Predictive Modeling of Random Fiber Composite Structures

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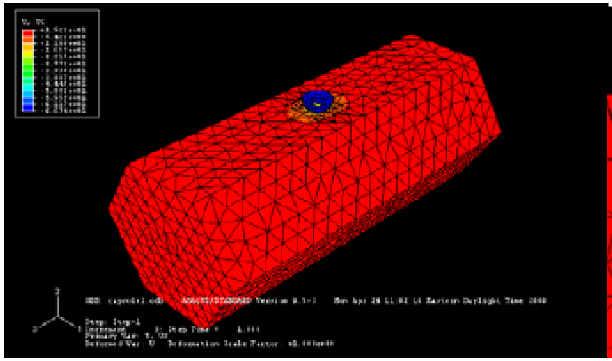
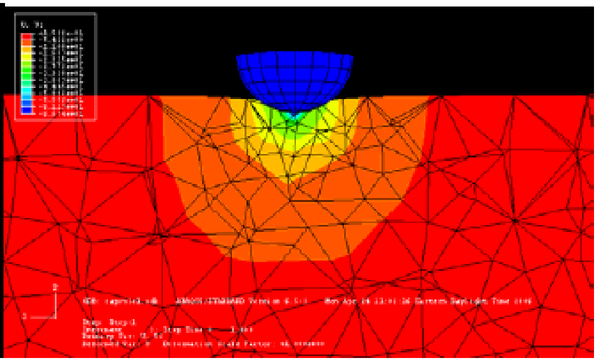
- ❑ Predictive Modeling
  - Laminated Structures
  - Random Fibers
  - Nano-composite
  - Smart structures

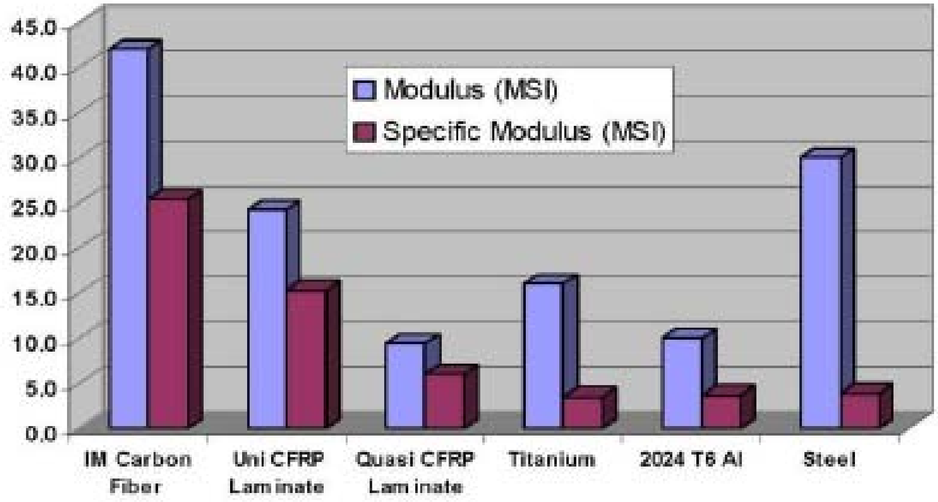


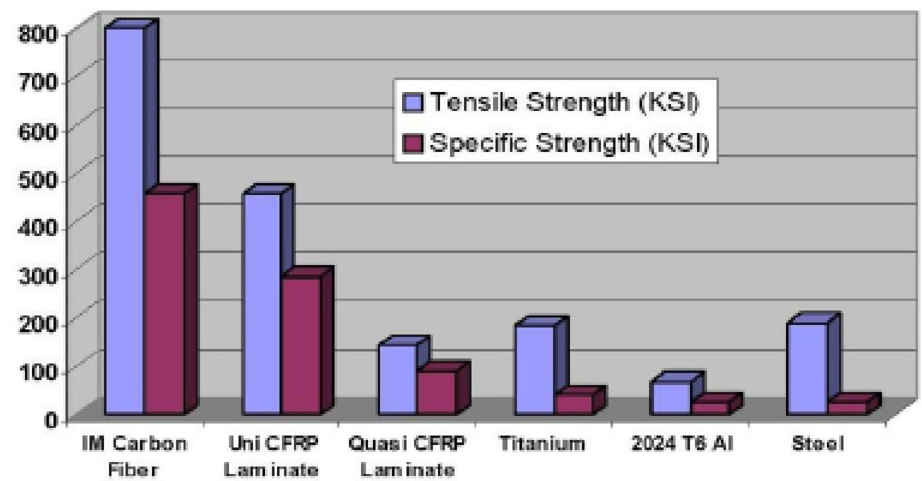


- ❑ Structural Health Monitoring
  - Vibration and Wave Propagation
  - Algorithm development
  - Prognosis

Composite Materials

- High specific strength
- High specific modulus
- Light weight
- Design flexibility
- Durability
- Corrosion resistance
- Fatigue/Crack resistance





Composite Applications

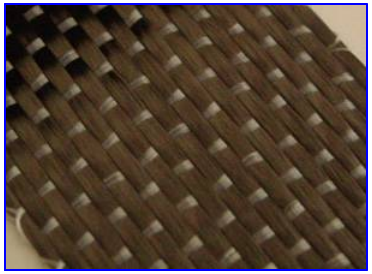
- Composites materials are widely used in commercial industries like
  - Aircraft
  - Automobiles
  - Wind power
  - Sporting goods
  - Biomedical
  - Construction




Classification of Composites

Fiber reinforced composites

- Unidirectional Composites

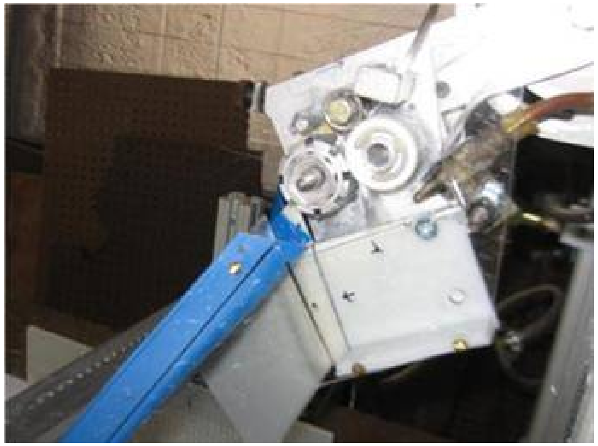


- Random Fiber Composites

- Woven Fiber Composites

MAS Fabrication Process

- ❑ MAS process is enhancement of spray lay-up process

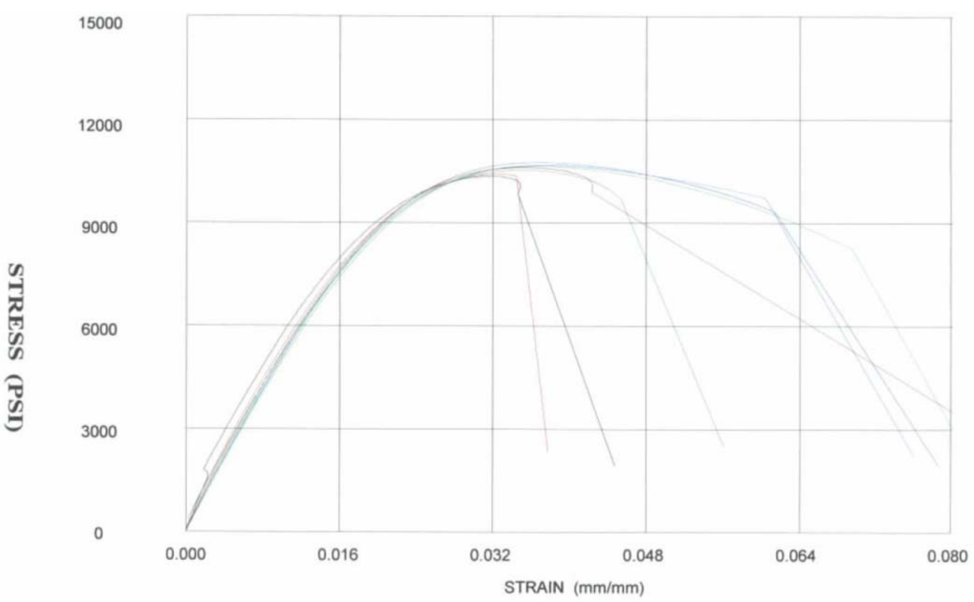


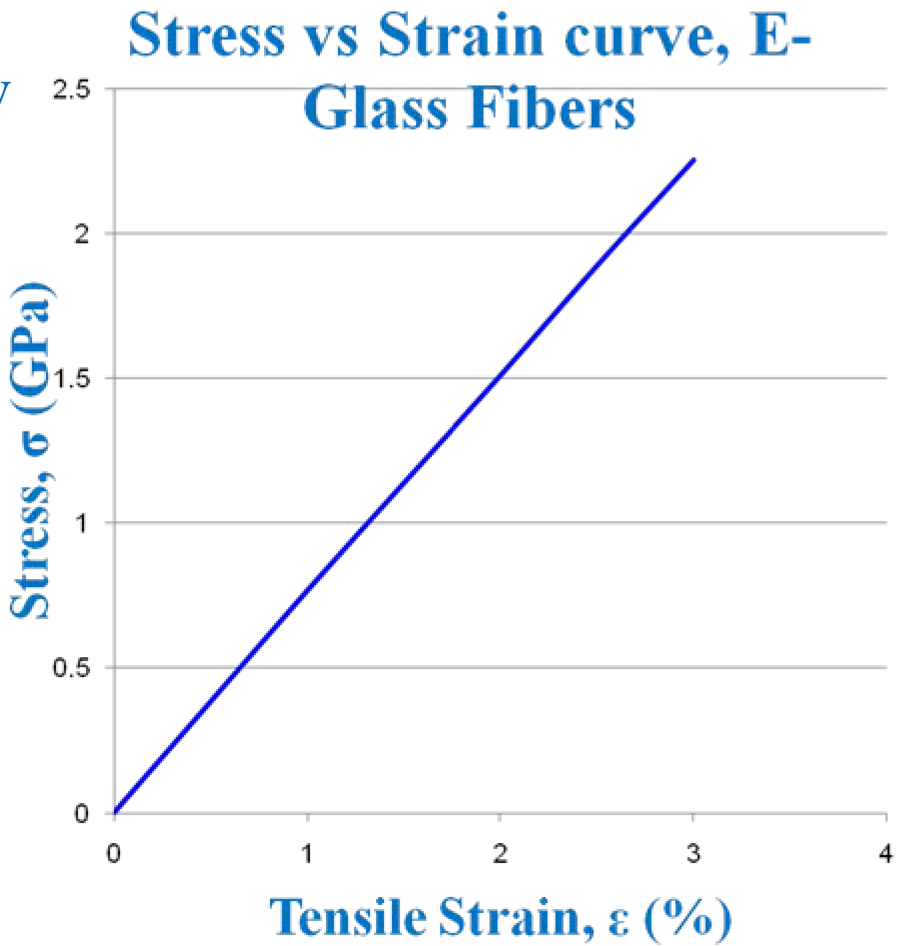
- ❑ Equipments used in this process
  - Chopping head for chopping fibers
  - Spraying unit for spraying fibers and matrix
- ❑ What's new in this process?
  - Computer instructs the spray equipment and controls the speed, location and the amount of chopped fiber
  - Chopped fibers are controlled in mid air using high speed feedback systems
- ❑ Advantages
  - Reduced processing time and manufacturing cost
  - Ease in manufacturing

Properties of Individual Constituents

- Properties* of E-glass fibers and epoxy resin used for specimen

Stress vs Strain curve, Epoxy Resin

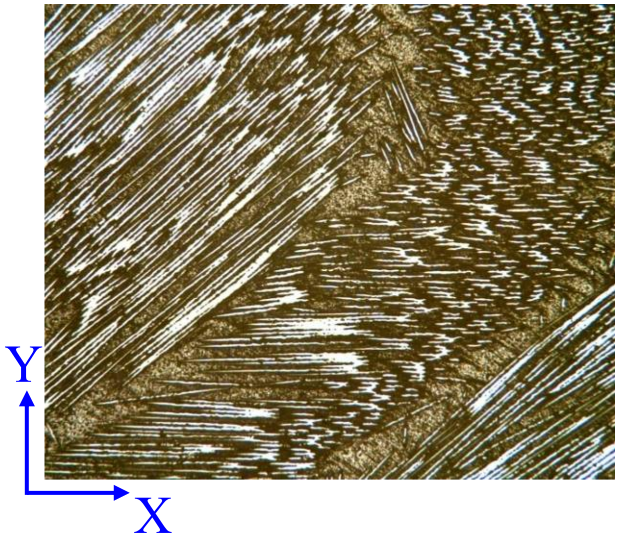


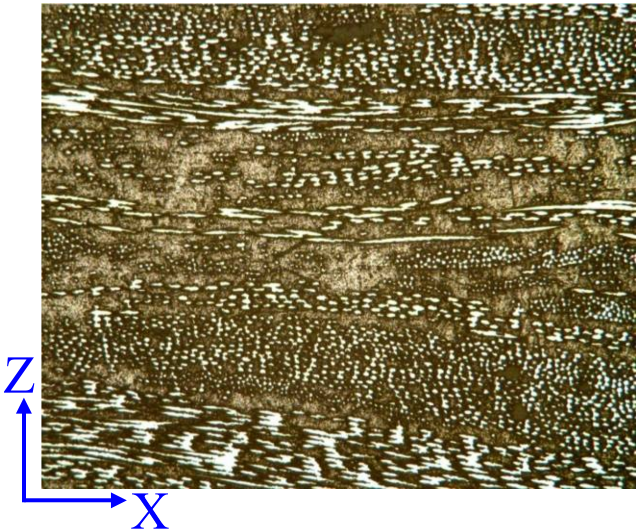


* Properties of materials from vendors

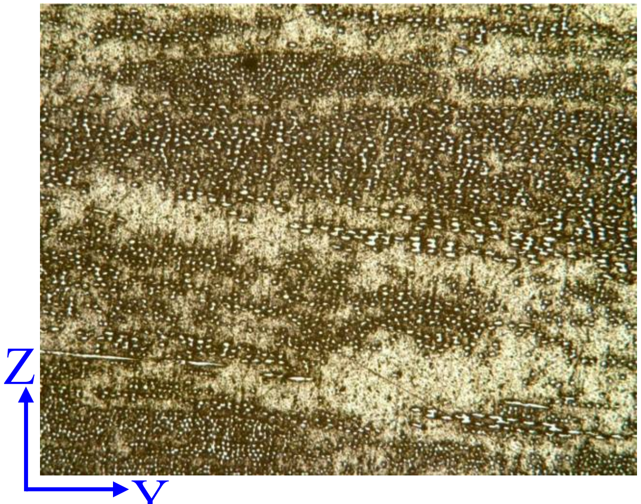
Microscopic Images of Samples

- Microscopic images of a sample manufactured using MAS process

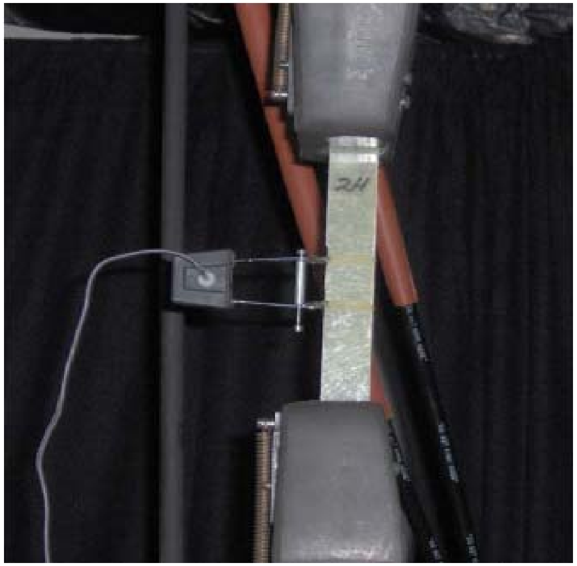




- Majority of the fibers are oriented in X-Y plane
- A few fibers are oriented in X-Z plane

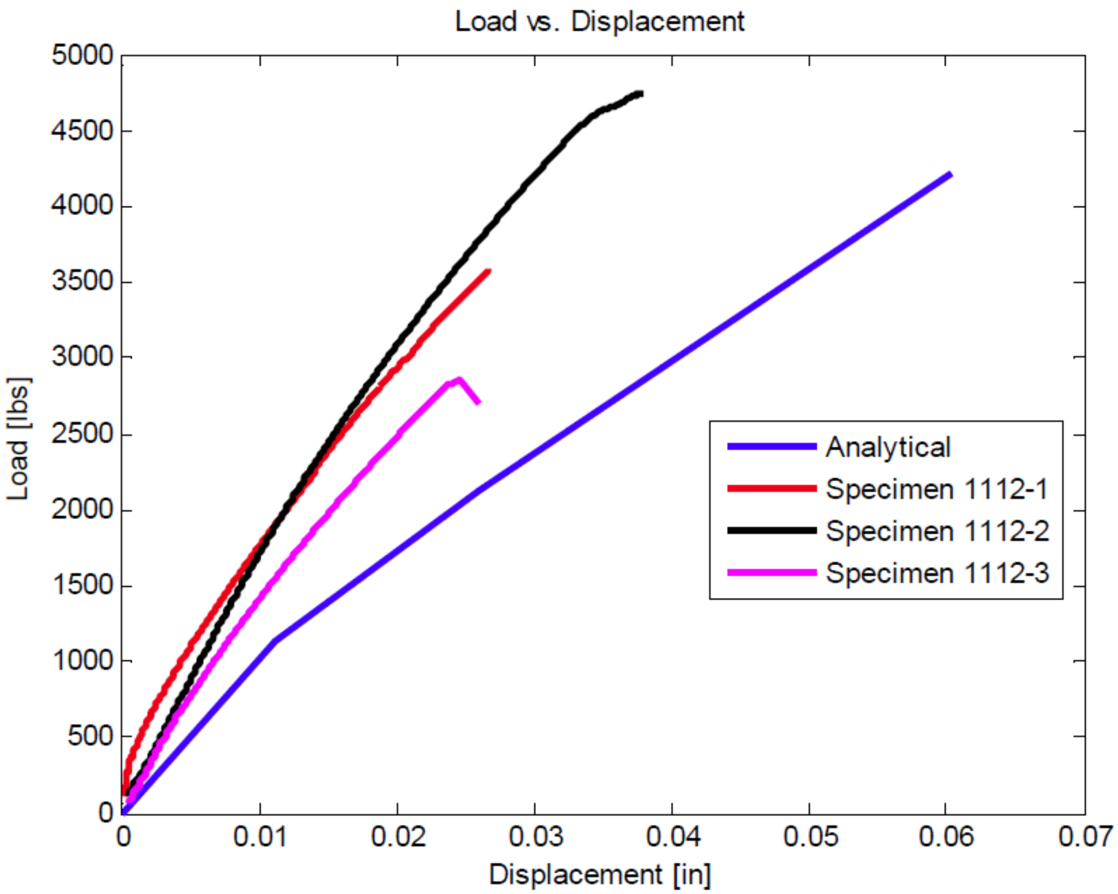


Composite Testing and Failure



- Testing of randomly oriented short fiber composites manufactured from MAS process for elastic modulus and strength predictions

Experimental Results

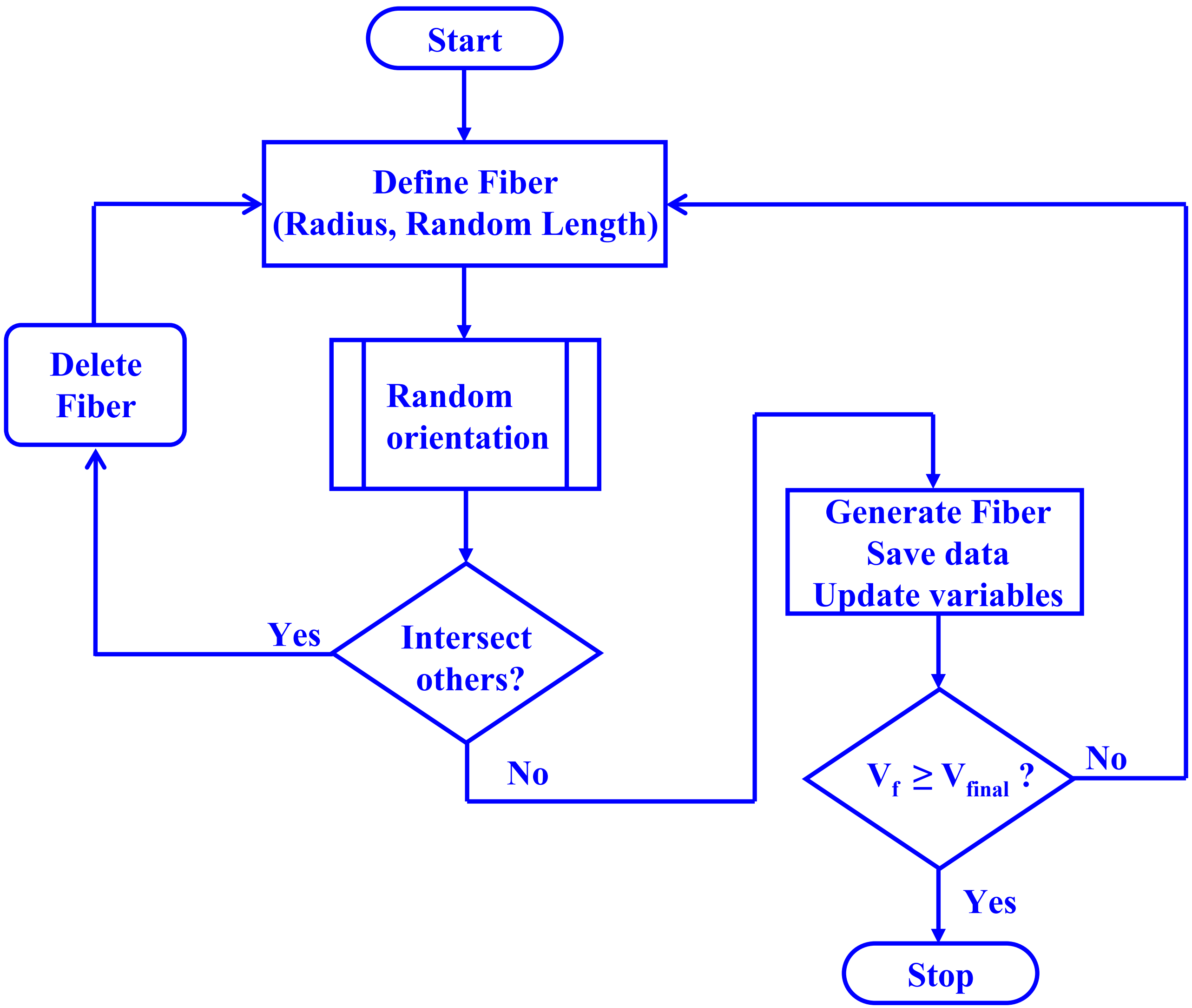


Specimen	Young's Modulus, E (GPa)
1112-1	16.18
1112-2	19.38
1112-3	15.14

Predictive Modeling

- ❑ Useful in predicting the behavior of the materials thereby reducing the laboratory and experiment cost
- ❑ Effectively predict fracture/crack analysis
- ❑ Used for delamination, buckling and other composite parts failure prediction
- ❑ Randomly oriented short fiber composite specimen manufactured from MAS process are considered for modeling (predicting the effective elastic properties of composite)

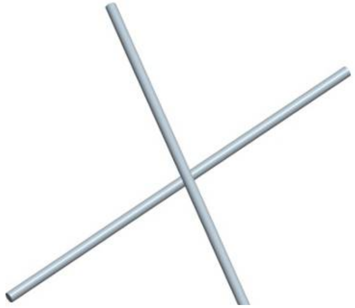
Random Sequential Adsorption Algorithm



Random Fiber Generation

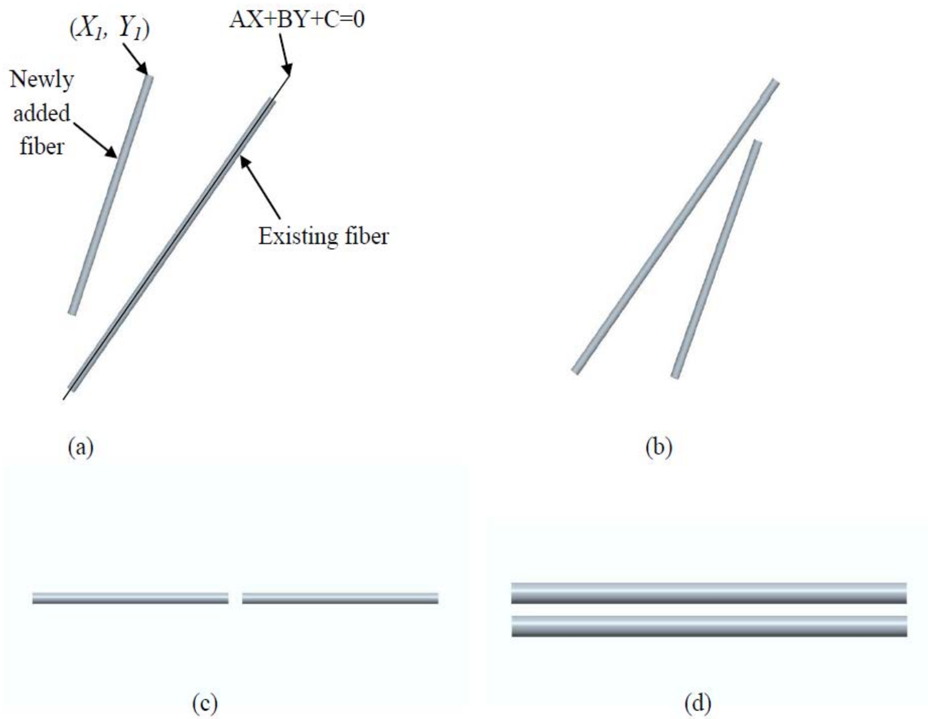
Perform intersection tests on fibers

(a) Fibers intersecting radially



(b) Fibers at any angle crossing each other

(c) Fibers intersecting on ends



Non intersecting fibers

- Calculate location of existing fibers
- Calculate distance between newly added fiber and existing fibers

$$d = \frac{|Ax_1 + By_1 + C|}{\sqrt{(A^2 + B^2)}}$$

- If $d >$ a predefined clearance the new fiber is created

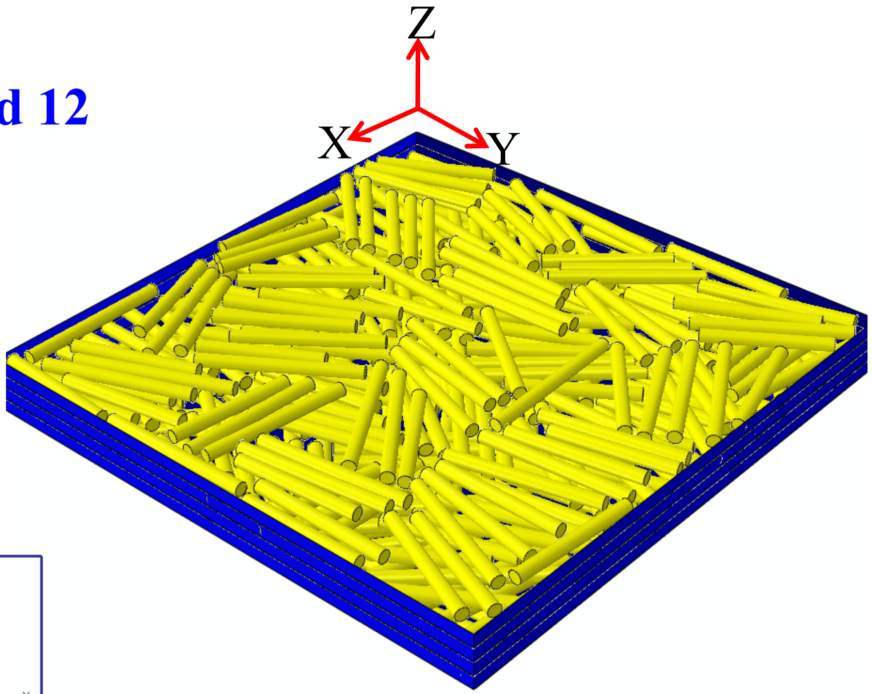
Modeling Process

1. Creating Random Fiber RVE in Matlab of desired fiber volume fraction
2. Saving the Geometrical information like the start and end co-ordinates of the fibers in a text editor
3. Reading the geometrical information from Matlab to ABAQUS via PYTHON Script
4. Making minor modifications to fibers and applying loading and boundary conditions in ABAQUS

Random Fiber Model

❑ Model description

- Total layers – **4**
- Thickness of each layer – **0.025mm**
- Aspect ratio of fibers – **Between 8 and 12**
- Diameter of Fibers – **0.0235mm**
- Fiber volume fraction – **33.9%**
- Number of Fibers – 326



Properties of Micro-constituents

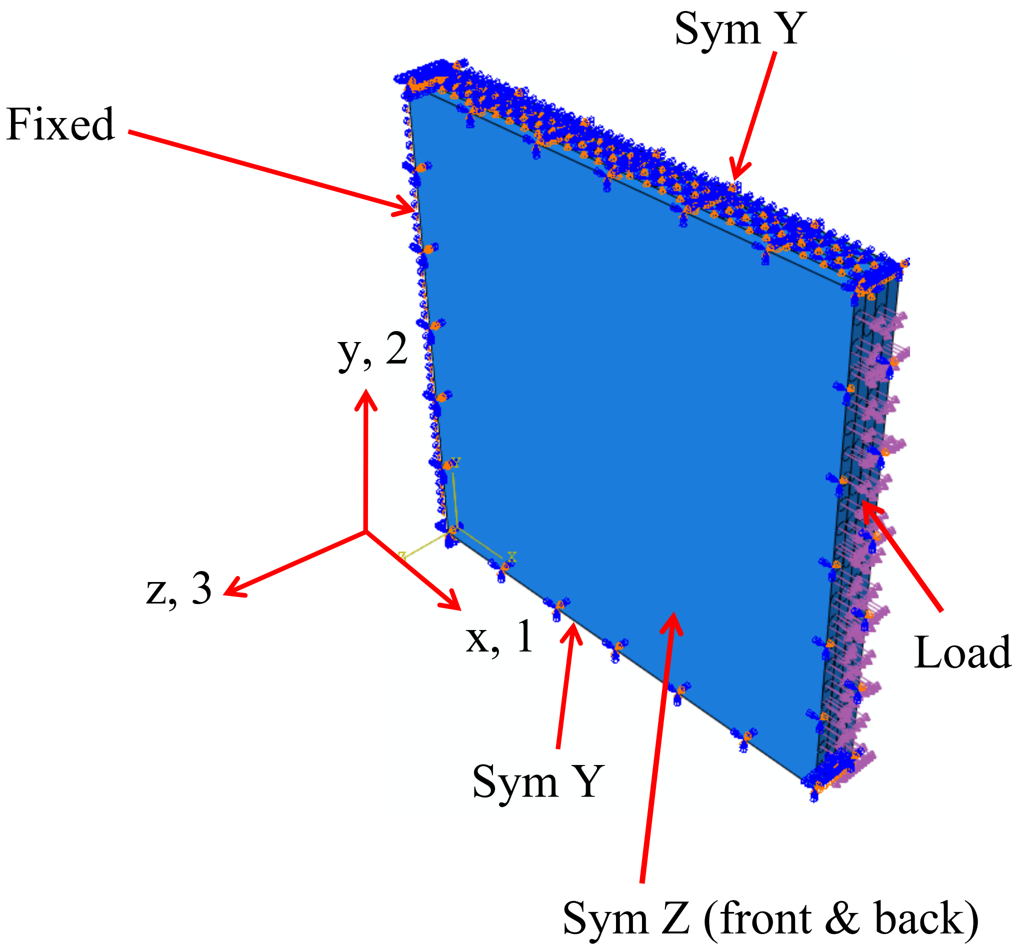
	ρ (Kg/m^3)	E (GPa)	ν
E-Glass Fibers	2541	74.46	0.2
Epoxy Resin	1091	3.516	0.33

Elastic Properties Prediction

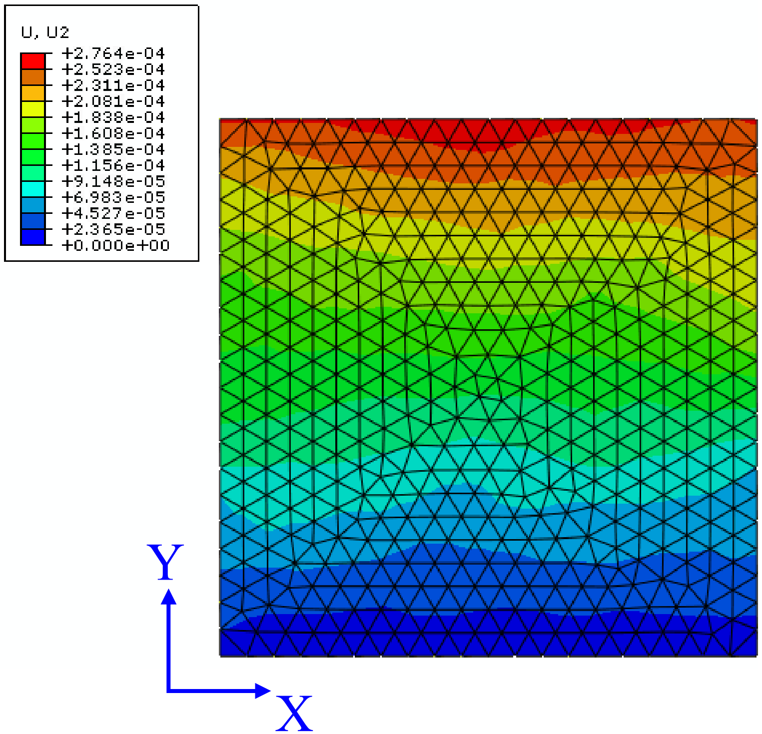
- ❑ Boundary conditions for predicting Young's modulus E_{11} (in plane)

$u(0,y,z) = 0$
$u(d_1,y,z)=$ constant $= \delta_1$
$v(x,0,z) = u(x,d_2,z) =$ sym in y
$w(x,y,0)=w(x,y,d_3)=$ sym in z

- ❑ Load applied on the face as shown

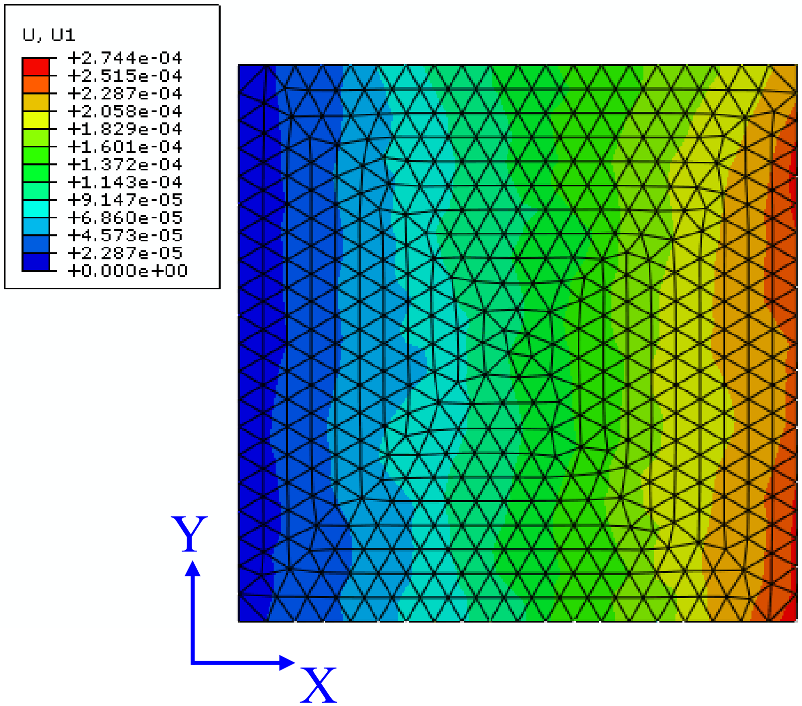


Displacement Plots



Displacement, U2 = 2.764e-04 mm

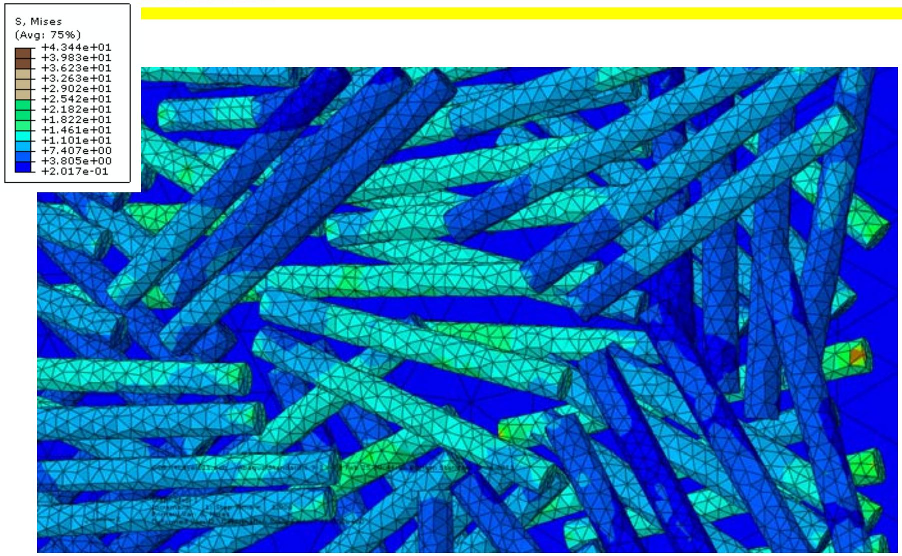
E_{22}= 14.47GPa



Displacement, U1 = 2.744e-04 mm

E_{11}= 14.57GPa

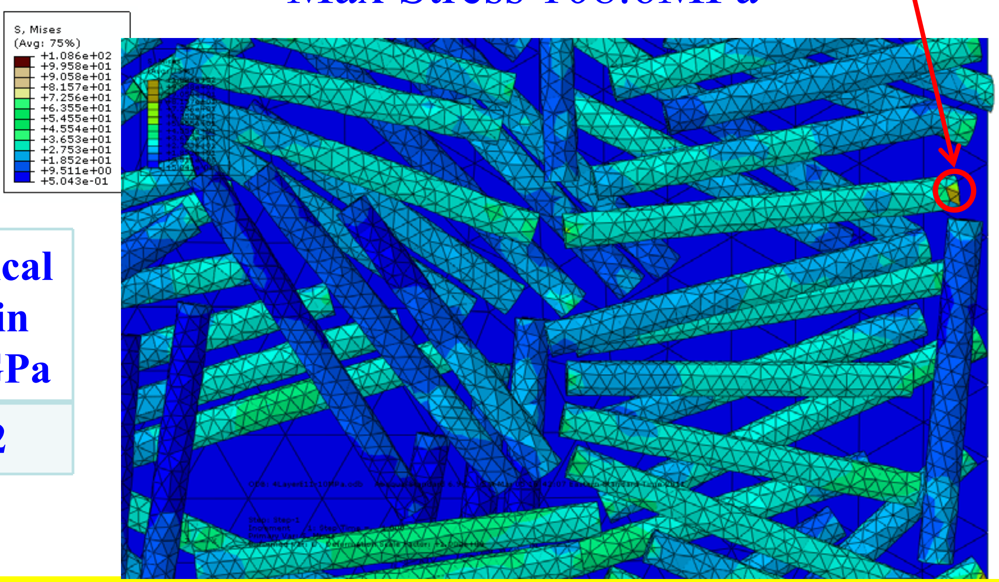
Stress Plot - Random Fiber



Stress plot – 4MPa load
Max stress – 43.44MPa

Max Stress

Stress plot – 10MPa load
Max Stress 108.6MPa



Exp (Avg GPa)	Random fiber (GPa)	Laminate Model (GPa)	Analytical (Halpin Tsai) GPa
16.90	14.52	14.52	15.32

Summary

- Random fiber composite model generated with correct fiber volume fraction
- Prediction of Young's modulus correlates well with experimental data
- Random fiber model provides local stress distributions (highly non-uniform)- likely location for damage initiation
- Prediction of complete load-displacement under progress

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Acknowledgements

- NYSERDA and CAMP for partial support of this research
- MAS Composite for specimen fabrication
- Prof. Dave Morrison and Mr. Zac Dean (undergradute student) for experiments

THANKS

THE FAR SIDE® By GARY LARSON

"Mr. Osborne, may I be excused? My brain is full."