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Micromechanical FE Modeling of Tensile Failure of Unidirectional Composites

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Key Goals and Technical Approach

- To experimentally determine the statistical distribution (size and spatial) of Critical surface defects in S-glass fibers
- Use this input in micromechanical FE models to accurately predict the dynamic localization and clustering of multiple fiber breaks (which ultimately leads to composite failure)
- **Integrative model** of lower length-scale constitutive models for the fiber, matrix and interphase
- **Materials by design**: Provide feedback to MEDE collaborators in terms of tailoring the matrix and interphase as a system to maximize strength and overall energy absorption in composites during high strain rate tensile loading

Resin Properties that can be controlled (Dr. Palmese's group, Drexel)

Young's modulus
Yield Strength
Strain to failure

Interface Properties that can be controlled through fiber sizing (Kubota, UD-CCM)

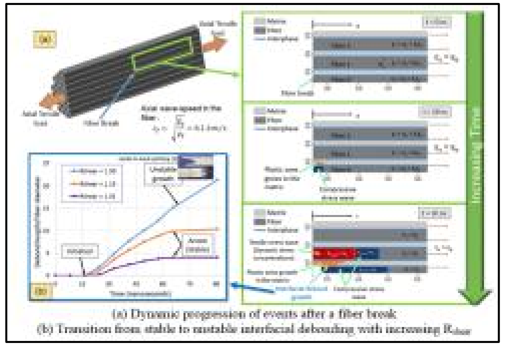
Peak Traction
Fracture toughness
Coefficient of Friction

Geometric Parameters

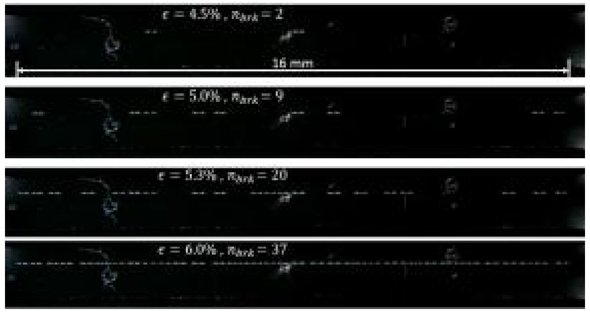
Fiber Volume Fraction
Ply Thickness

Major Results, Key Accomplishments

- Developed and validated a 3D fiber-level FE modeling framework to capture the dynamic effects of a single fiber break
- Identified influential non-dimensional parameter, $\mathbf{R_{shear}}$, which gives insights into micromechanical damage mechanisms and demonstrated the need to tailor the matrix and interphase as a system


(a) Dynamic progression of events after a fiber break
(b) Transition from stable to unstable interfacial debonding with increasing R_{Shear}

Shear Yield Ratio, $R_{Shear} = \left(\frac{\sigma_{Y-mises}}{\sqrt{3}}\right)/T^{iface}_{II-Peak}$



- Extended the scope of SFFT using in-situ visualization of fiber break progression
- Created LabView script to track the locations of each fiber break in SFFT and index them

- Developed novel experimental method (Continuous Fiber Bending Experiment) to characterize spatial distribution of critical defects in S-glass fibers

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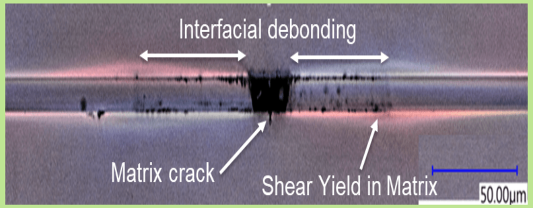
Transitions (materials, codes/tools, legacy publications)

- Experimentally determined Size and spatial distributions of critical defects in S-glass fibers
- Generation of a defect-distribution based FE model capable of predicting progression of fiber breaks under a range of applied strain rates
- Framework for tailoring interface and matrix to enhance tensile properties and energy absorption in the composite
- Study the interaction of micromechanical damage mechanisms inside a realistic composite system

Micromechanical Energy Dissipation mechanisms (in addition to Fiber breaks)
- Matrix Plasticity
- Interfacial Debonding
- Post-debond Frictional Sliding



- Generate inputs for homogenized models at higher length scales : MAT-162 (ARL), PHCDM-RVE (Dr. Ghosh, Hopkins), Meso-scale woven fabric model (Chris Meyer, ARL)
- Will also provide direct input to dynamic Punch-shear models (Dr. Haque, UDel)
- Legacy publications in progress:
  1. Experimental determination of size and spatial distribution of critical surface defects in S-Glass fibers
  2. Dynamic effects of a single fiber break in a unidirectional composite: Effects of residual stress and interfacial friction

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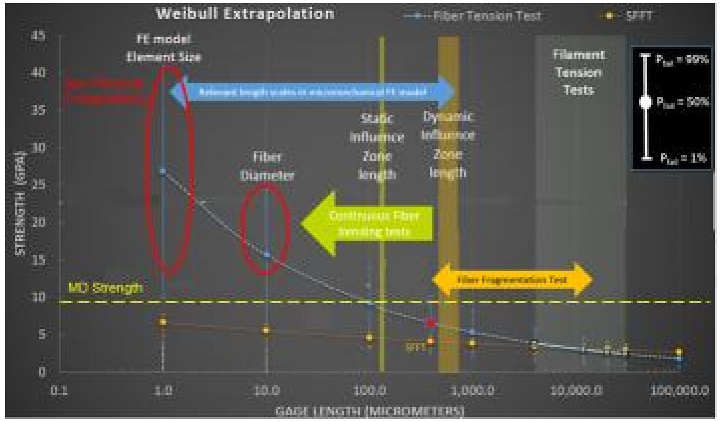
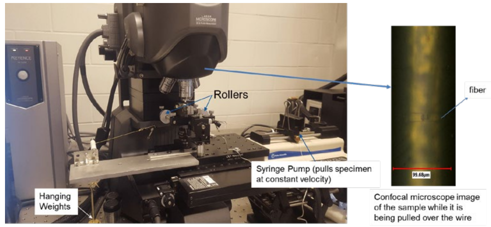
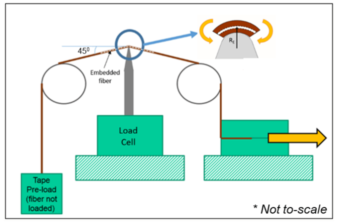
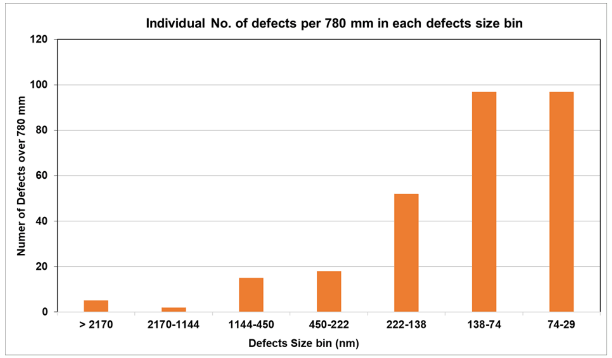
Continuous Fiber Bending Experiment

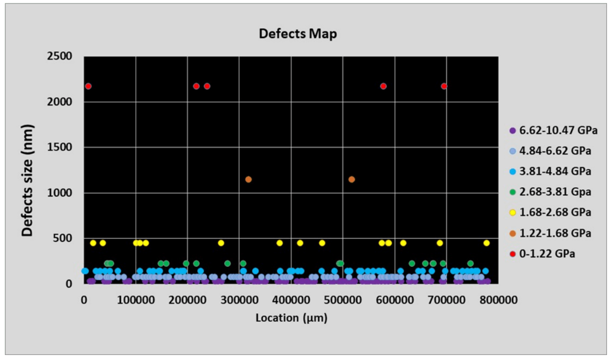
- Weibull extrapolation of fiber strengths to lower length scales is non-physical and it does not provide any information on the spatial distribution of the critical defects











- The smallest experimentally observed defect spacing in the continuous bending test is 22 um!
- Defect mapping obtained from the Continuous Bending Experiment will enable us to account for the actual sizes and spacing of critical defects in S-glass fibers

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