U.S. ARMY RDECOM

Micromechanical FE modeling of tensile failure of unidirectional composites

ARL

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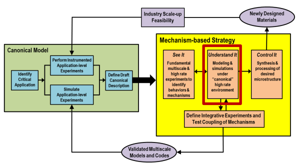
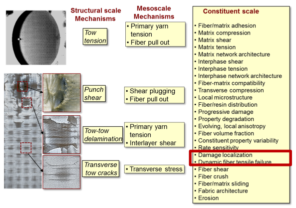
Enterprise for Multi-scale Research of Materials

How We Fit

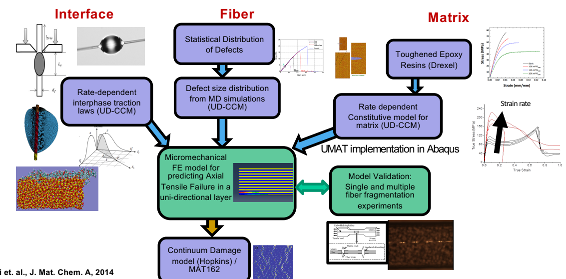
Materials-by-Design Process



Mechanism-based Approach



Interaction with Composites CMRG tasks



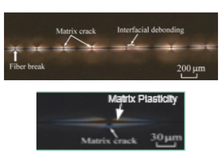
Sharifi et. al., J. Mat. Chem. A, 2014
Ghosh, Integ. Mat. & Mfg. Innovation, 2015
Nishikawa et. al., Mat. Sci. and Engg., 2008
Sockalingam et. al., Composites Part A, 2014

Key Goals

Develop a detailed FE modeling framework to predict the high strain rate tensile failure of unidirectional composites while accounting for micro-mechanical damage mechanisms

Materials by design: Use this framework to tailor interface and matrix to enhance tensile properties and energy absorption in the composite

Develop a systematic method to translate the results from these models into inputs for homogenized models at higher length scales (eg. MAT162 in LS-DYNA)

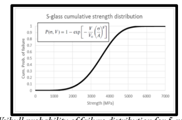


Nishikawa et. al., Mat. Sci. and Engg., 2008

Micromechanical damage mechanisms
- **Matrix plasticity**
- **Interfacial debonding**
- **Matrix micro-cracking**

Technical Approach

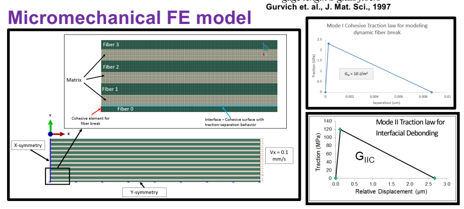
- S-2 Glass fibers exhibit a statistical distribution of strength based on size and spatial distribution of critical defects
- Due to their brittle nature, breaking of glass fibers is a locally dynamic process



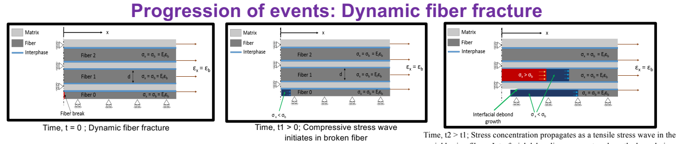
Weibull probability of failure distribution for 5-mm gage length S-glass fibers
Gurvich et. al., J. Mat. Sci., 1997

Micromechanical FE model

- Dynamic brittle fiber fracture using cohesive elements
- Interface modeled as 'zero-thickness' cohesive surface



Progression of events: Dynamic fiber fracture



Time, t = 0 ; Dynamic fiber fracture

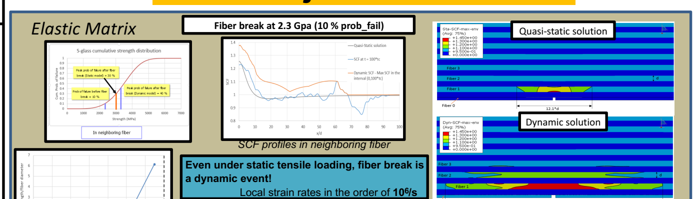
Time, t1 > 0; Compressive stress wave initiates in broken fiber

Time, t2 > t1; Stress concentration propagates as a tensile stress wave in the neighboring fibers. Interfacial debonding propagates along the boundaries of the broken fiber

Ganesh et. al., J. Comp. Mat., 2016

Major Results

Elastic Matrix

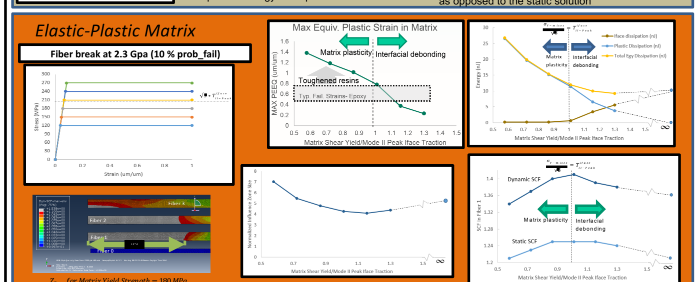


Even under static tensile loading, fiber break is a dynamic event!
Local strain rates in the order of 10^6/s

- Unstable debond stress - **2.4 Gpa**
- Avg. Strength of fibers – **3.5 Gpa**
- Important energy absorption mechanism

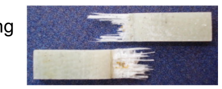
Zone-of-influence (Dyn. SCF > 1.1) of the fiber break is 5 times greater due to the dynamic effects as opposed to the static solution

Elastic-Plastic Matrix



Key Accomplishments

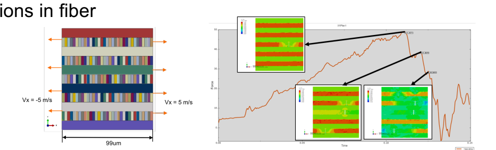
- Developed and validated a fiber-level FE modeling framework to capture the dynamic effects of a single fiber break while relaxing the inherent assumptions in theoretical shear lag models.
- Dynamic stress concentrations are shown to be significantly higher and are shown to envelop a much larger volume of the microstructure than the corresponding predictions based on quasi-static models
- Dynamic interfacial failure is predicted where debonding initiates, propagates and arrests at longer distances than predicted by models that assume quasi-static fiber breakage.
- At larger break strengths, unstable debonding is predicted by the dynamic model.
- Agrees with experimental observation of axial splitting of fibers under tensile loading



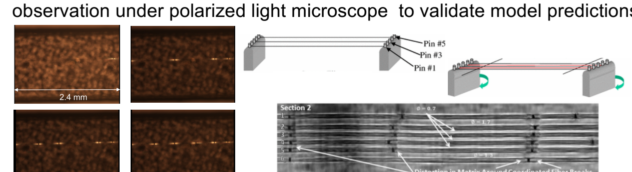
Shokrieh et. al., Comp. Struct., 2009

Future Directions in 2017

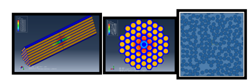
- Dynamic model with fracture planes representing characteristic defect distributions in fiber



- Perform Single and Multi-fiber fragmentation experiments with in-situ observation under polarized light microscope to validate model predictions



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



- Extension to 3D packing of fibers
- Effects of random fiber arrangement

Impact

- Generation of a defect-distribution based 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
- Generate inputs for homogenized models at higher length scales

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