavior [45/-45] Tension σ_y, σ_1, δ, H

Matrix Brittle Behavior



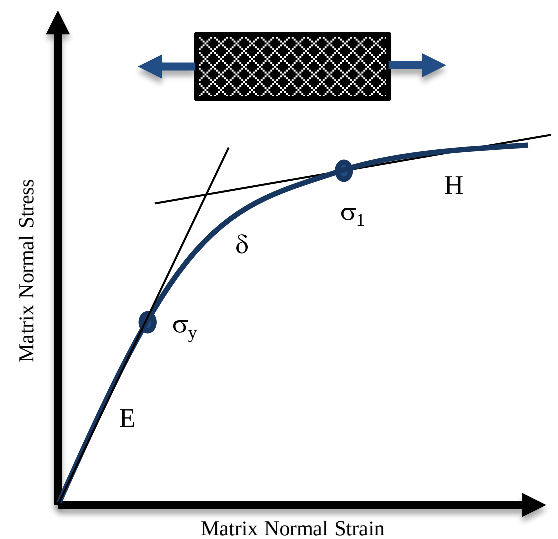
$$\sigma_{mean} = K * J1$$

$$K = \frac{E}{3(1-2\nu)}$$

$$\sigma_{mean} = \frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3)$$

$$J1 = \varepsilon_1 + \varepsilon_2 + \varepsilon_3$$

Matrix Ductile Behavior



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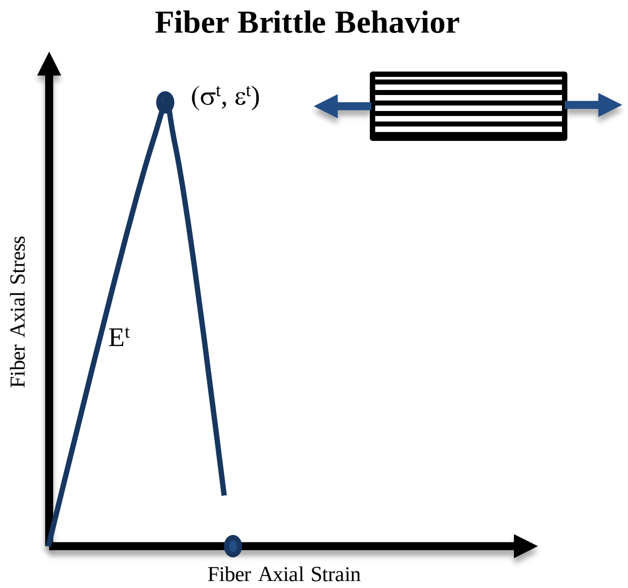
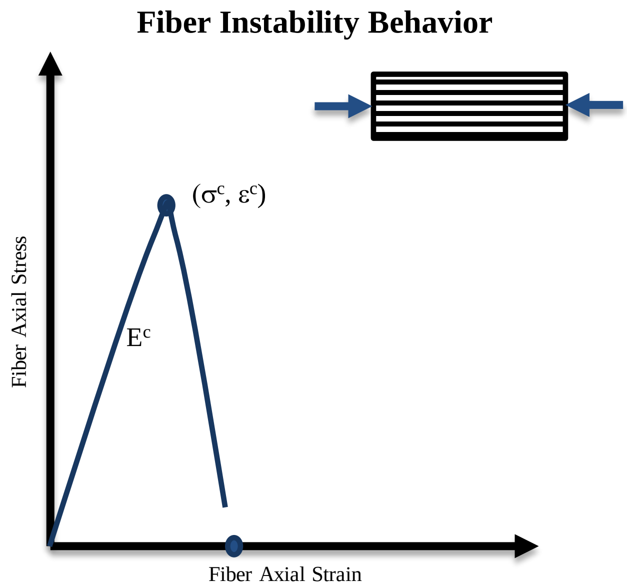
Carbon Fiber Material Behavior

Two critical modes of carbon fiber behavior need to be characterized for a Unidirectional Product Form

1. Fiber Brittle Behavior [0] Tension σ^t, ε^t
2. Fiber Instability Behavior [0] Compression σ^c, ε^c





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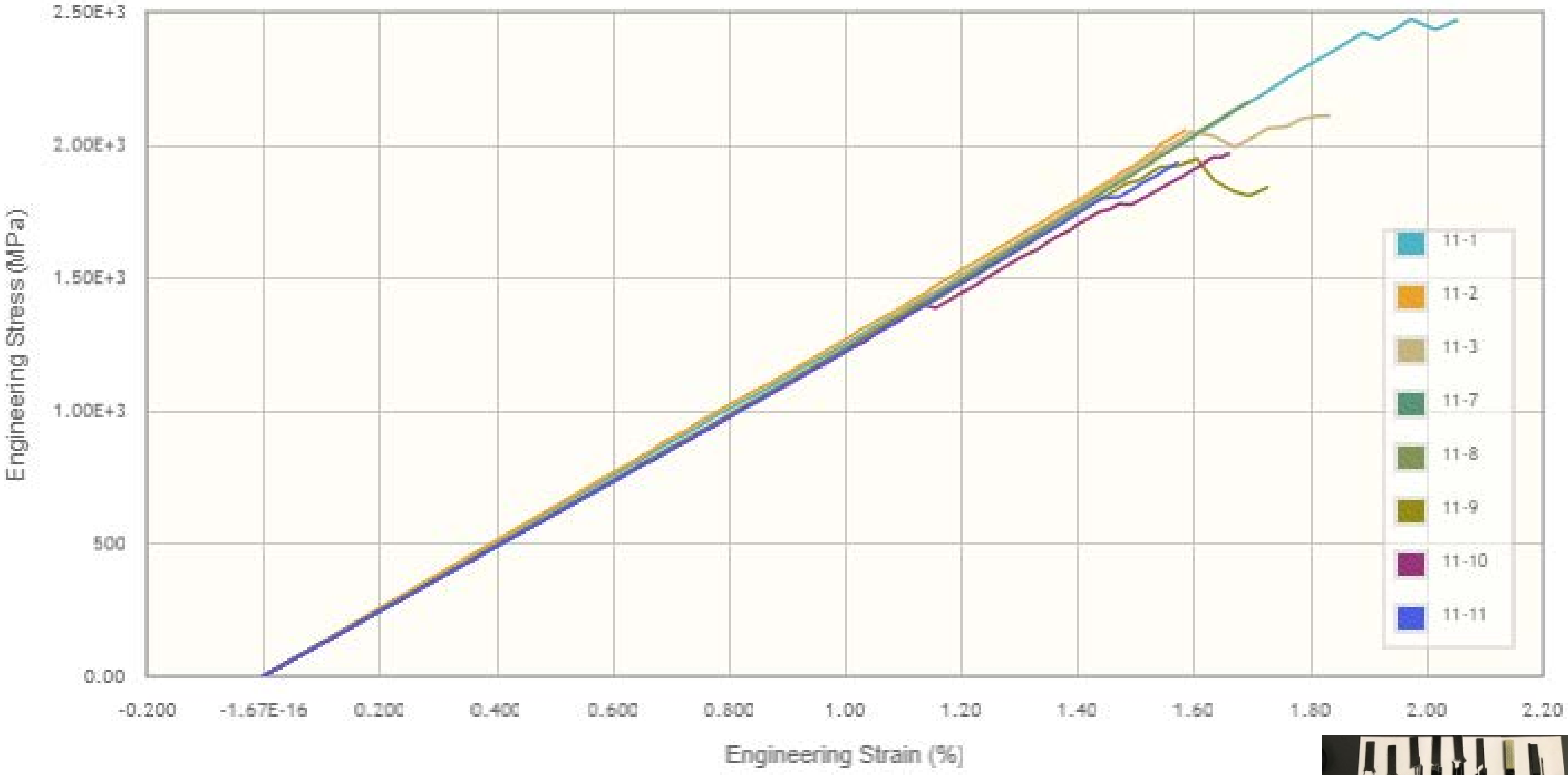
Multiscale Material Model Development Test Matrix

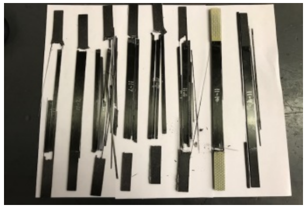
Tested T700/2510 UD Carbon Fiber Composite

Test	Test Standard	Layup	Specimens per Panel	Total Panels	Total Specimens
0 Tension	ASTM D3039	$[0]_8$	3	2	6
90 Tension	ASTM D3039	$[90]_{16}$	3	2	6
[45/-45] Tension	ASTM D3518	$[45/-45]_{4s}$	3	2	6
0 Compression	ASTM D6641	$[0]_{16}$	3	2	6
90 Compression	ASTM D6641	$[90]_{16}$	3	2	6
[90/0] Tension *	ASTM D3039	$[90/0]_{2s}$	3	2	6
[90/0] Compression *	ASTM D6641	$[90/0]_{4s}$	3	2	6
[50/40/10] * OHT	ASTM D5766	[-45/02/45/90 /45/02/-45/0]s	3	2	6
			Totals	16	48

*Used for validation

Calibration Tests 0° deg. Tension





Calibration Tests- 90° Tension

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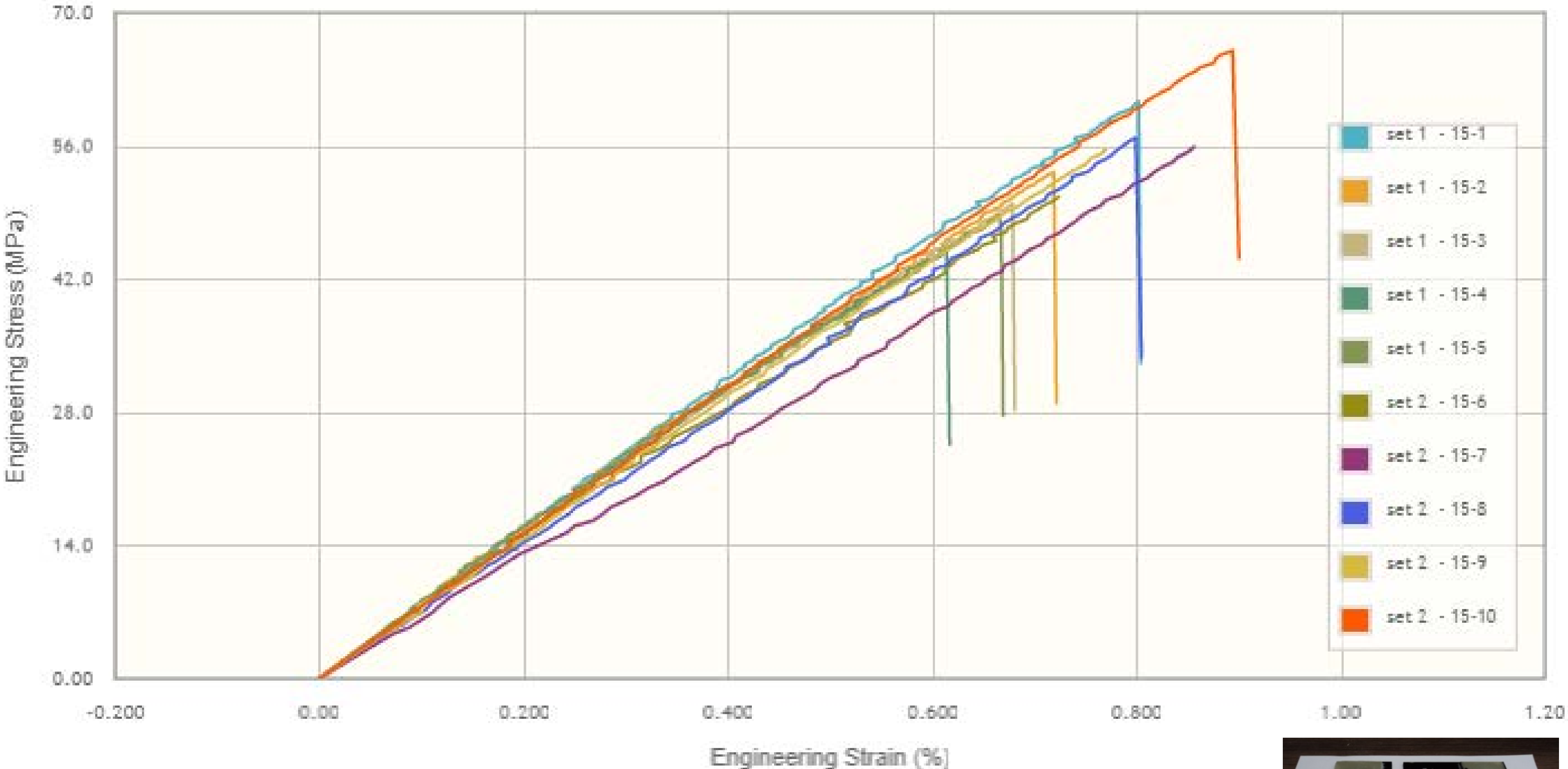
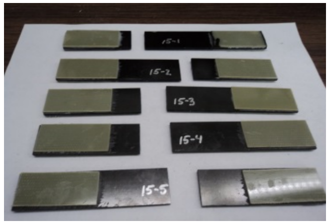
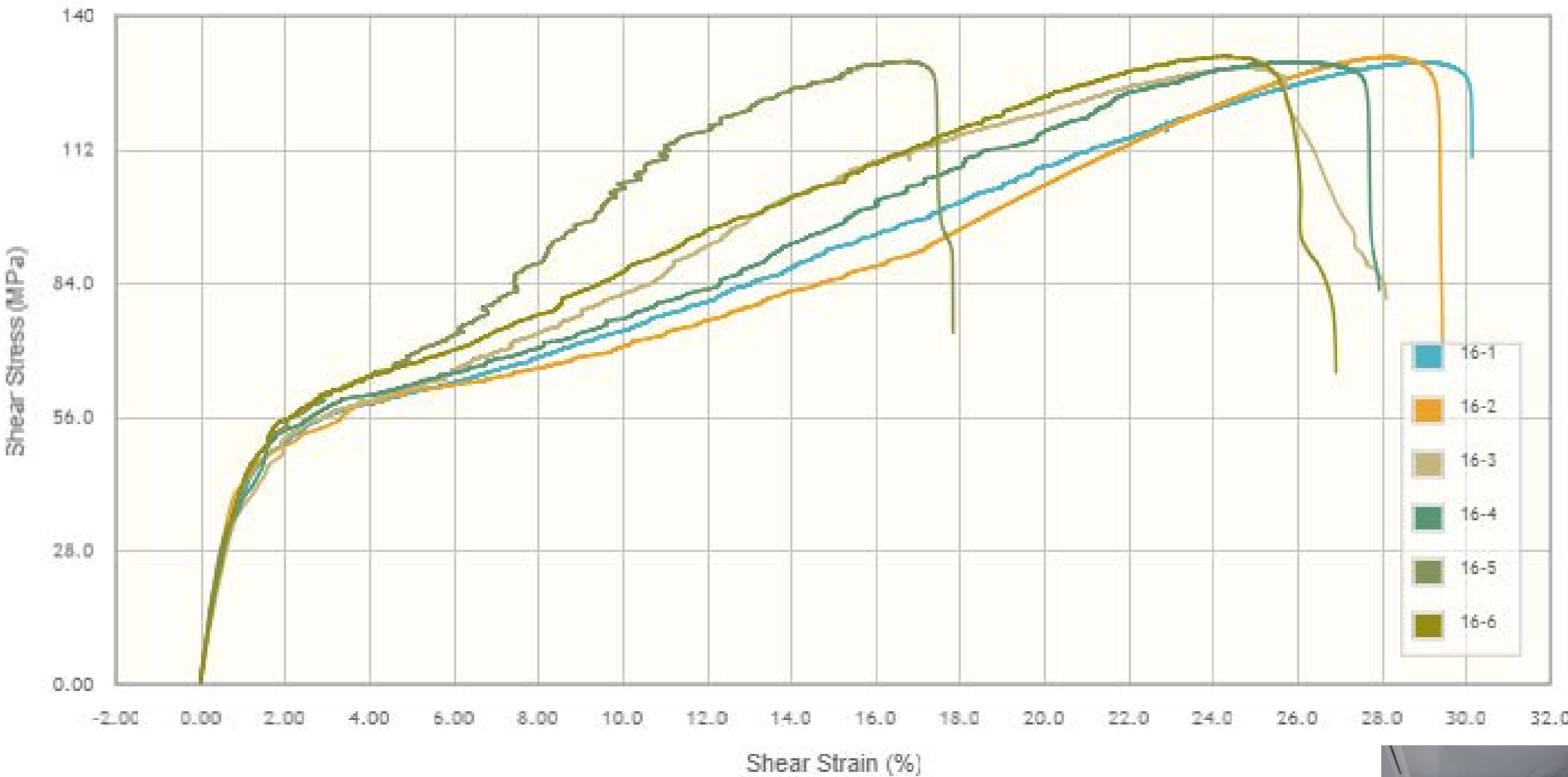
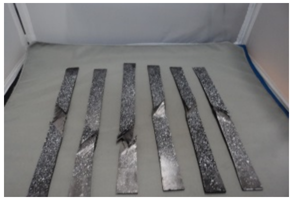




Calibration Tests [45/-45] Tension





Calibration Tests 0° Compression

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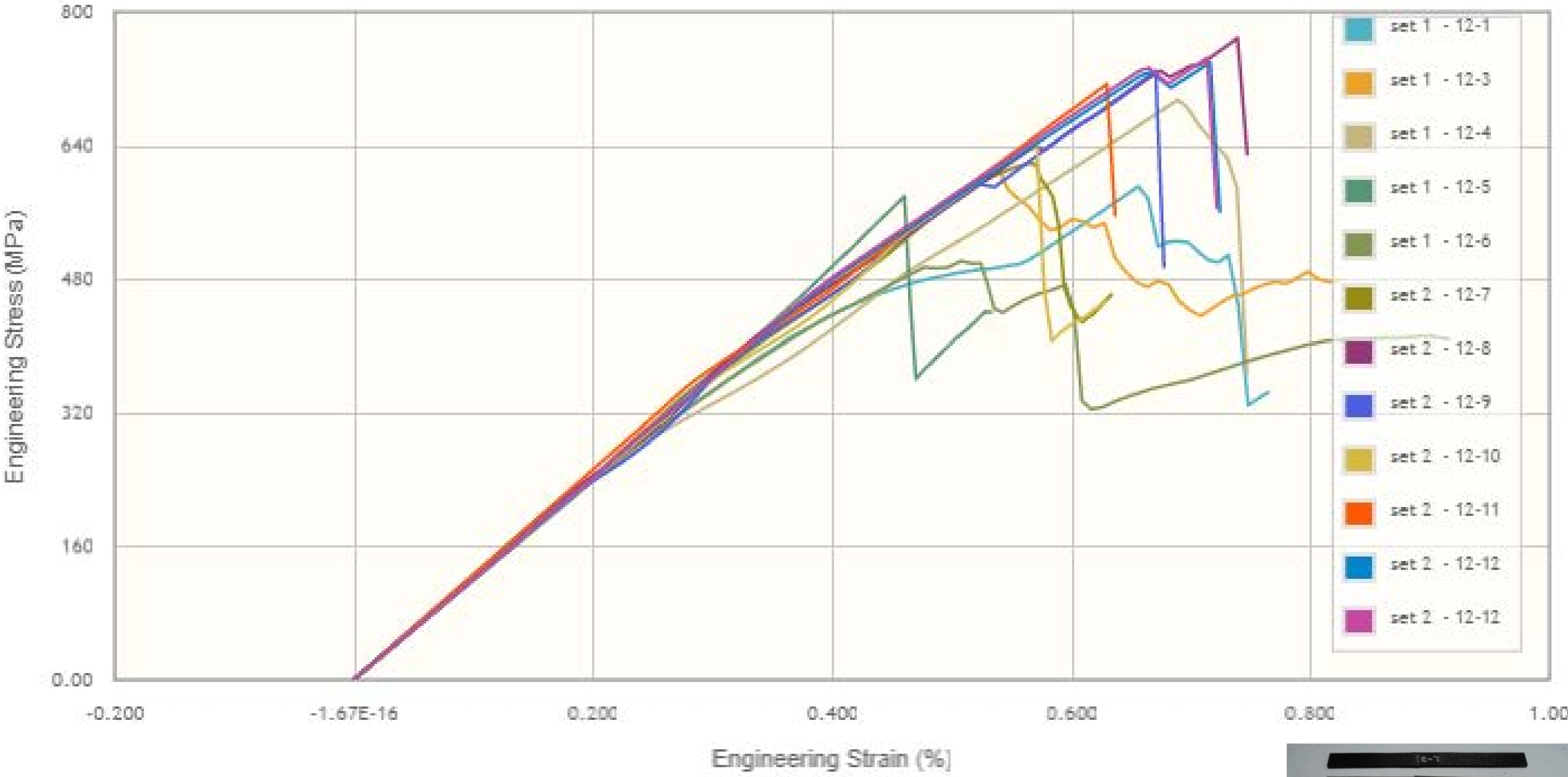

Calibration Tests 90° Compression

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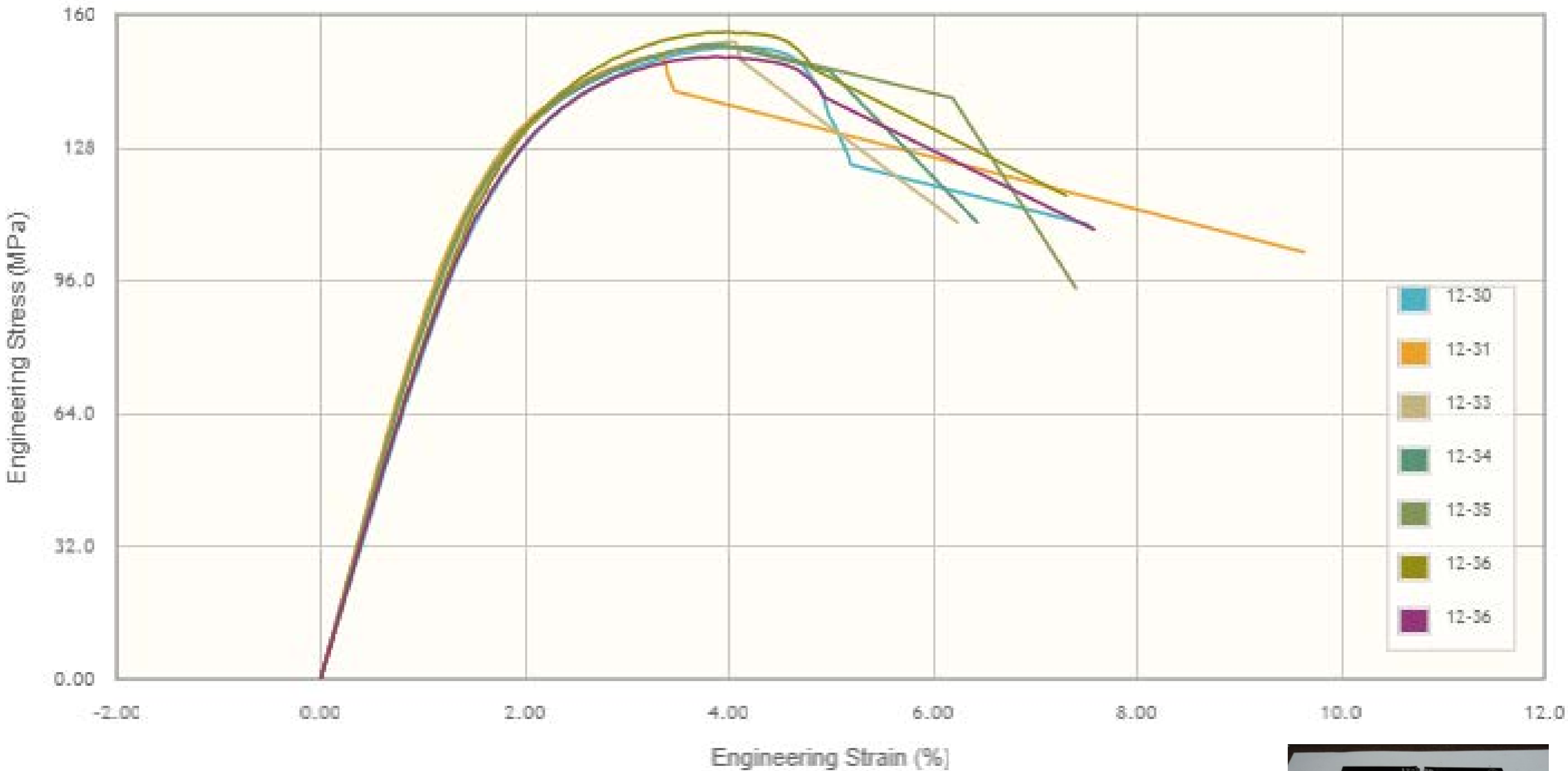

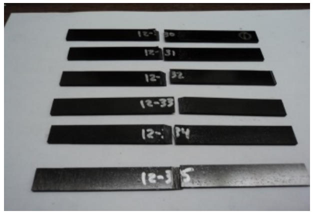

Simulation Comparison [90/0] Tension

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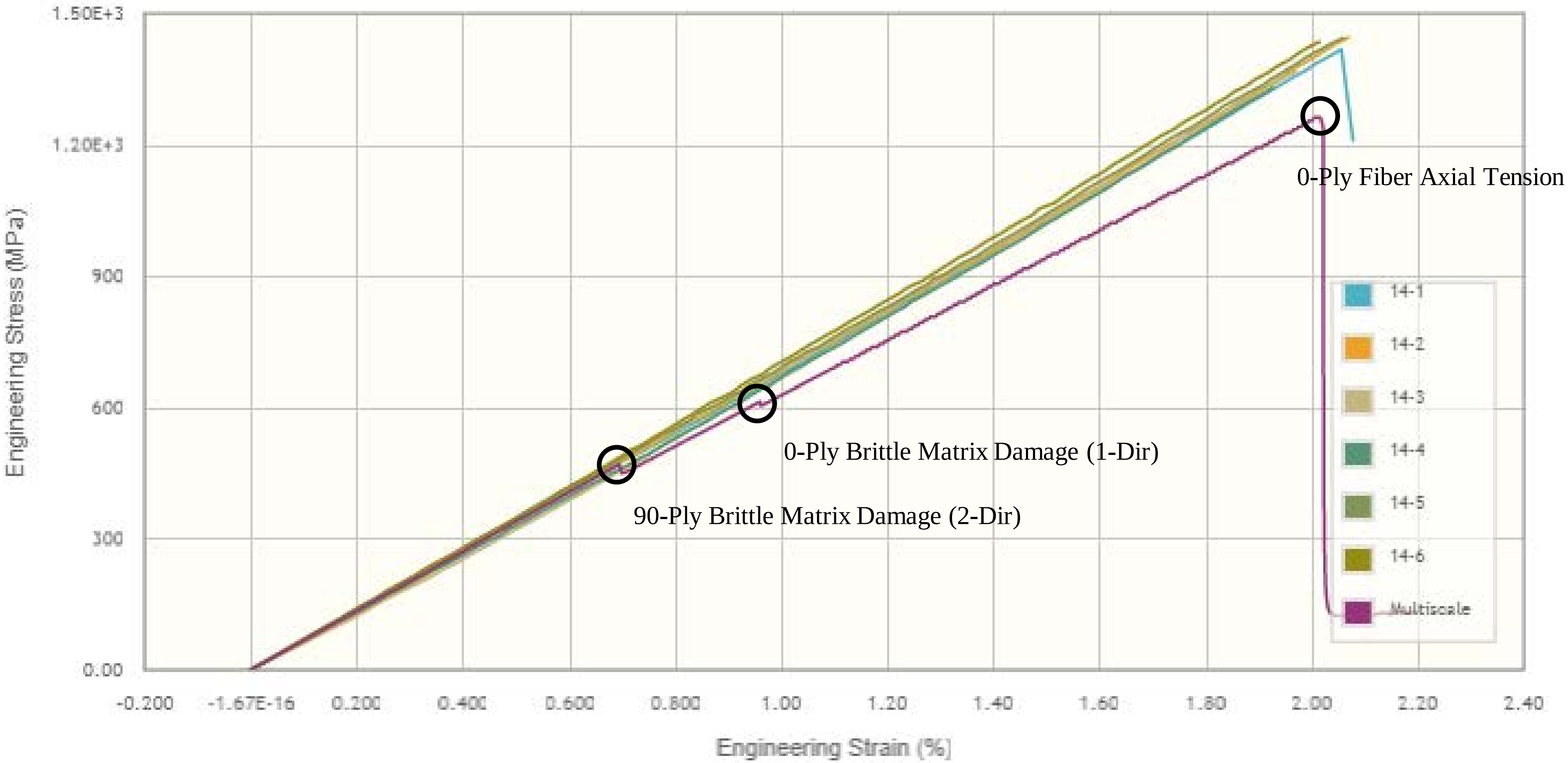
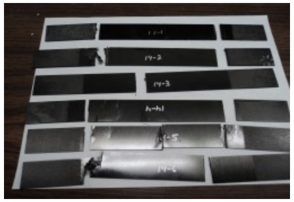
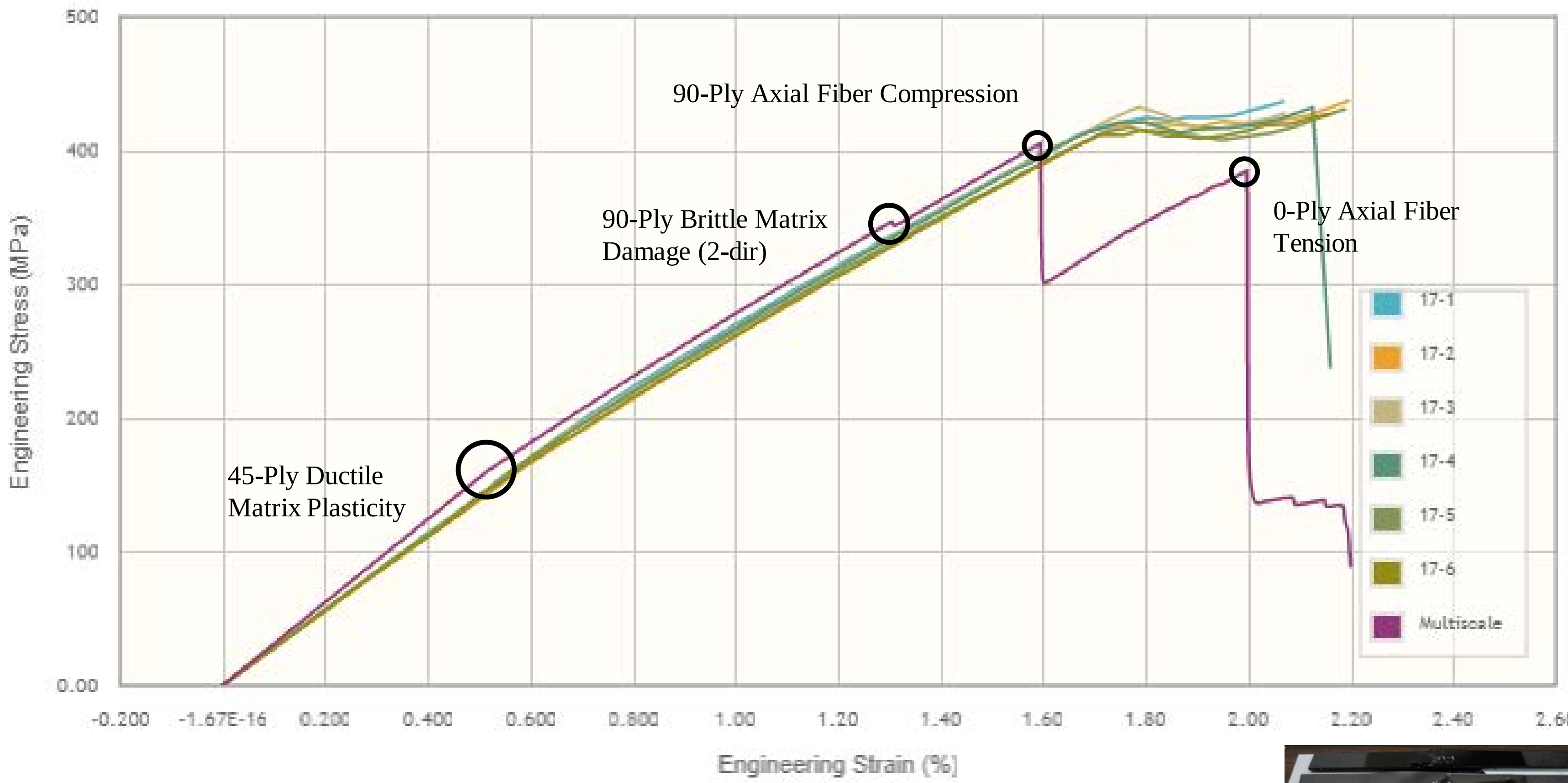


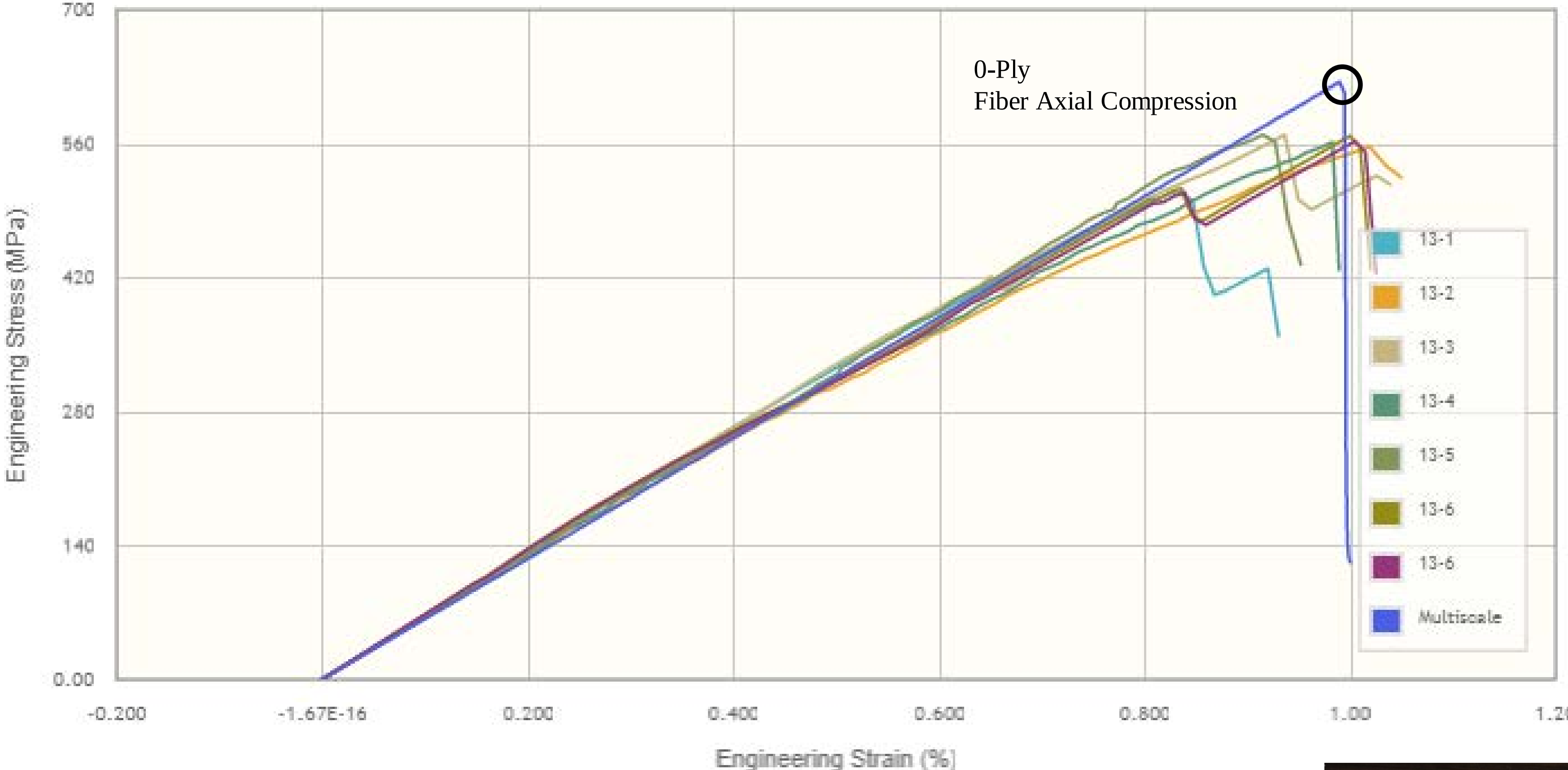


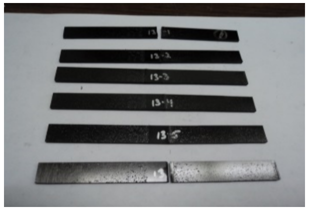
Simulation Comparison [10/80/10] Tension

Applus laboratories

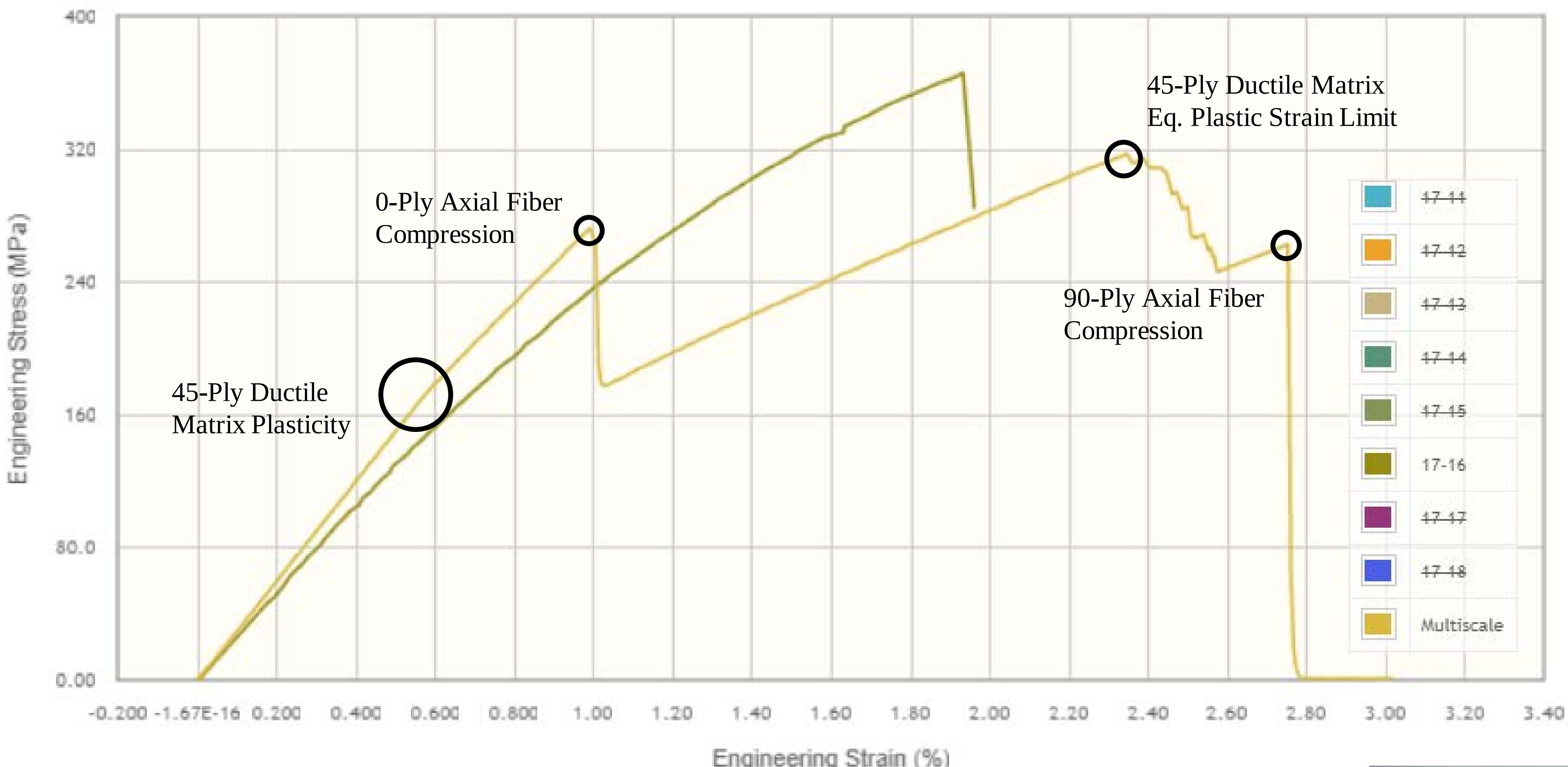


Simulation Comparison [90/0] Compression

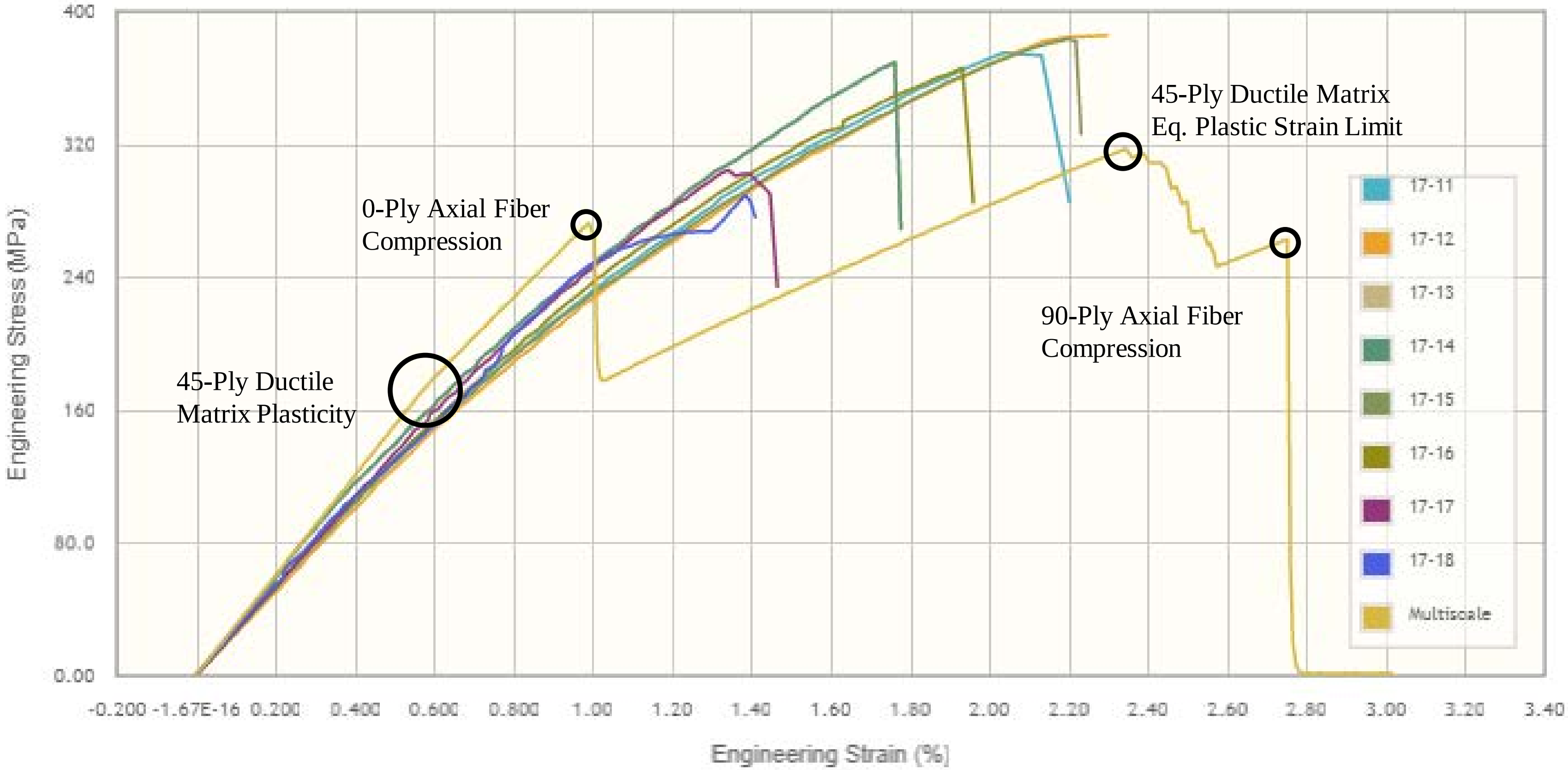


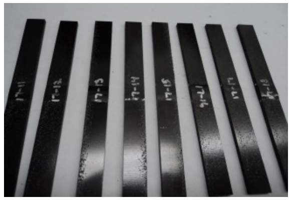


Simulation Comparison [10/80/10] Compression



Simulation Comparison [10/80/10] Compression





Simulation Comparison [50/40/10] Compression

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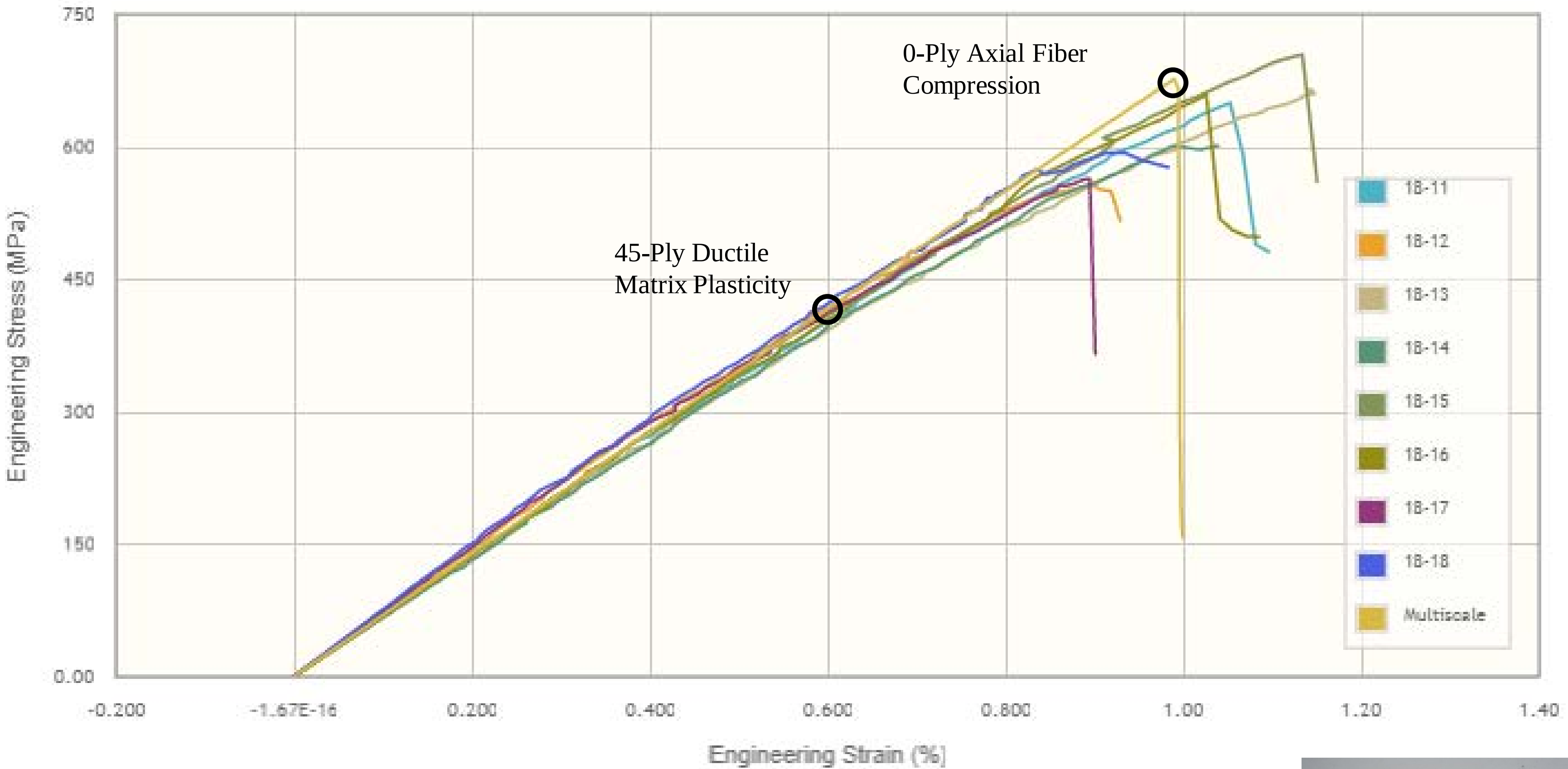
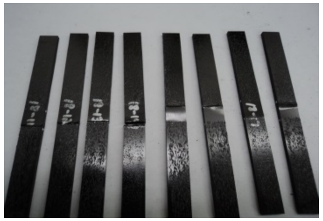
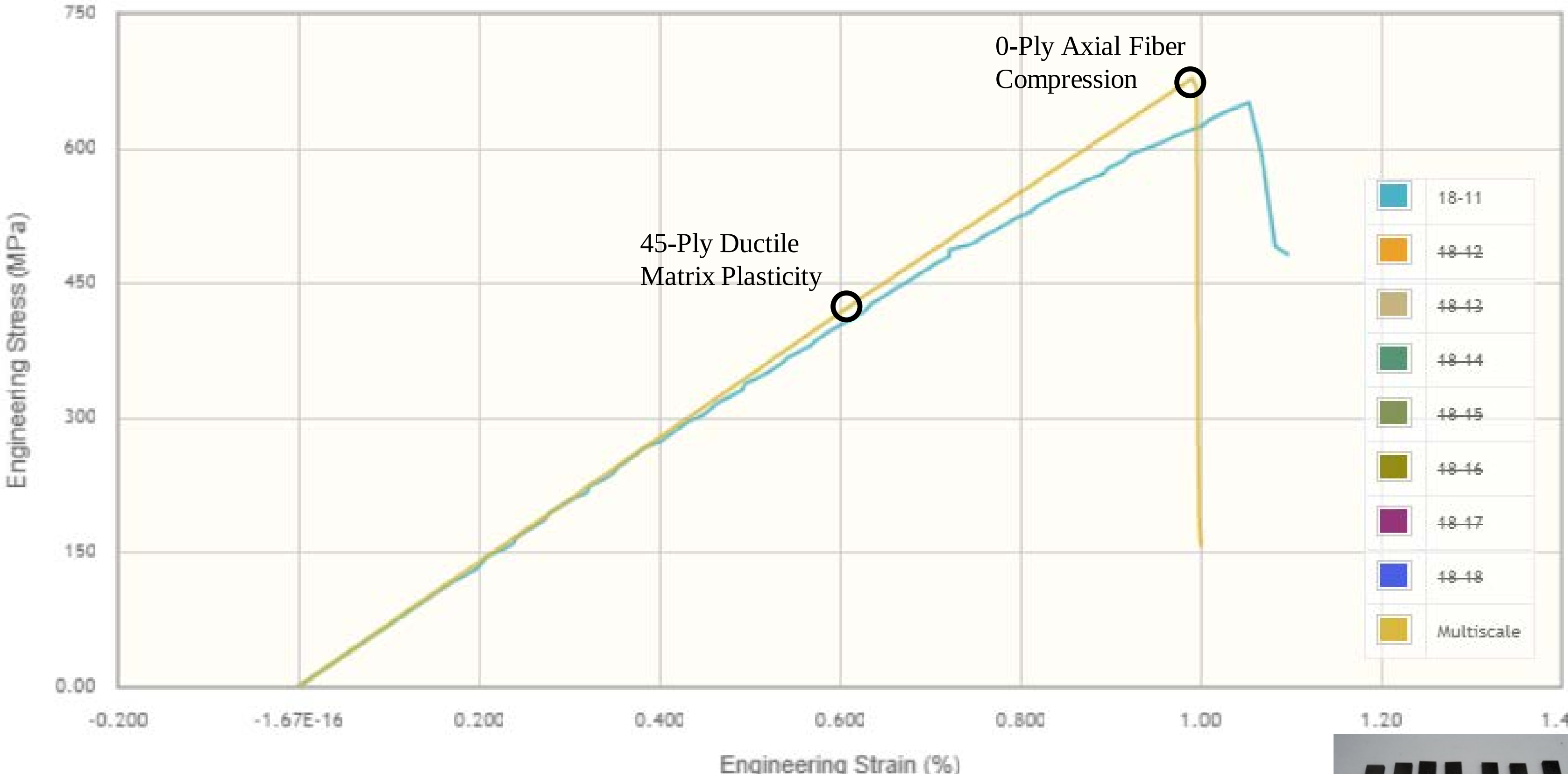
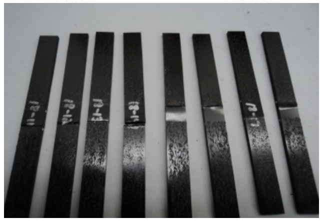


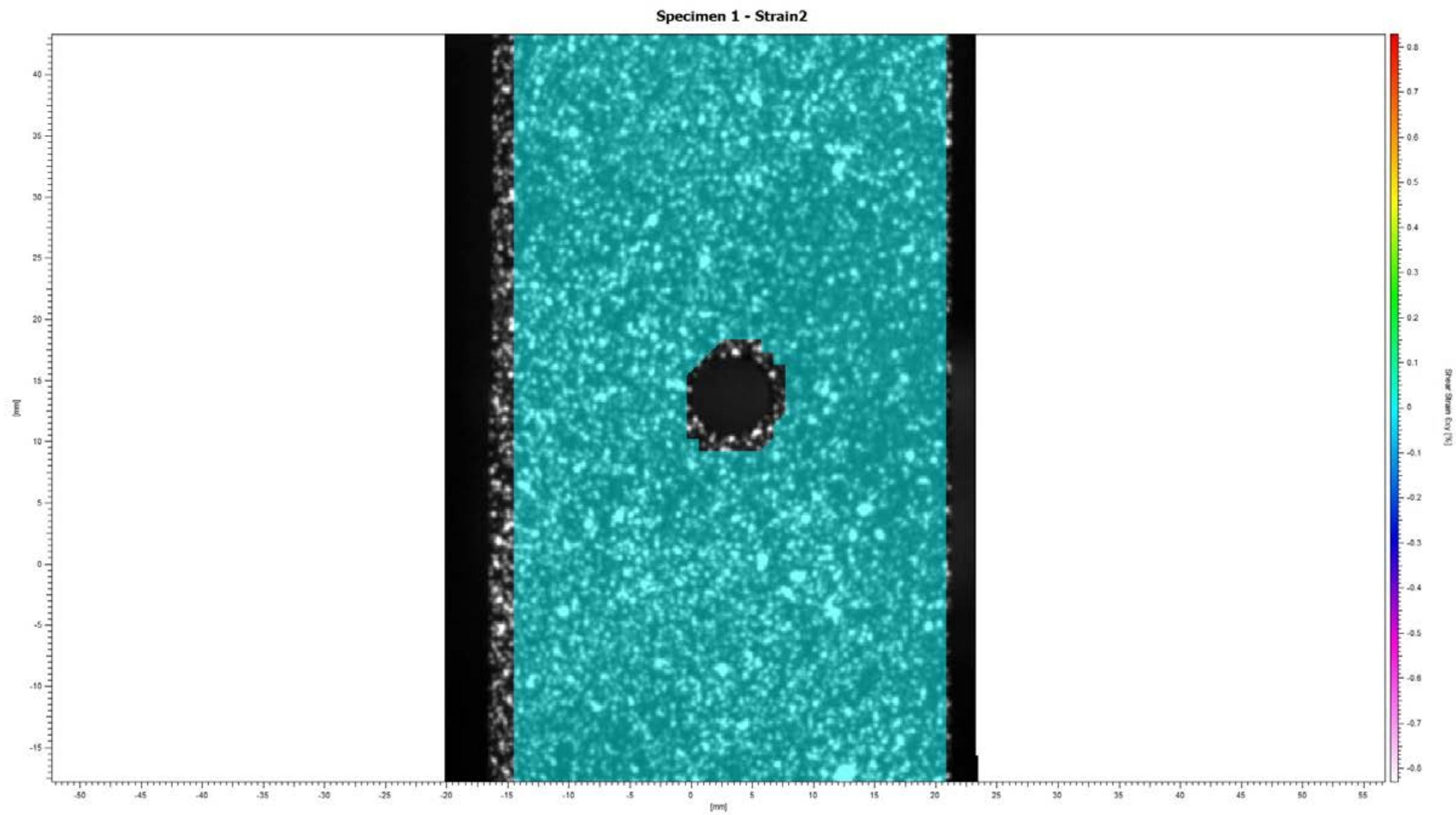


Simulation Comparison [50/40/10] Compression





Open Hole Tension ([50/40/10] Video)



Simulation Comparison [50/40/10] Open Hole Tension

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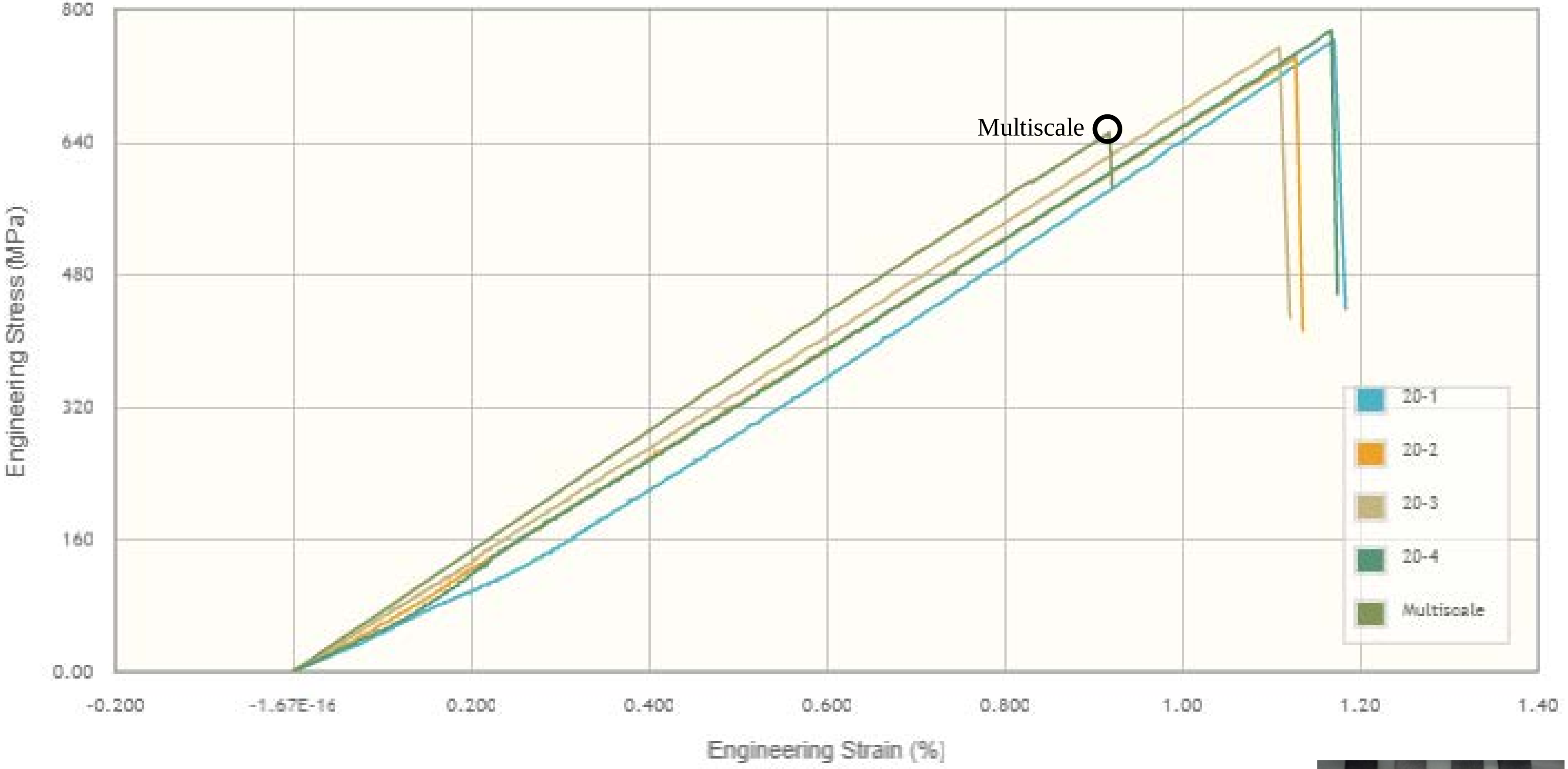
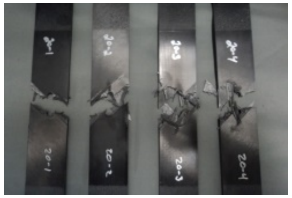
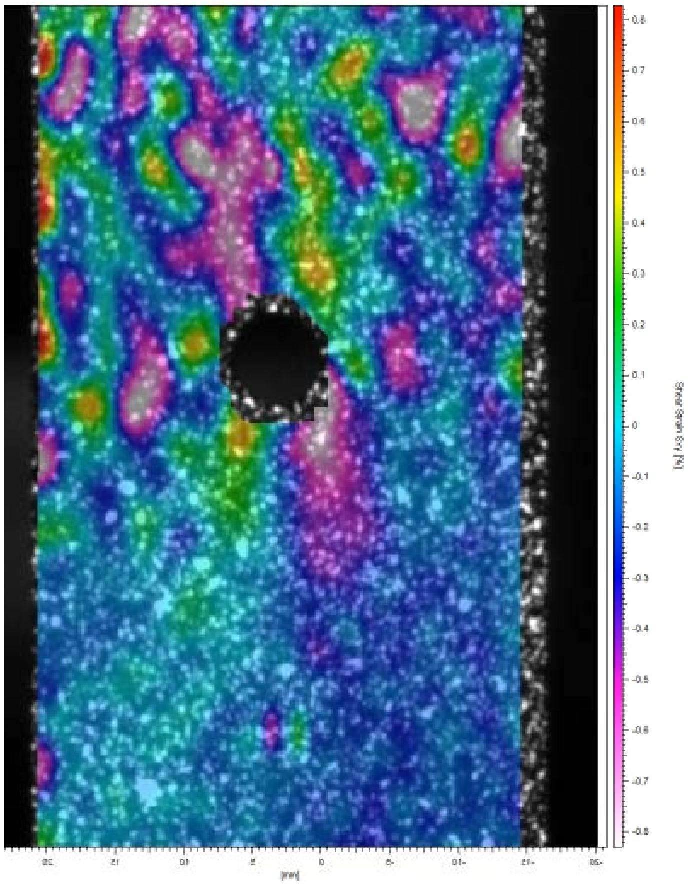
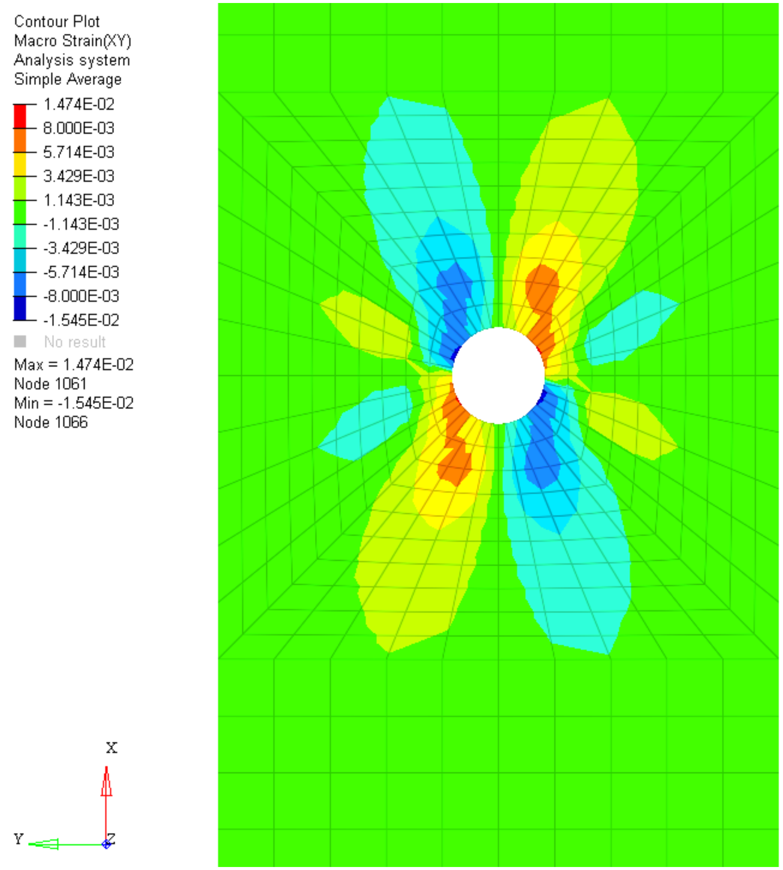


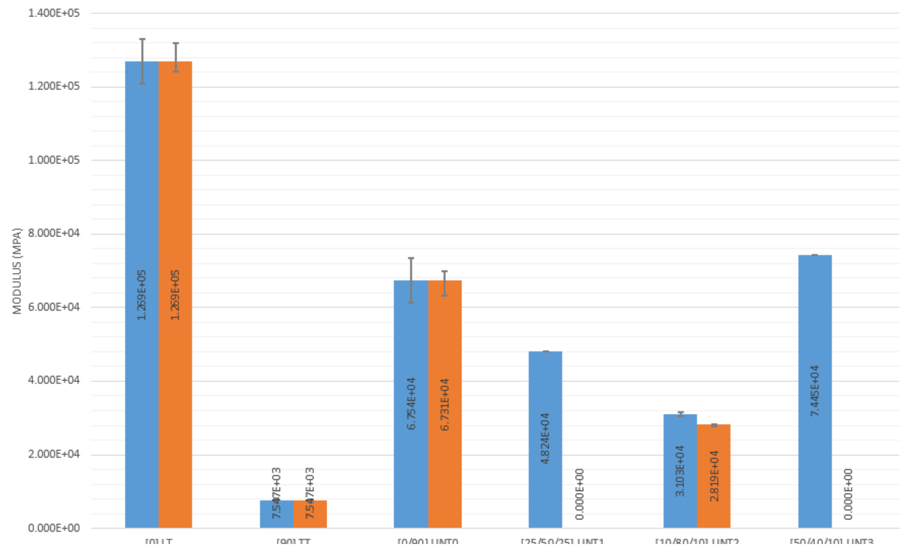


Shear Strain DIC Comparison

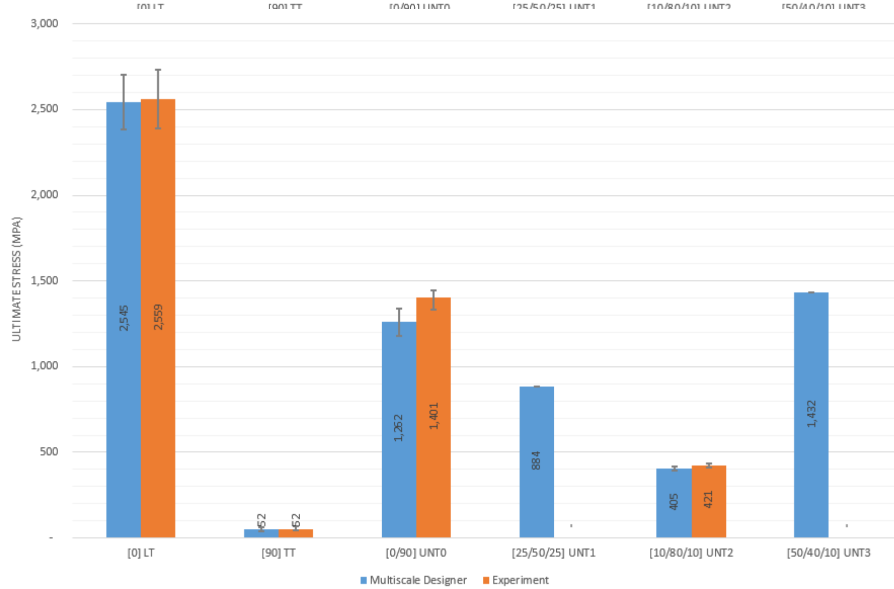




Summary Chart- UNT

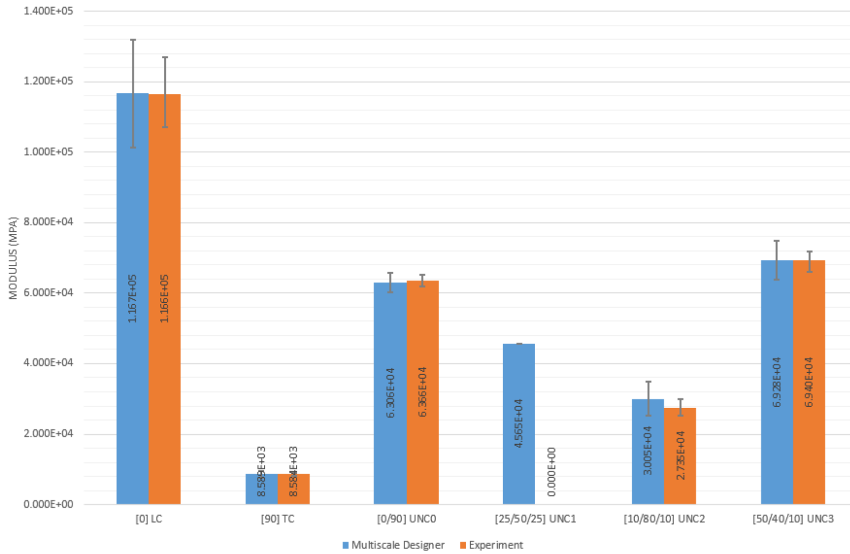


UNT Modulus

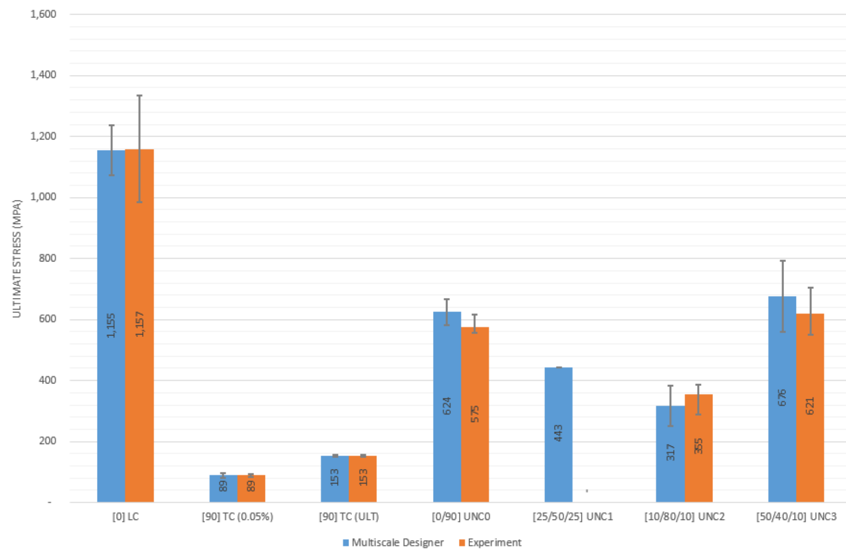


UNT Strength

Summary Chart - UNC

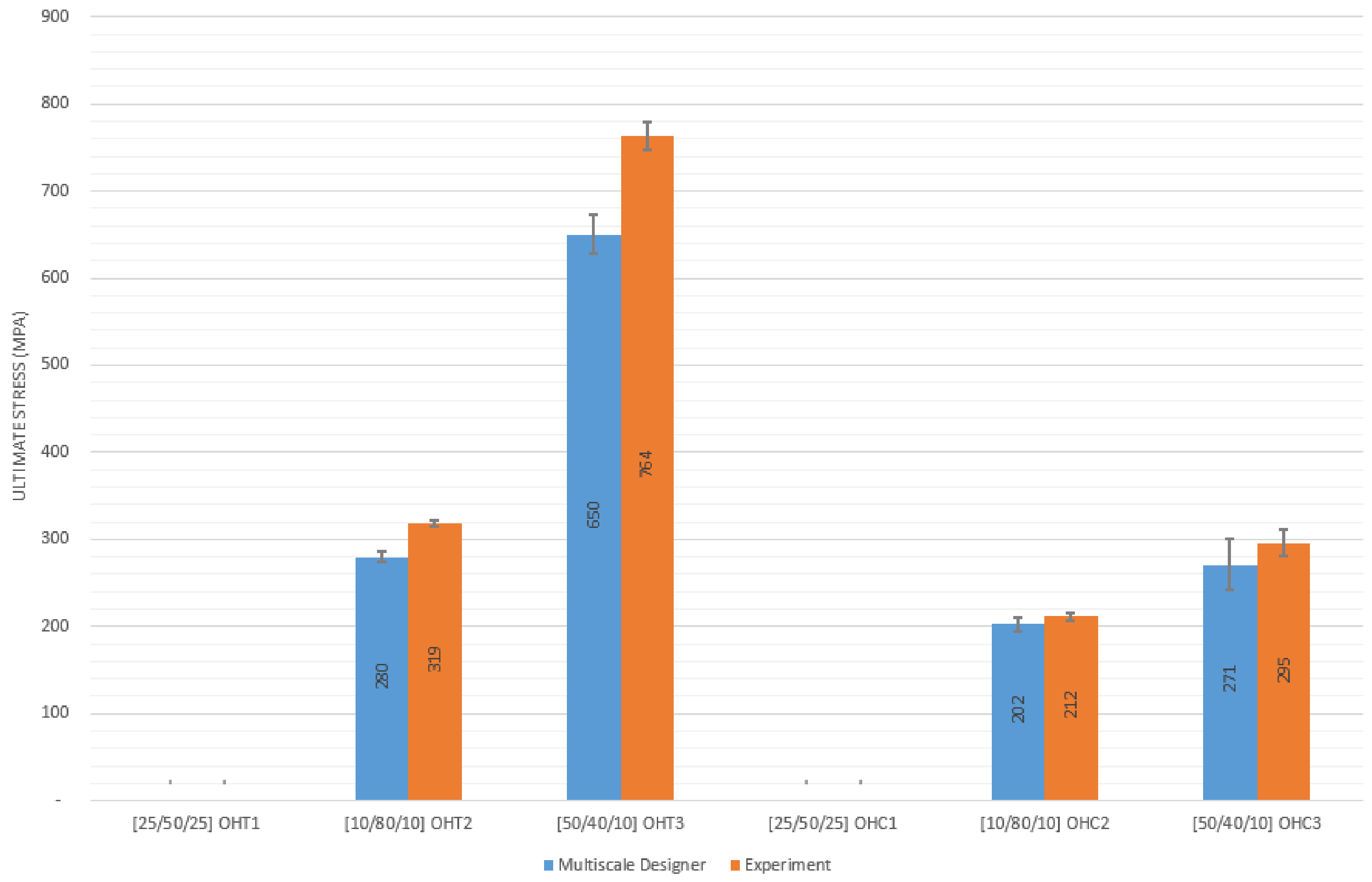


UNC Modulus



UNC Strength

Summary Chart: OHT/OHC Strength



Summary

- We have a methodology to calibrate multiscale scale material models for unidirectional composite materials
- Using that model we can validate more complex layups
  - Both the stress-strain curves and the moduli, strength, and failure strain correlate well
  - The damage modes are over exaggerated due to how the failure criteria are imposed in the simulation
- Can also validate OHT experiment [50/40/10] layup

End

Thank You