Three-dimensional Stress Analysis in Complex Fiber Architecture Composites by Using Independent Mesh Method

Composite Testing and Modeling Identification

Dayton OH
October 20-23, 2008

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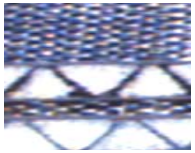
Motivation



- ***Tailorable*** **materials and properties!**
- **High Strength-to-Density**
- **High Stiffness-to-Density**
- **Nonconductive & Conductive**
- **Fatigue/Corrosion Resistance**
- **Creep & Stress Rupture Resistance**
- **Controlled (Low) Thermal Expansion**
- **Dimensional Stability**
- **Formable to Complex Shapes**
- **Lower Life Cycle Costs**

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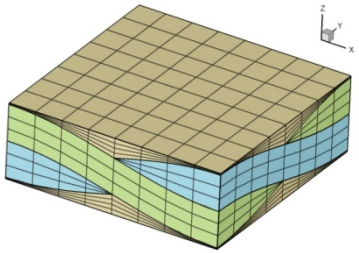
Outline

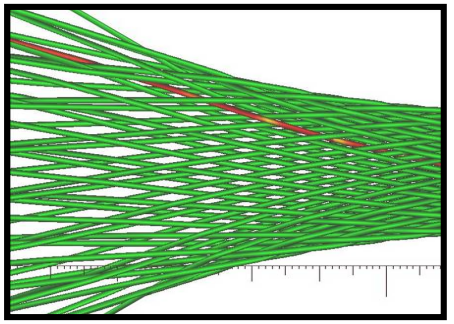
- ***Overwiev***
- ***Morphology***
  - *Processing Simulation Based*
- ***Stress Analysis: Independent Mesh Method (IMM)***
  - *Description*
  - *Simple Validation*
- ***Experimental / IMM Comparison on Triaxially Braided Composite***
  - *Moiré Interferometry*
  - *Virtual Preform Compaction*
  - *Description of Models*
  - *Results*
- ***Conclusions***

Fiber Tow Morphology

Approaches:

- *Directional f.v.f.*
- *Idealized Tow Path (shape)*
- *Process Simulation-Based*
  - *Method of Digital Chains*
- *Image-Based*
  - *Image reconstruction*
- *Goal:*
  - *Geometry for mechanics model*



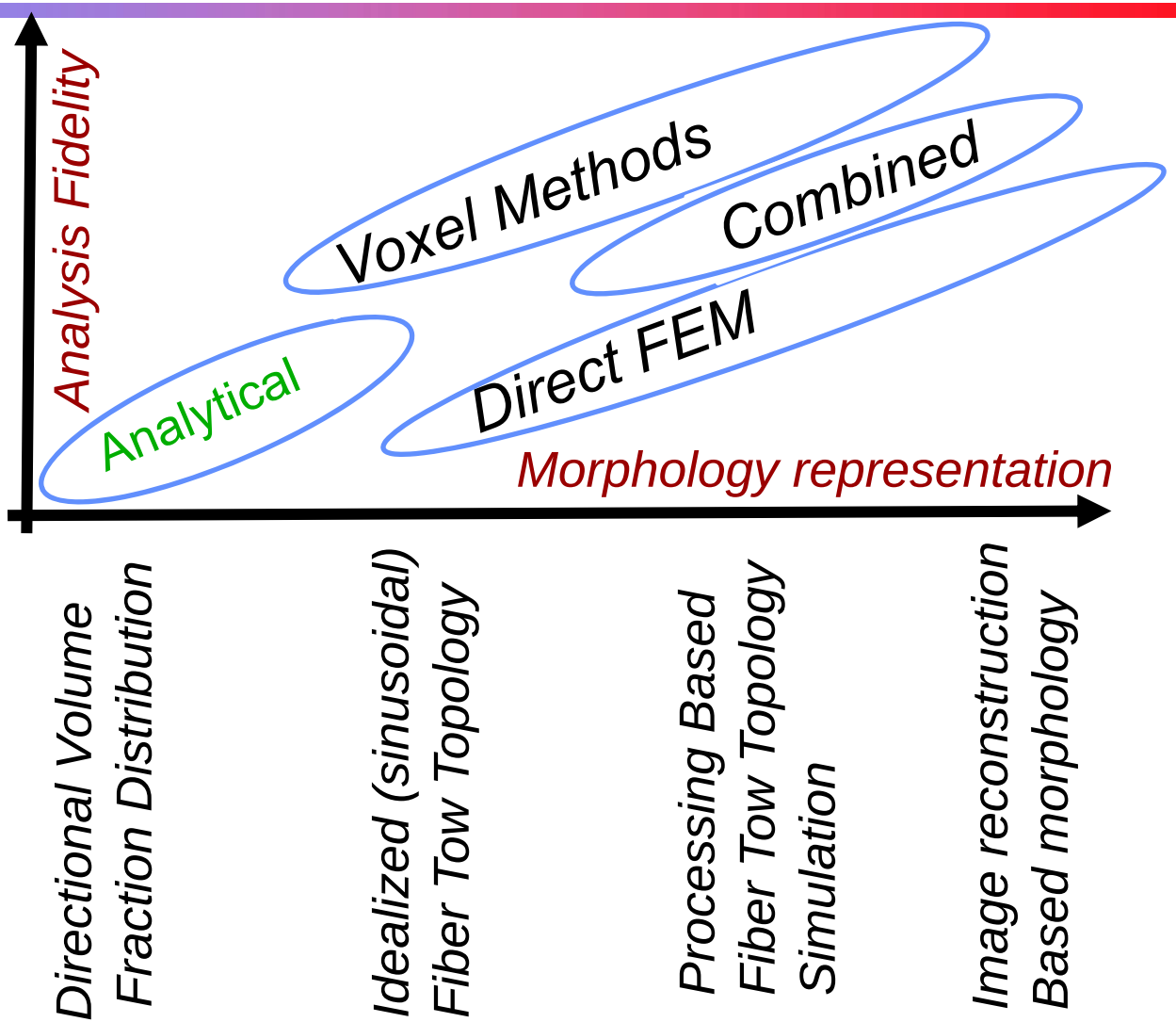


Morphology & Analysis

Certification by analysis

Stress Concentrations, Fracture

Stiffness Homogenization models



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Computational Methods

Direct FE discretization

Voxel Methods

Combined methods

3D MOSAIC, *Bogdanovich et al., 1993*
Binary Model, *B. N. Cox et al., 1994*
xFEM*, Belytchko, et al., 2003*

A-FEM*, Q. Young, B.N. Cox ,2008*
Independent Mesh Method, *Iarve, E.V., Mollenhauer, D.H., Zhou, E., and Whitney, T.J.,, 2007*
Mesh Superposition Methods, *Fish, J, et al., 1999*
Nakai, H., Kurashiki, T., and Zako, M.,, 2007
Domain Superposition Methods, *Jiang,W.-G., Hallett, S.R., 2007*

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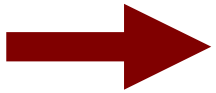

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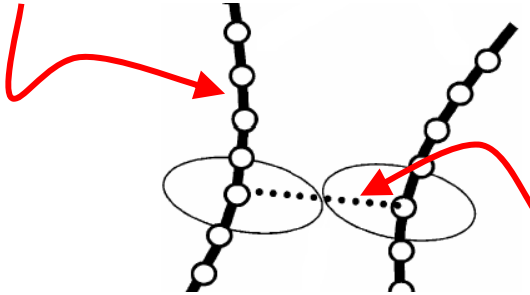
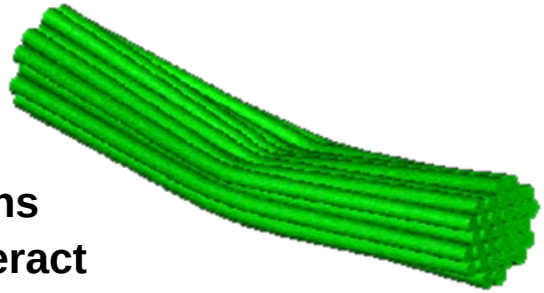
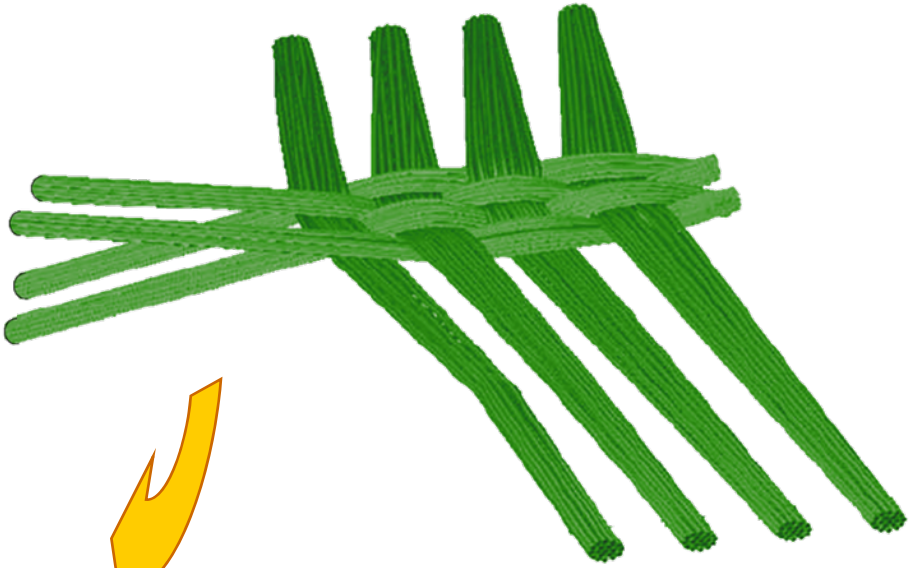
Fiber Tow Morphology
(simulated via “digital chains”)

- A tow consists of many “digital chains”

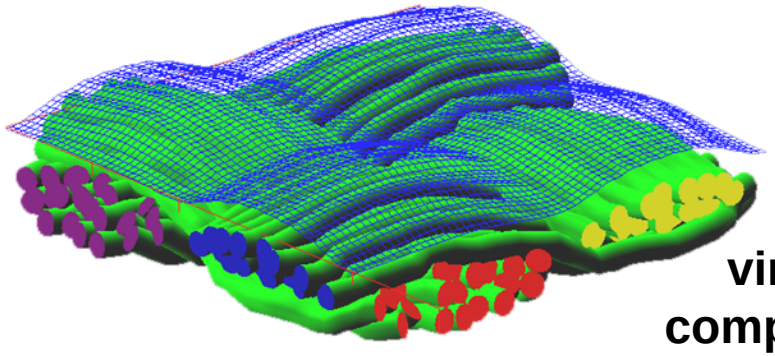


- Chains interact through contact elements





virtual compaction



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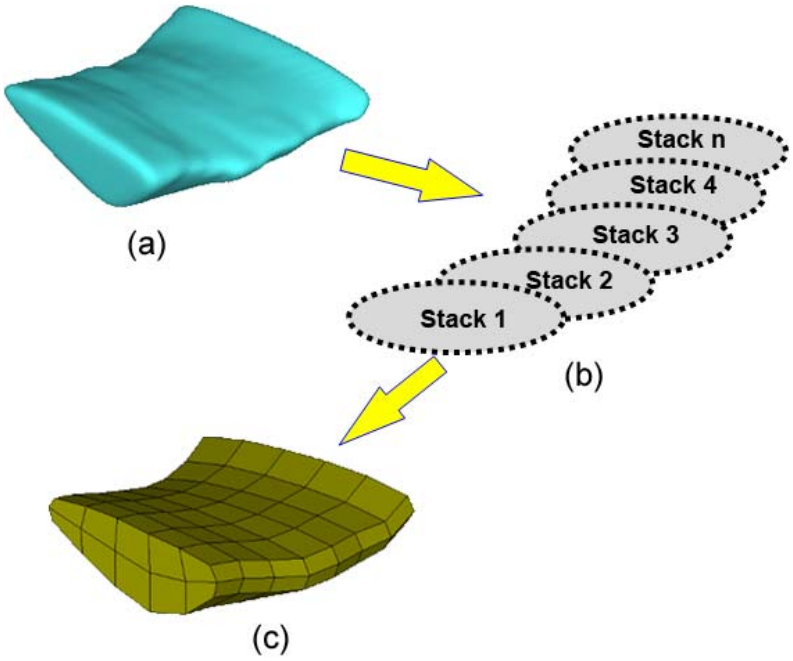
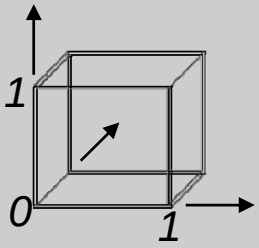
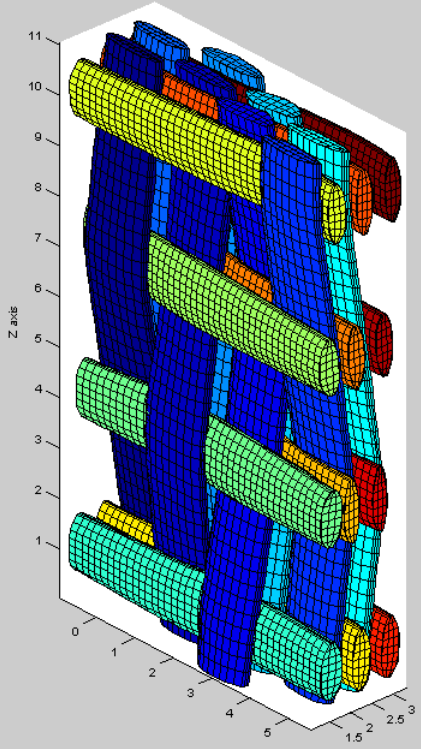
Fiber Tow Model



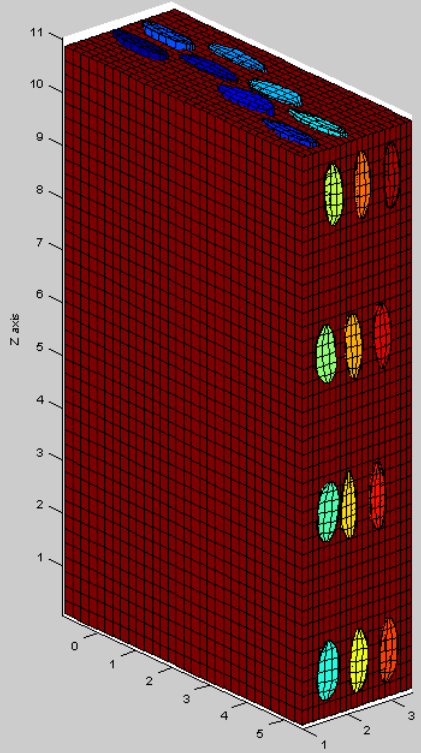
Independent Mesh Method

1. Parametric geometry representation for each yarn





2. Independent mesh modeling of matrix



Independent Mesh Method, Matrix Model

1. *Yarn deformation modeled directly*
2. *Yarn-matrix connection modeled by penalty minimization*
3. *Matrix domain meshed independently*
    - *Shape functions truncated*
    - *Volume integration cubes*

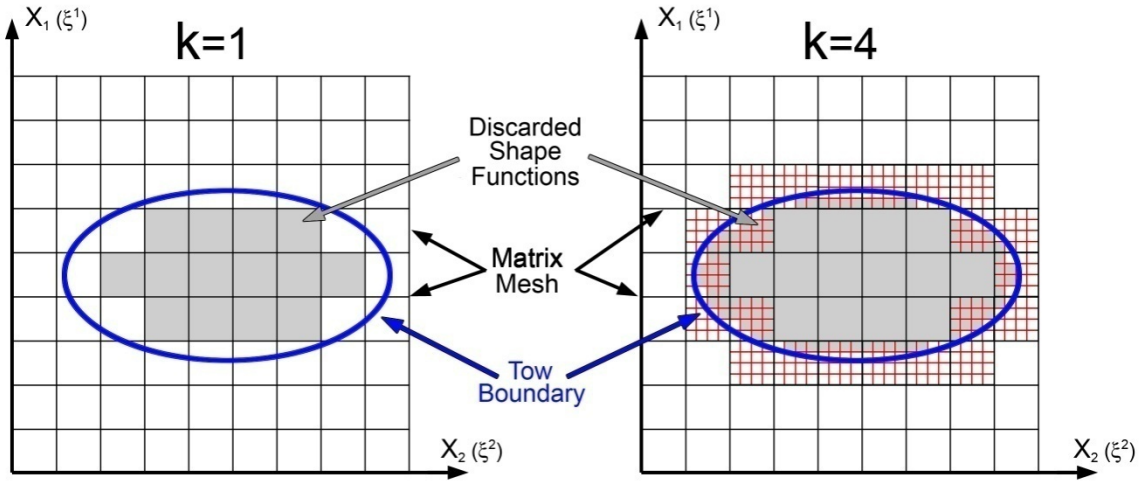
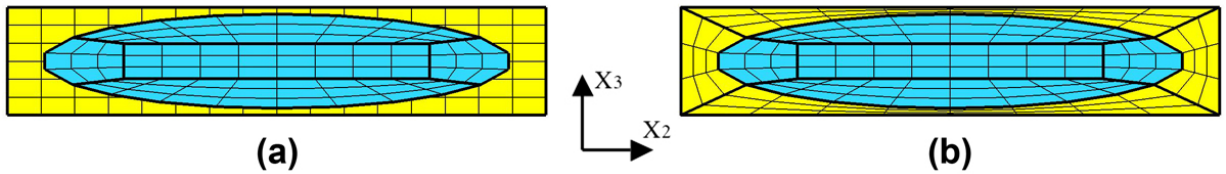


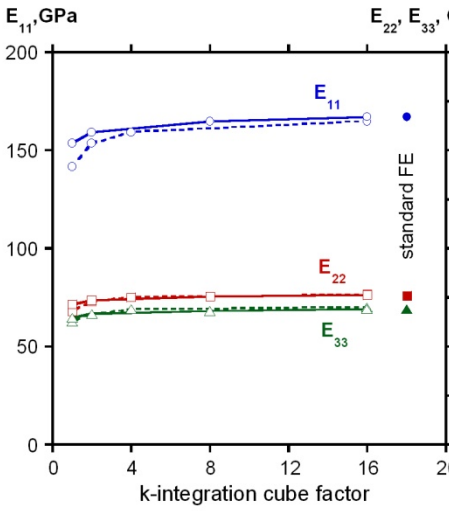
Figure 3: Schematic of matrix displacement approximation function definitions, boundary interval integration, and extra degree of freedom elimination.

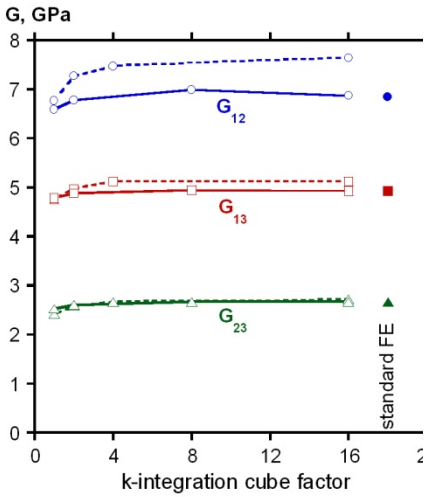
Independent Mesh Method, Oval Fiber RVE

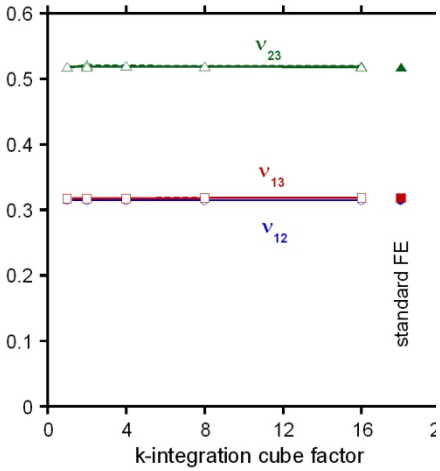
IM7- fiber, epoxy matrix

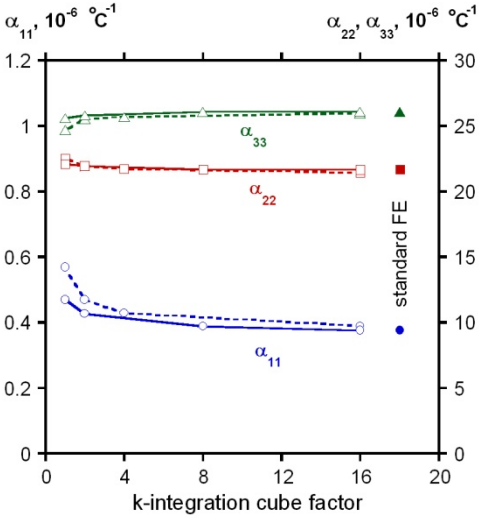
IMM *FEM*





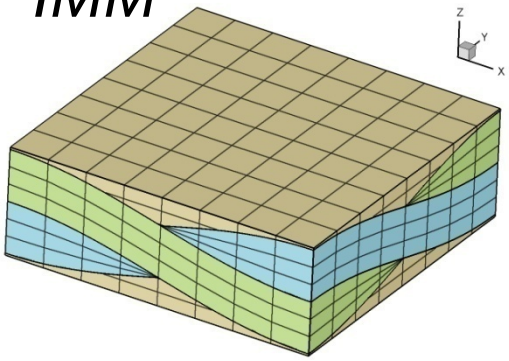






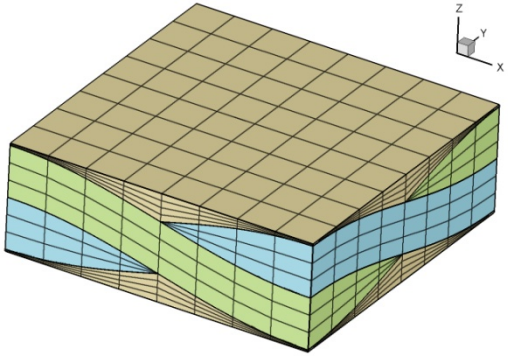
Independent Mesh Method, Textile RVE

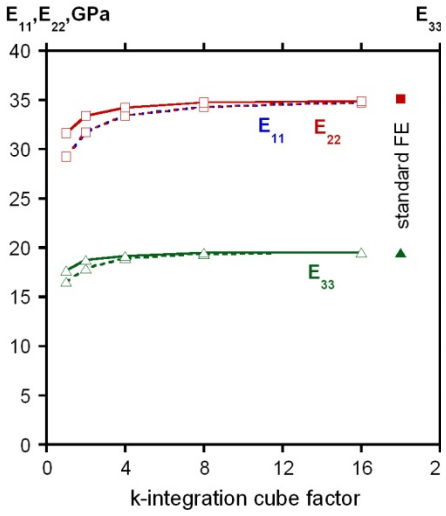
IMM

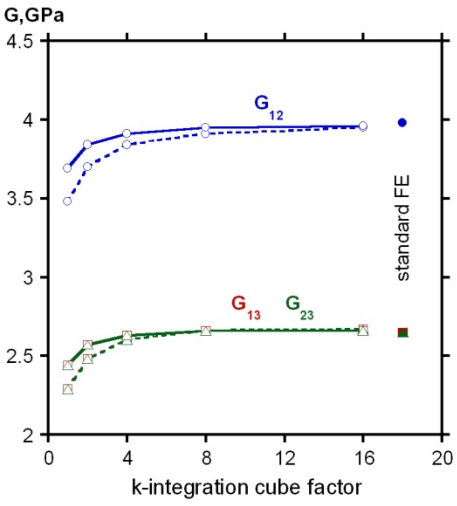


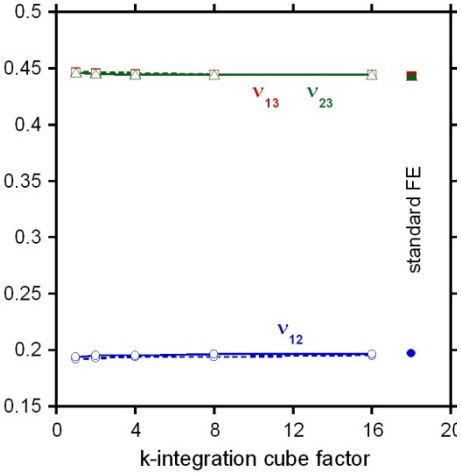
GRP fiber tow, Epoxy matrix

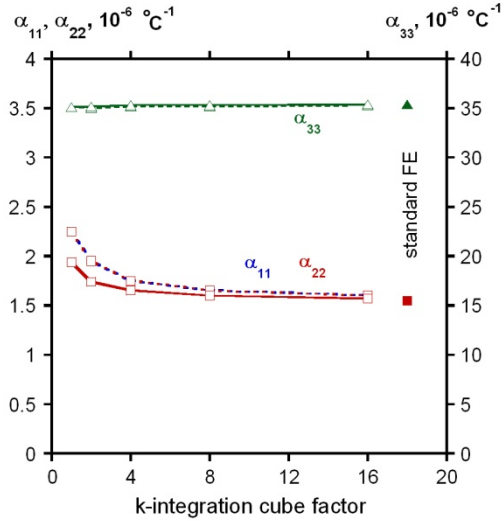
FEM











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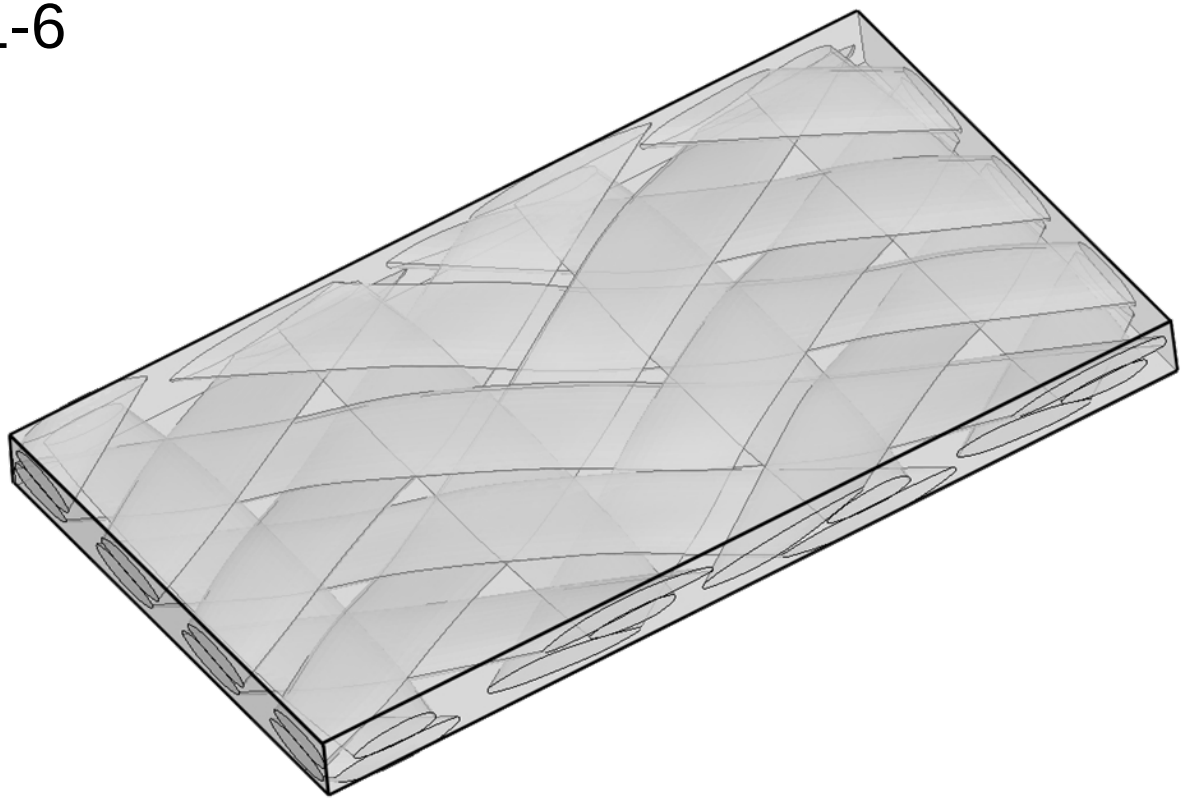
Residual Stress Evaluation

Triaxial Braided Composite
AS4/3501-6



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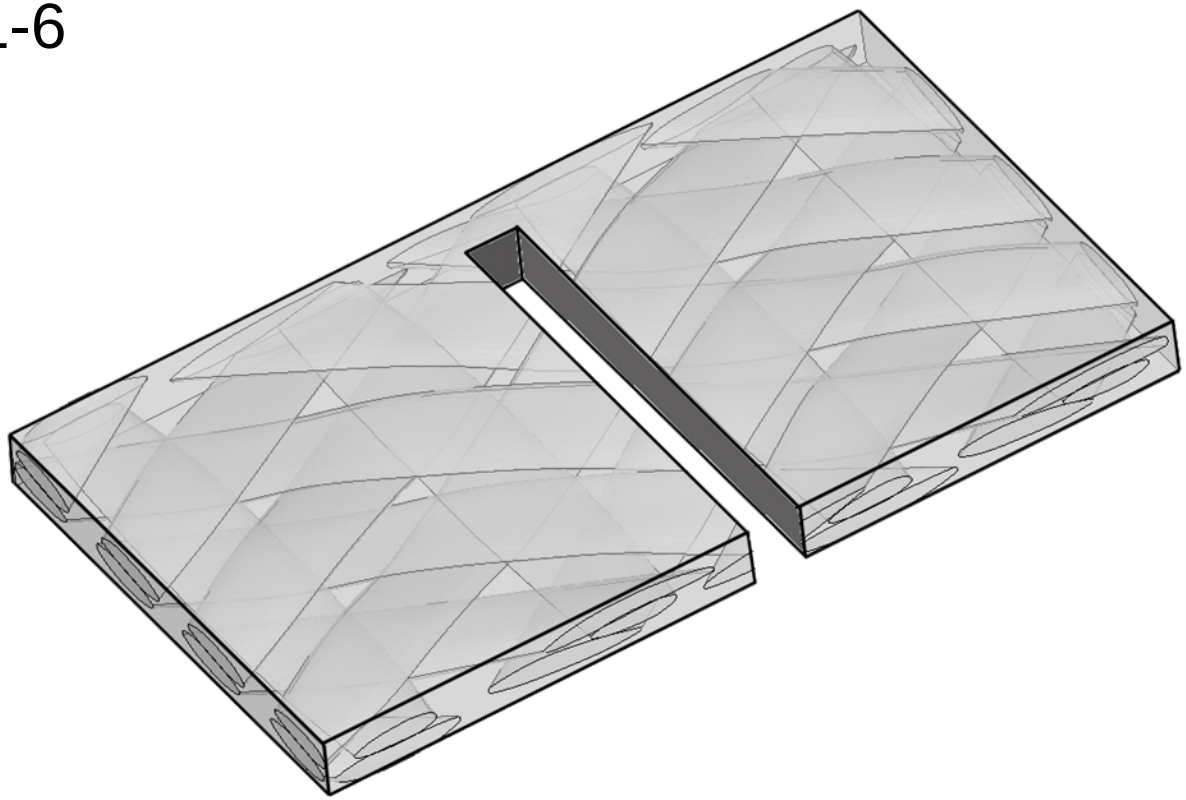
Residual Stress Evaluation

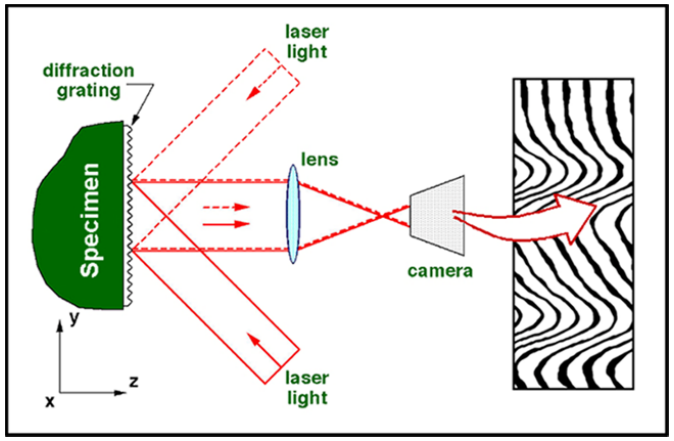
Triaxial Braided Composite
AS4/3501-6



Experimental Validation
(general description of test & models)

- Experiment: 5-layer Compacted triax-braid
- Model 1: 1-layer Uncompacted triax-braid (i.e. resin rich)
- Model 2a: 5-layer Compacted braid (only top layer modeled)
- Model 2b: same as 2b except Virtually "Sanded"

Photomechanics Lab



Moiré Interferometry

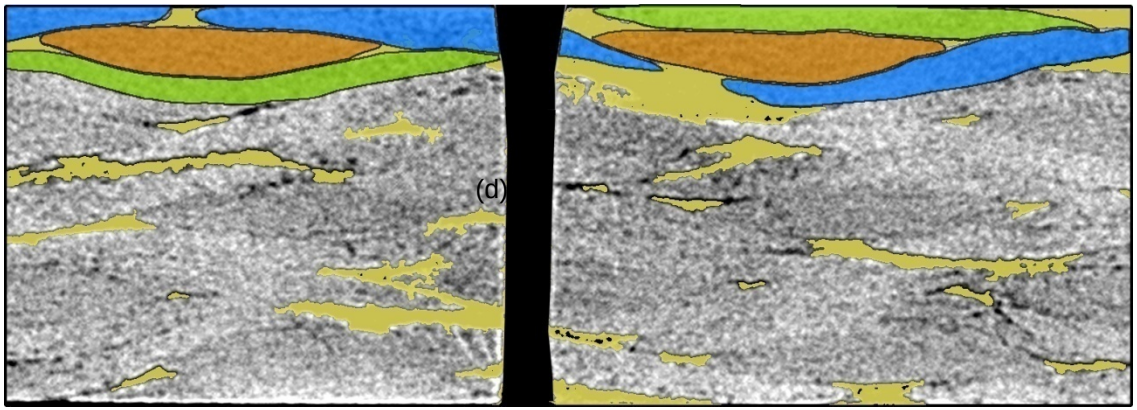
Comparison of Cross-Sections

Uncompacted Morphology

Compacted Morphology

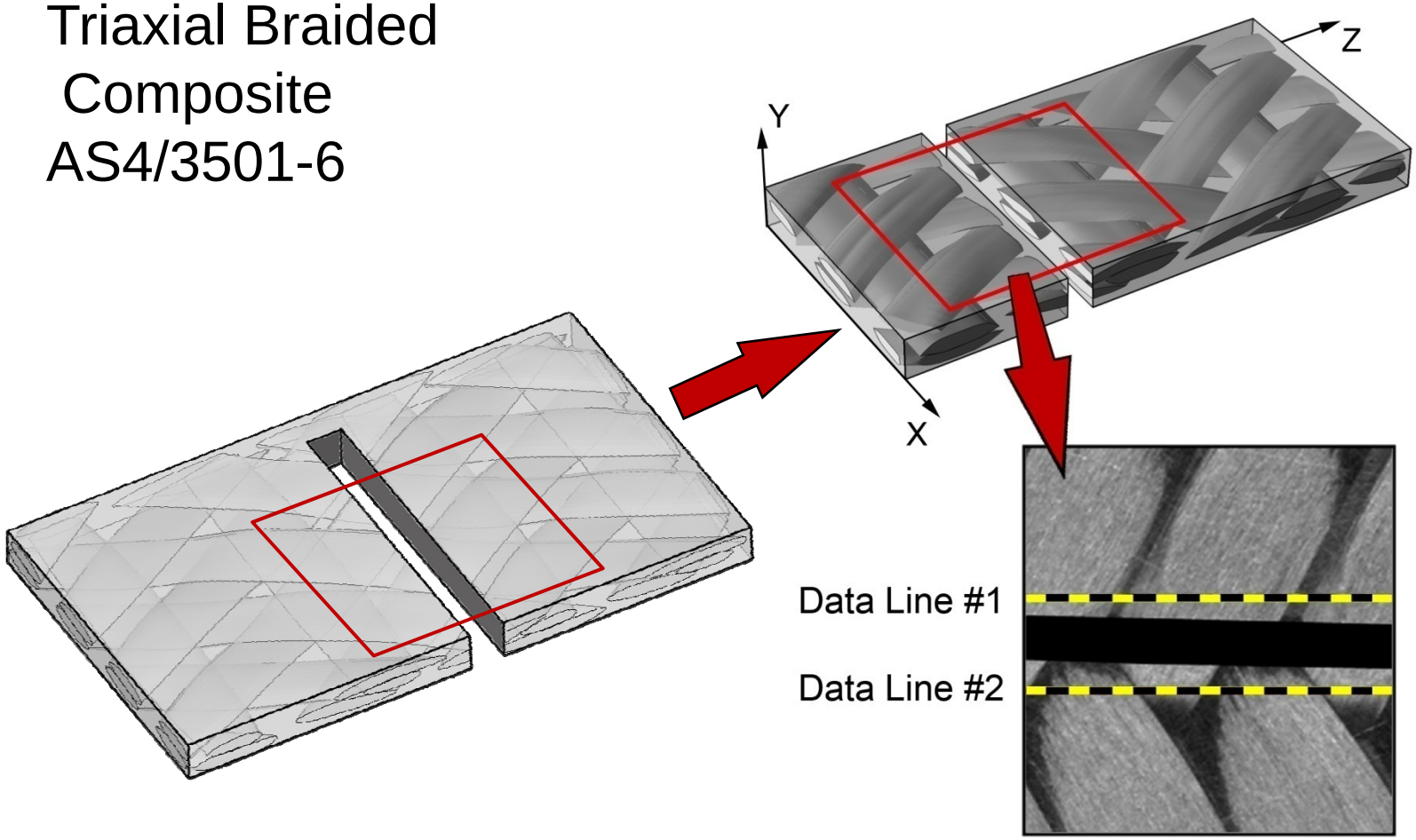
Compacted, Sanded Morphology

CT Image of Top Portion of Specimen



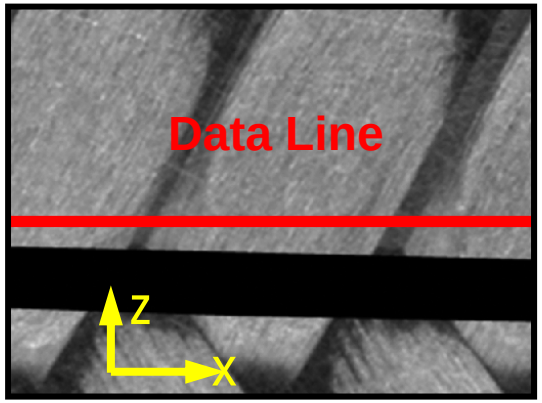
Residual Stress Evaluation

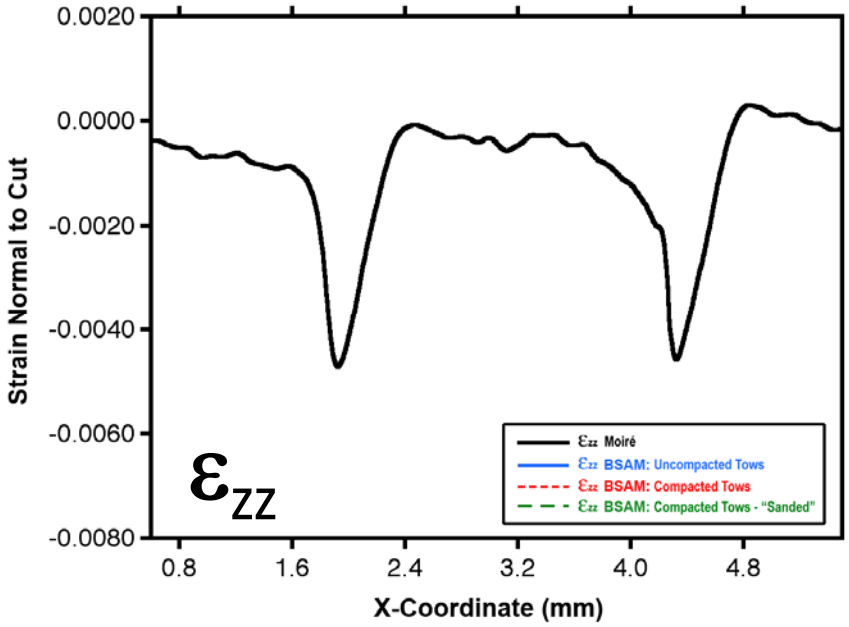
Triaxial Braided
Composite
AS4/3501-6

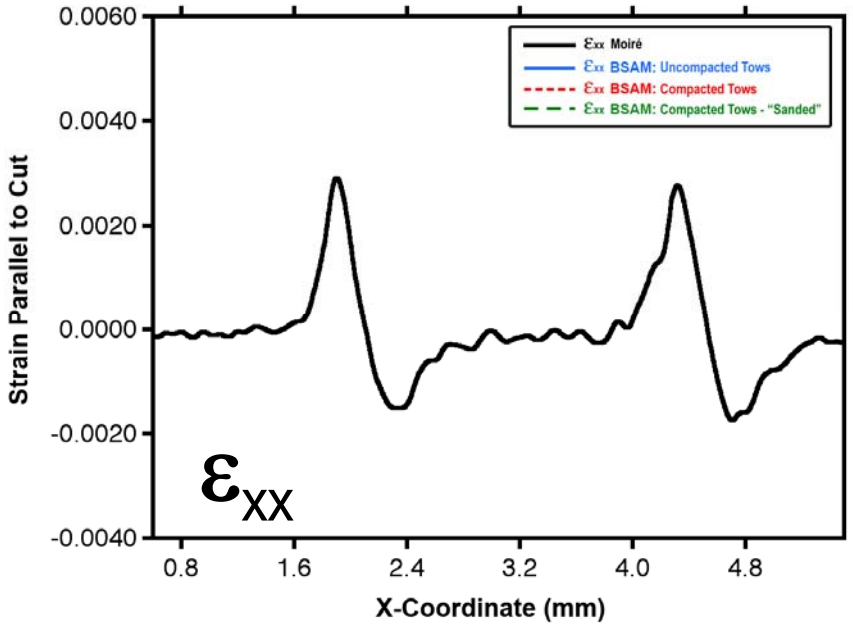


Extracted Strain Results

Data plotted along a line 0.25 mm from the top edge of slot for…







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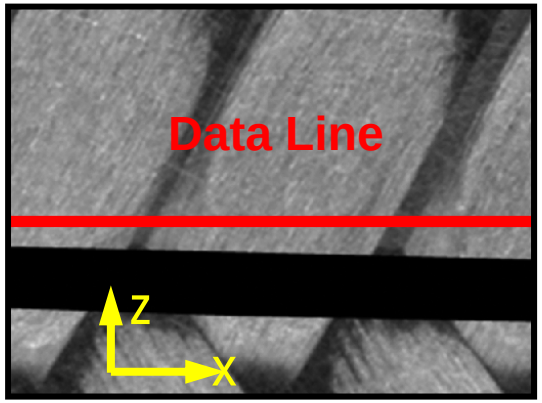

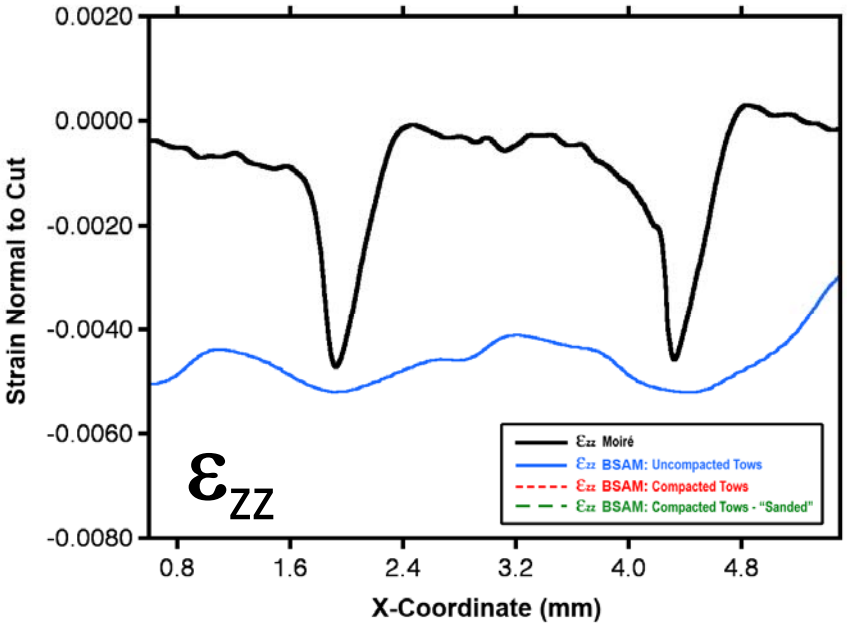

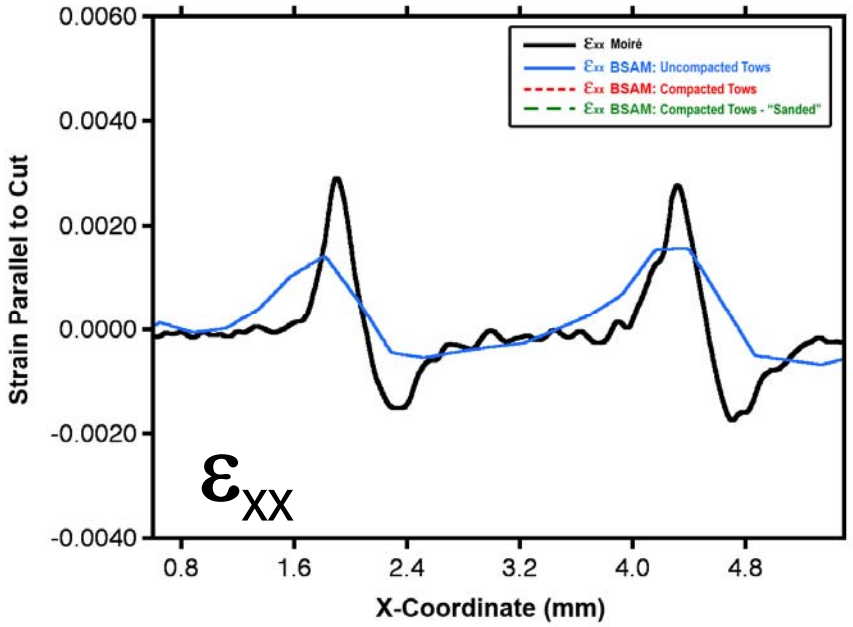

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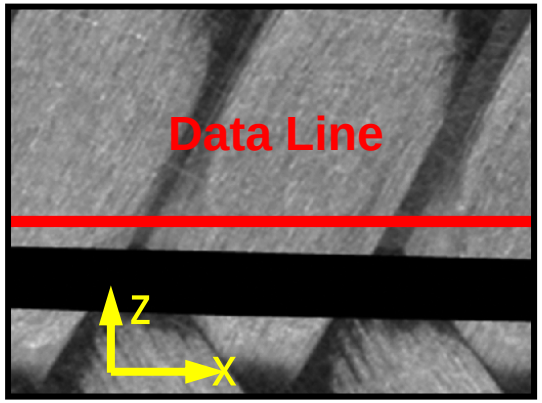

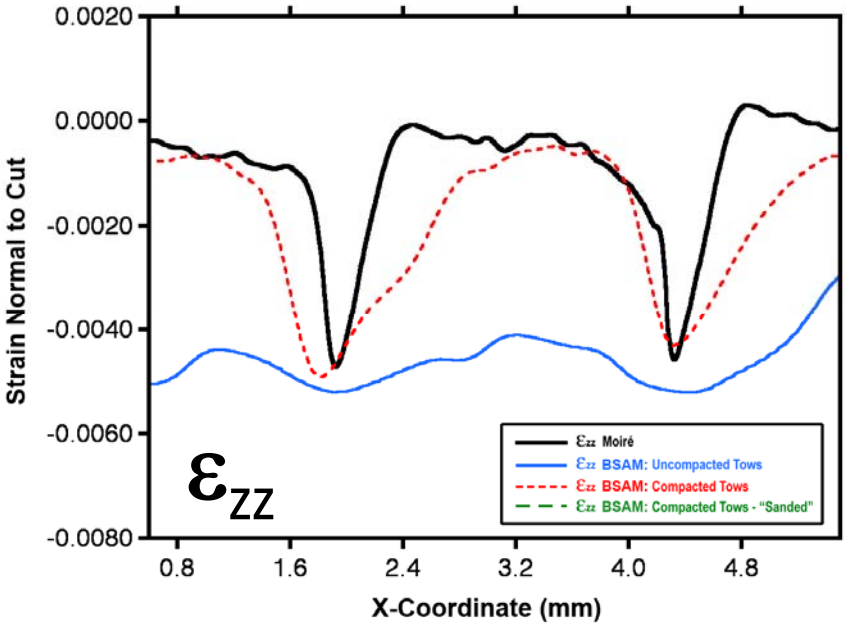

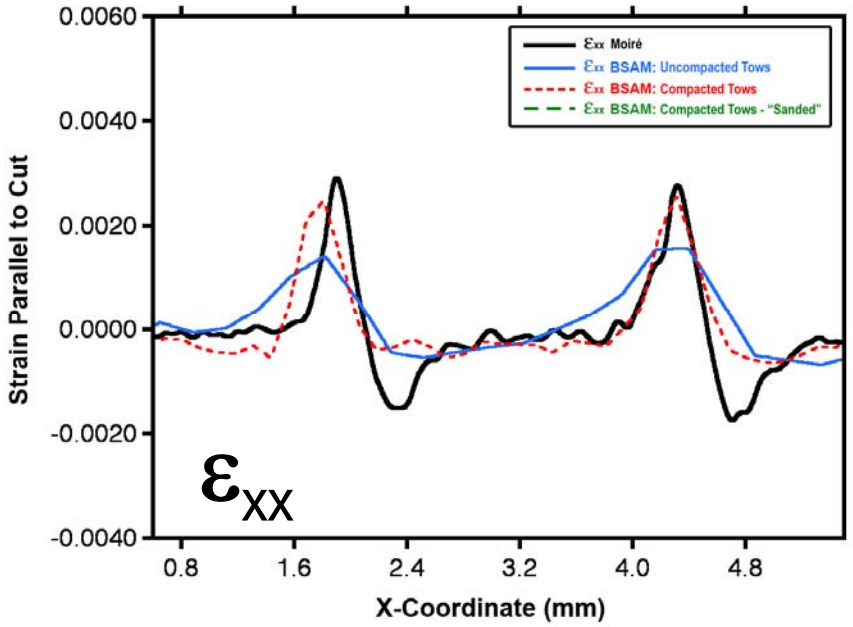

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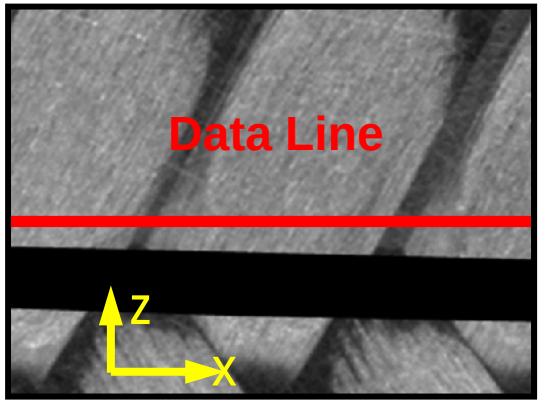

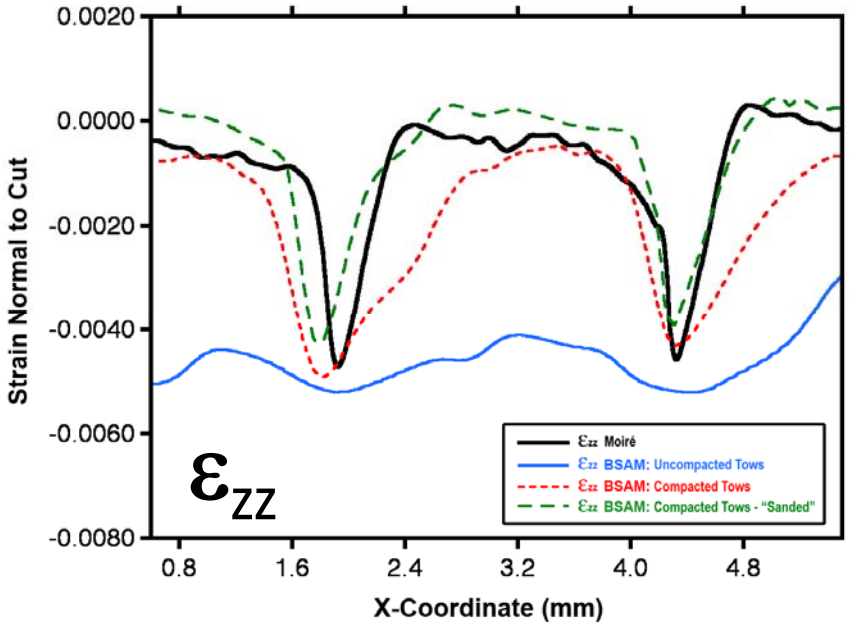

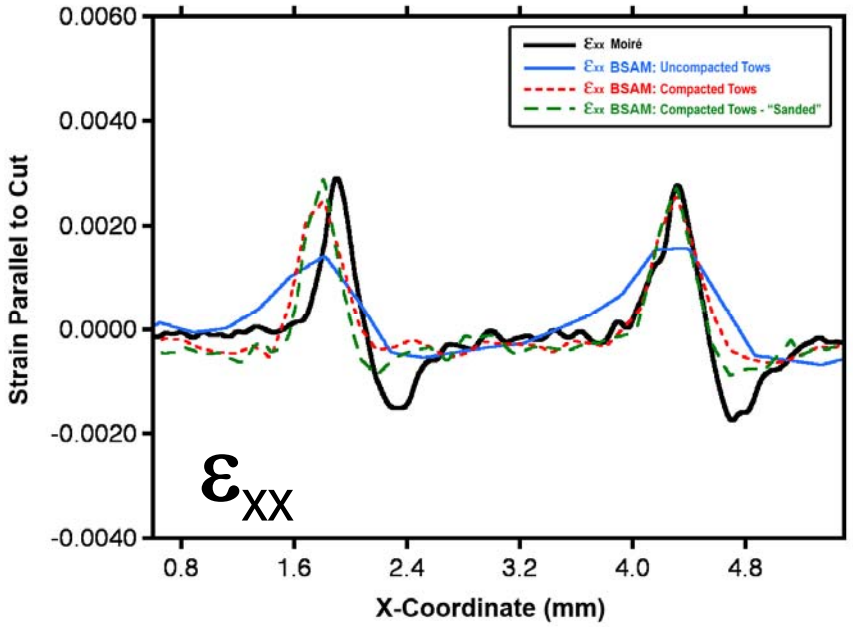

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Conclusions/Future

- ***Research Conclusions***
  - *Textile morphology tool is on the right track*
  - *Independent Mesh Method allows modeling of otherwise intractable problems*
  - *Experimental investigation*
    - *critical step in understanding complex materials*
    - *validating new modeling methods*
- ***Future Efforts***
  - *Introduce damage with Mesh Independent Cracking*
  - *Extract fully-3D textile morphology with CT scan*
  - *Add "structural-level" feature/stress concentration*

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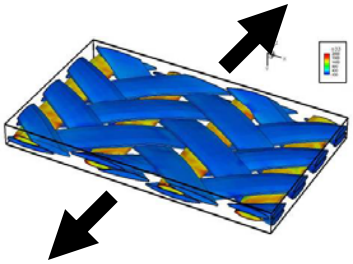
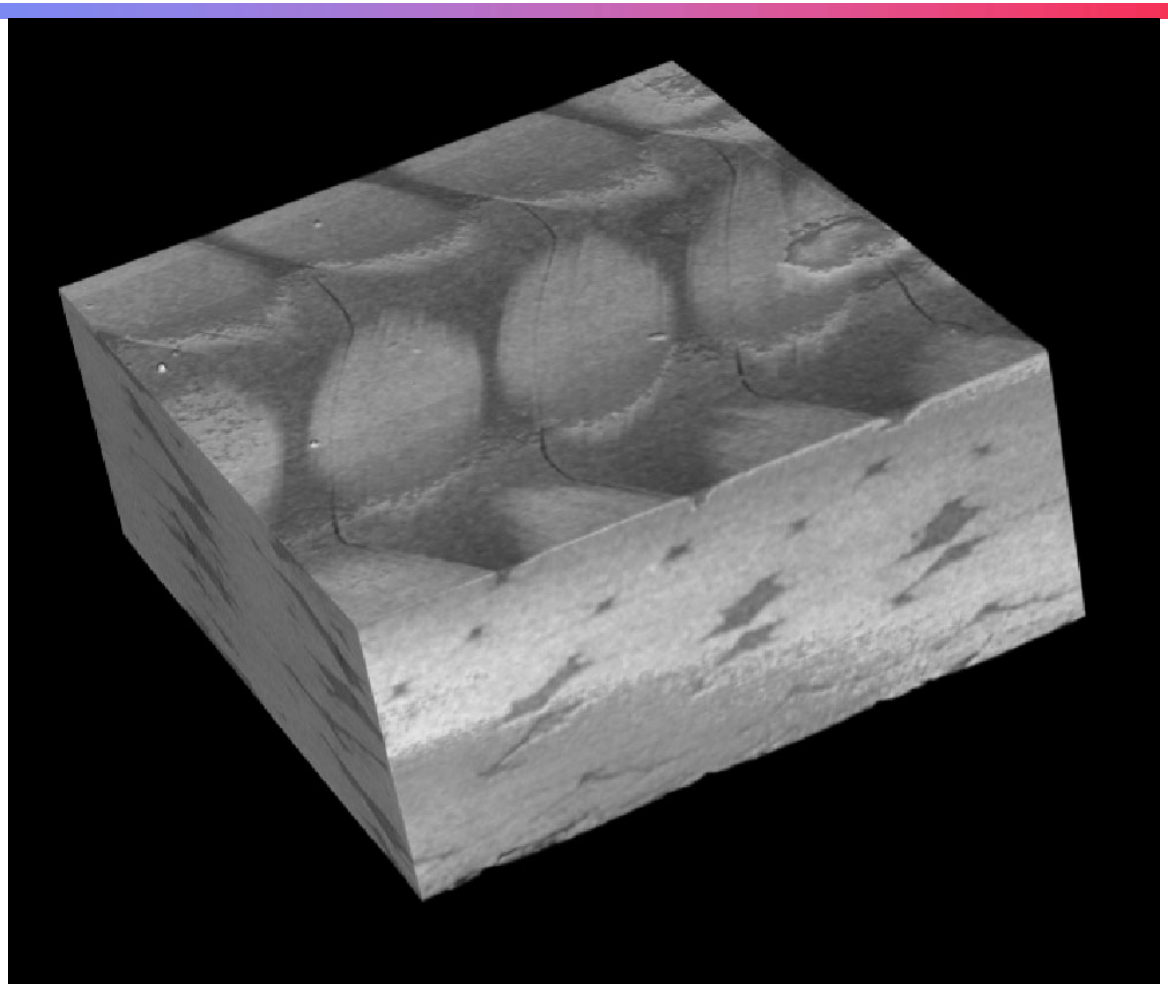
Uniaxial loading of 3-axial braid (3D X-ray tomography)





Cracks:
- Matrix
- Inter tow
- Intra tow

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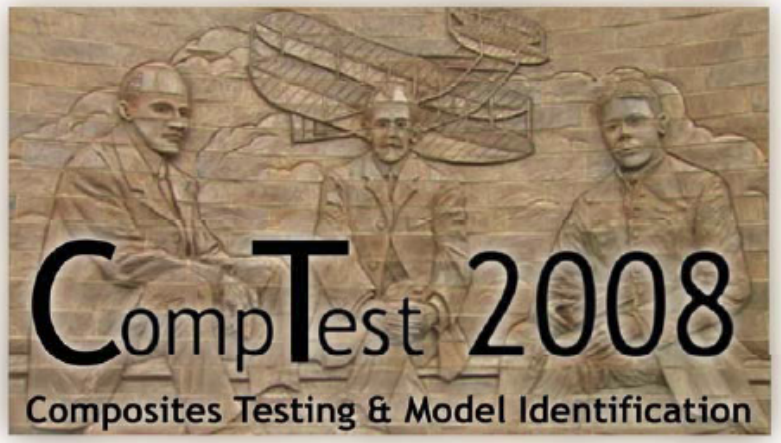
4th International Conference of



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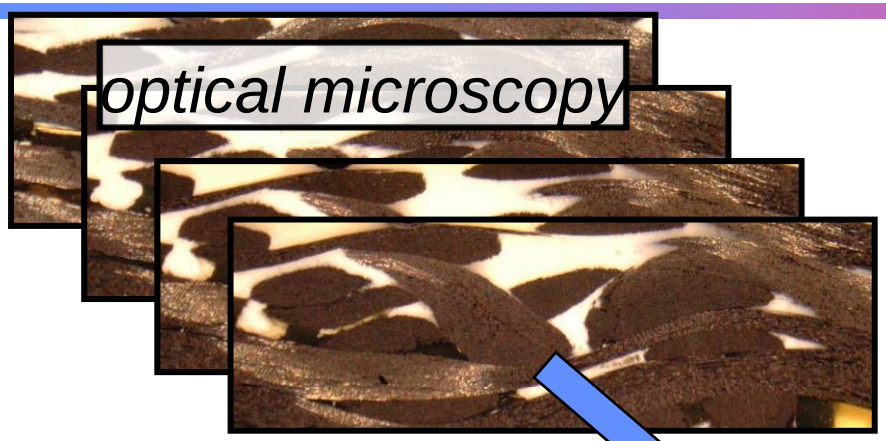
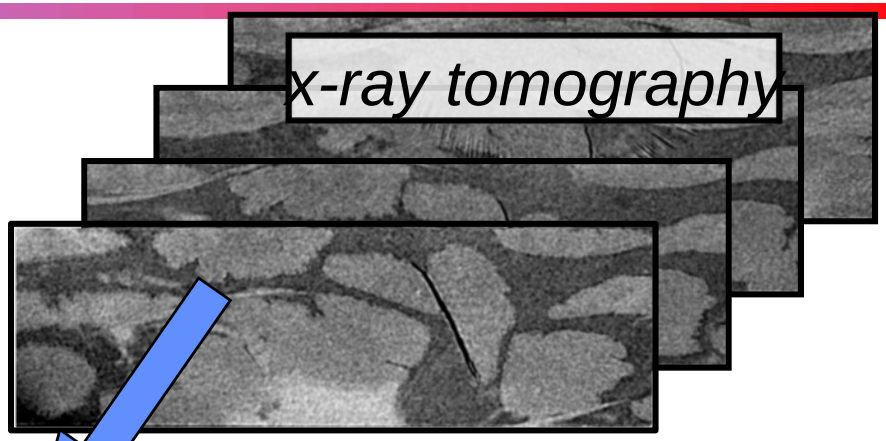
Questions?

Fiber Tow Morphology
(image-based)





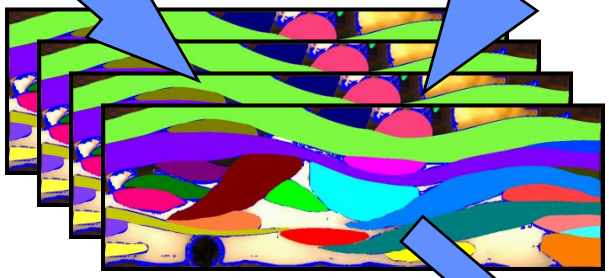


Image segmentation involves noise removal, histogram, edge detection, line segmentation, region segmentation, and edge smoothing

Image reconstruction involves characteristic function computation, integration, & surface extraction.