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Micromechanical FE modeling of tensile failure of unidirectional composites – Experimental determination of fiber defect distribution

ARL

Enterprise for Multi-scale Research of Materials

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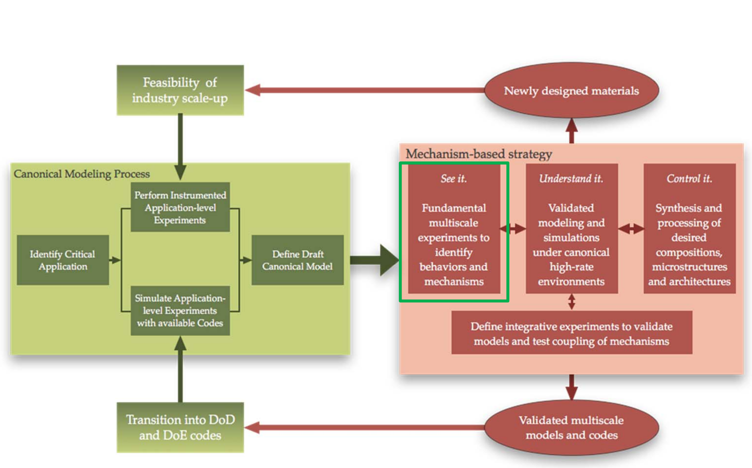
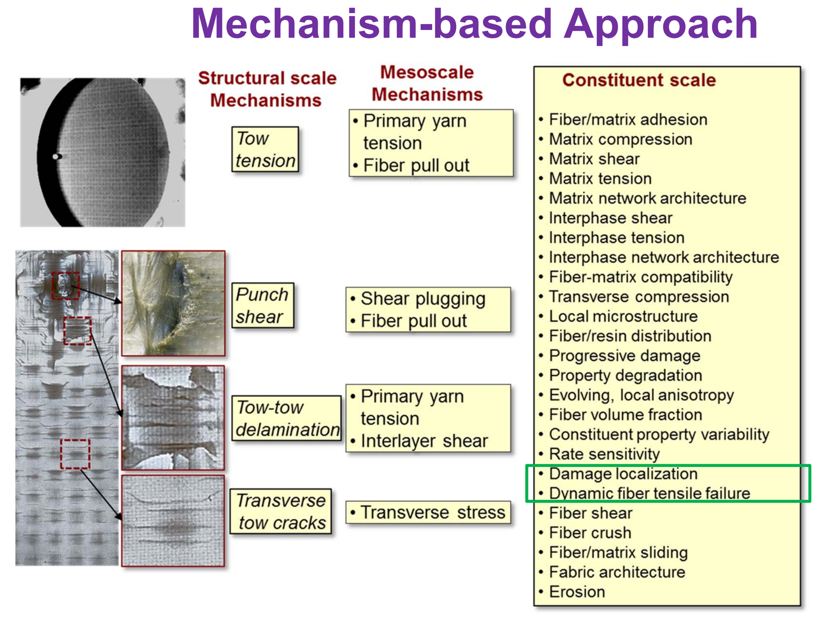
How We Fit

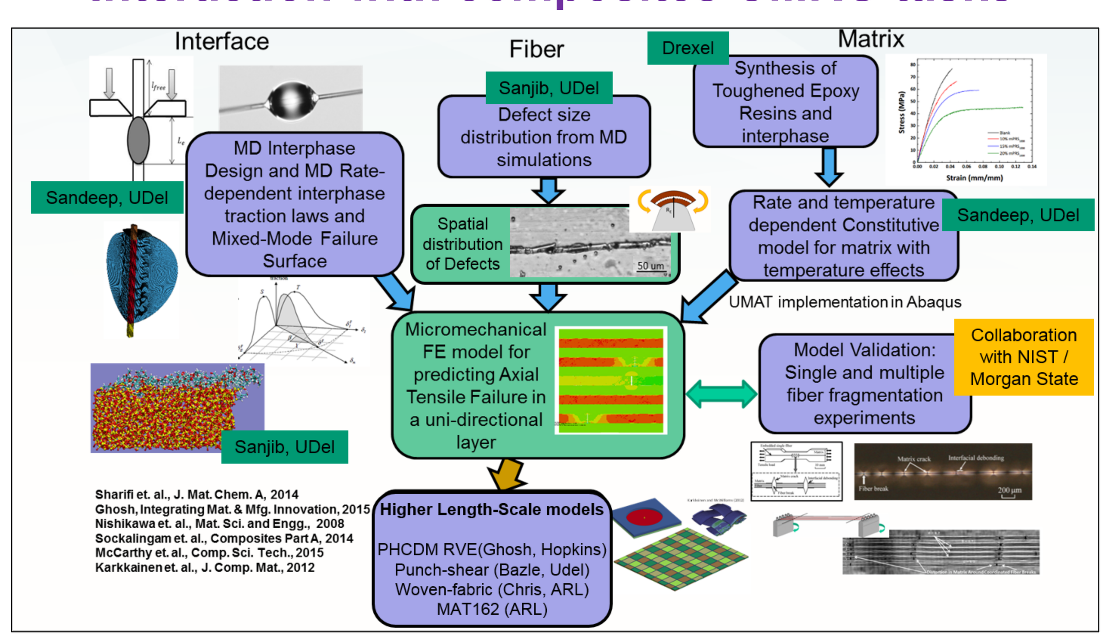
Materials-by-Design Process



Mechanism-based Approach

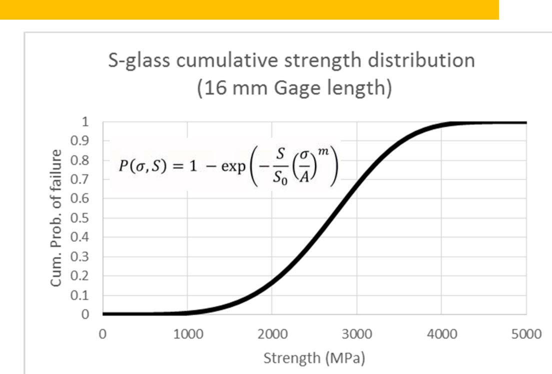


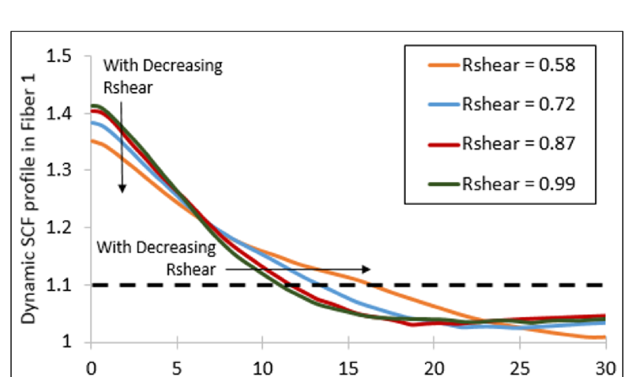
Interaction with composites CMRG tasks



Background and Motivation

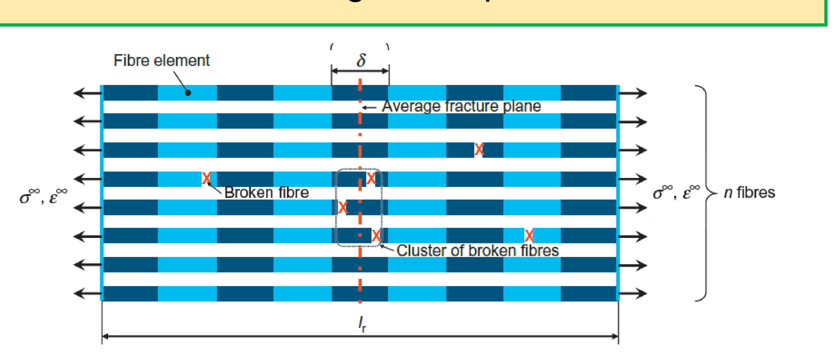
- Due to their brittle nature, S-2 Glass fibers exhibit a probabilistic distribution of strength
- Typically described using a Gage-length dependent
- 2-parameter Weibull distribution
- Depends on the size and spatial distribution of critical defects





- The optimal stress concentration profile will depend on the distribution of fiber defects

What combination of interface and resin properties will lead to maximum energy absorption before formation of critical cluster of fiber breaks leading to composite failure?



P. Camanho & S. Hallett, Woodhead publishing, 2015

To experimentally determine the statistical distribution (size and spatial) of Critical surface defects in S-glass fiber
Use this input in micromechanical FE models to accurately predict the evolution and clustering of multiple fiber breaks (which ultimately lead to composite failure)

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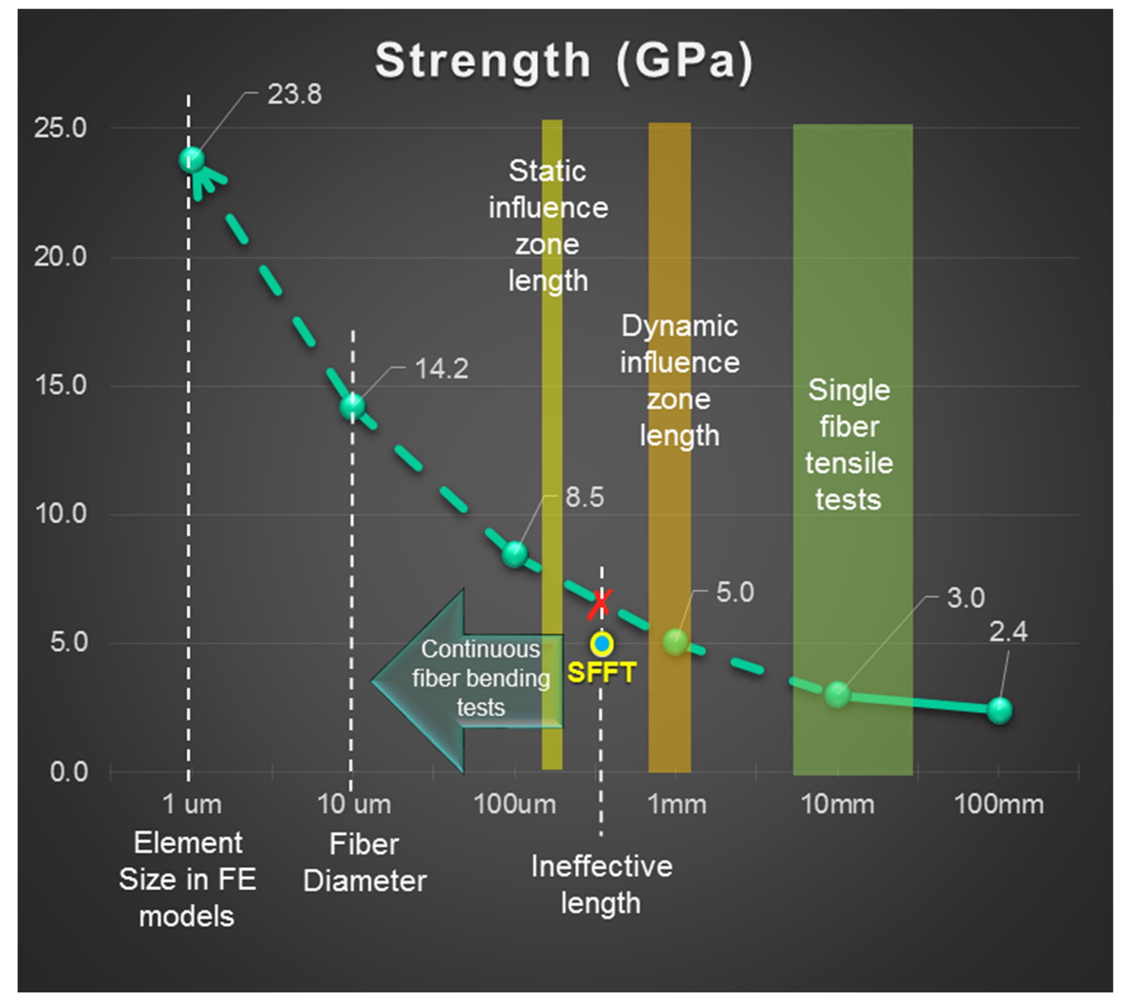
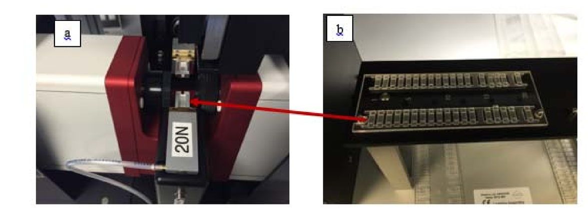
Technical Approach

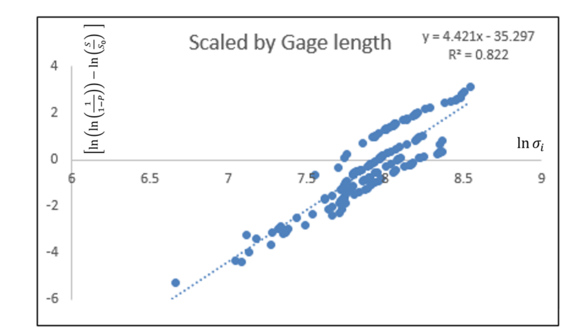


Single Fiber Tensile Tests

- Diastron automated fiber tensile tester
- Gage lengths tested = 4mm, 12 mm, 20 mm, 30 mm



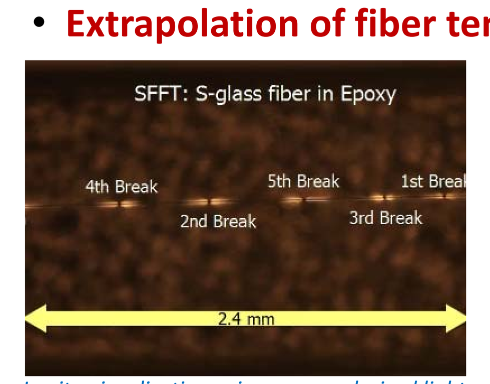
Diastron Fiber Tensile Tester: (a) Test stage (b)Specimen feeding Cassette



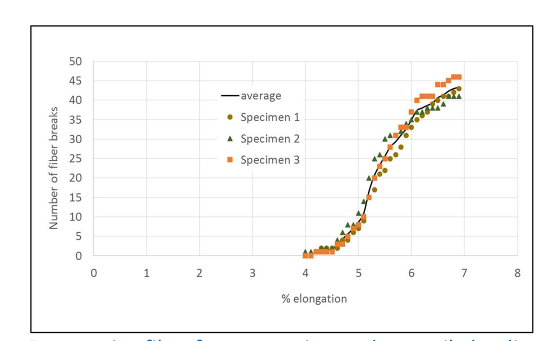
Weibull Plot of single fiber tensile test data (n = 154 specimens)

Single Fiber Fragmentation Test (SFFT)

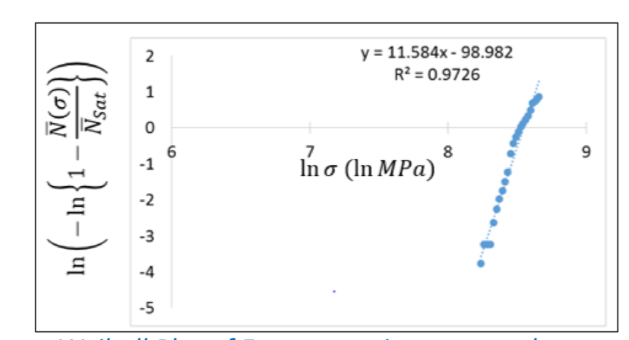
- Single S-glass fiber embedded in DER353-Epoxy Dogbone (16 mm gage length)
- Saturated fragment length of 365 microns (defects spaced within this length are shielded)
- **Extrapolation of fiber tensile test data leads to over-estimation of mean strength by ~25%**



In-situ visualization using cross-polarized light



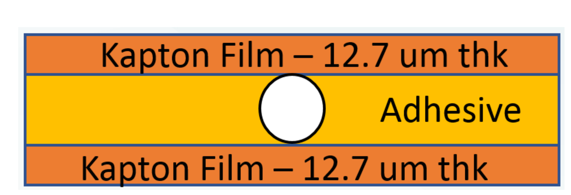
Progressive fiber fragmentation under tensile loading

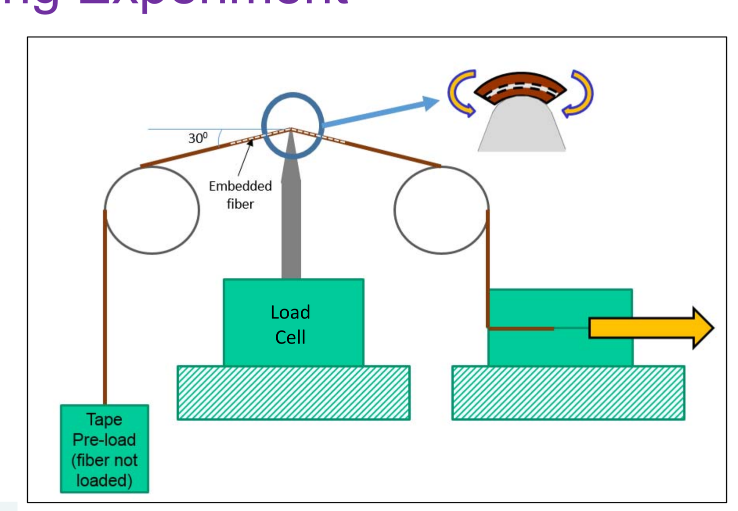


Weibull Plot of Fragmentation test results

Measuring Critical Stress/Defect Size and Location Continuous Fiber Bending Experiment

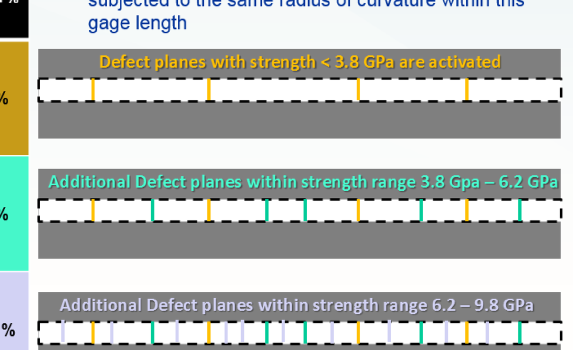
- Fiber surface sprayed with WD-40 to prevent shear transfer with adhesive
- All contact surfaces lubricated with Mineral Oil
- Kapton tape at bottom ensures fiber surface does not get abraded by the blade/wire

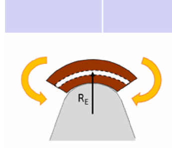




Tip	Radius (μm)	Effective Radius, R_E (μm)	Max. Bending Stress (GPa)	Max. Strain %
Steel Wire	100	118	3.8	4.2%
Boron Fiber	55	73	6.2	6.8%
Razor Blade	10	28	9.8	10.9 %

- Sandwich specimen is moved over a distance of 25 mm to ensure that all cross-sections of the fiber are subjected to the same radius of curvature within this gage length

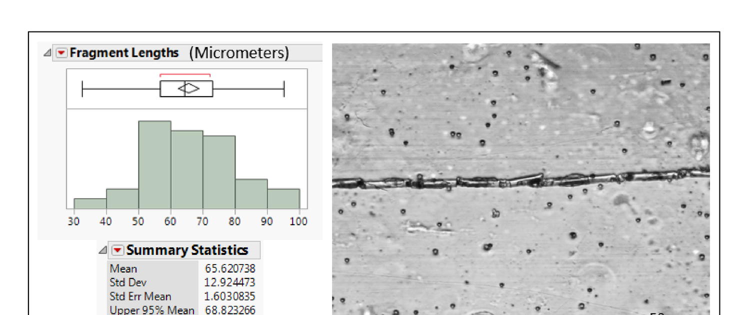




$Effective\ Radius = Tip\ Radius + Tape\ Thickness + Fiber\ Radius$

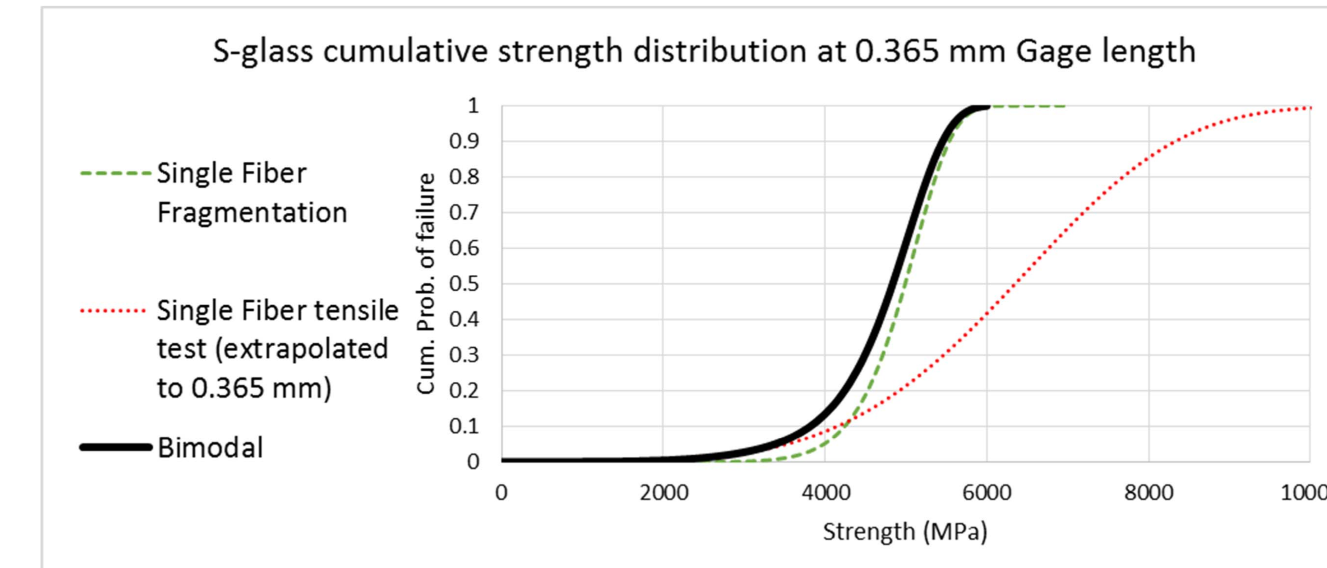
- Limitation: Only surface defects on the tension side will be activated. A large number of samples will be tested to construct the strength/size and spatial distribution of defects.

Ganesh et. al., ASC Conference Proceedings, 2017



- Preliminary tests by hanging 1.7 lb weight as pre-load
- Average fragment length with Razor blade (8 um radius) = 65 um

Major Results



- Bimodal nature of Weibull distribution

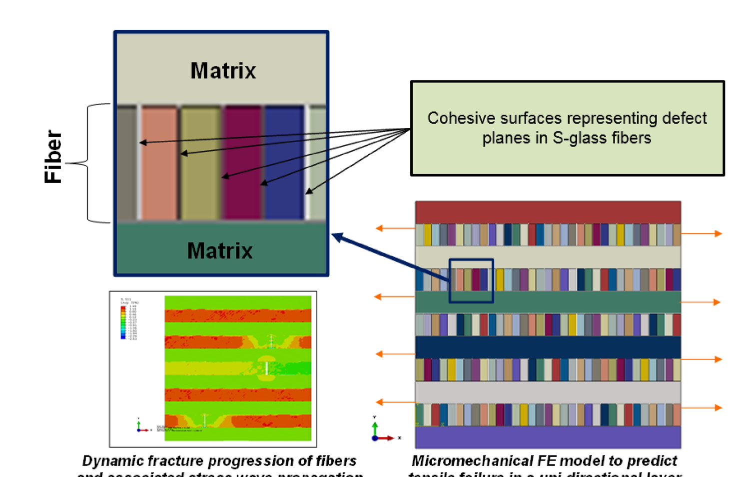
$$P(\sigma, l) = 1 - \exp\left(-\frac{l}{l_{01}}\left(\frac{\sigma}{\sigma_{01}}\right)^{\beta 1} - \frac{l}{l_{02}}\left(\frac{\sigma}{\sigma_{02}}\right)^{\beta 2}\right)$$

Parameter	Value
l_{01}	16 mm
σ_{01}	2.93 GPa
$\beta 1$	4.45
l_{02}	0.365 mm
σ_{02}	5.15 Gpa
$\beta 2$	11.58

Watanabe et al. J. Mater. Adv. Comosite. Materials, 2014

Work in-progress

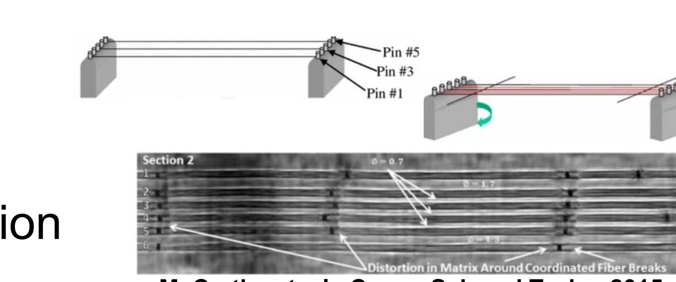
- Standardize the Continuous fiber bending experiment
- Fixture built to perform experiment in-situ under confocal microscope



Micro-Mechanical FE Modeling of Composite Tensile failure

- Use defect distribution data in Micromechanical FE models to predict evolution and clustering of multiple fiber breaks

- Validate model using single and multi-fiber fragmentation experiments (potential collaboration with NIST)



McCarthy et. al., Comp. Sci. and Tech., 2015

Impact

- Generation of a defect-distribution based model capable of predicting progression of fiber breaks under a range of applied strain rates
- Will also provide direct input to dynamic Punch-shear models (Dr. Haque, UDel)

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