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High Strain Rate Fiber-Matrix Interfacial Traction Laws

ARL

Enterprise for Multi-scale Research of Materials

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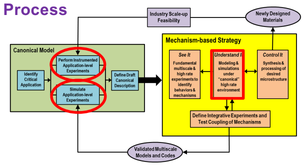
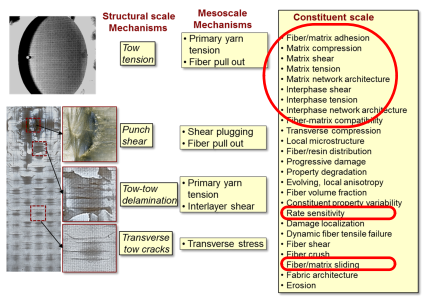
How We Fit

Materials-by-Design Process



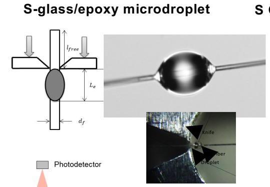
Mechanism-based Approach



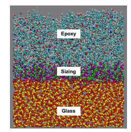
Technical Approach

Novel Kolsky Bar Techniques at the Nanometer to Micron Scale With Real Time Sensing and Visualization

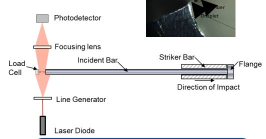
S-glass/epoxy microdroplet

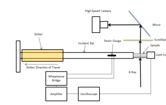


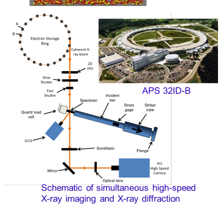
S Glass/Epoxy Interphase

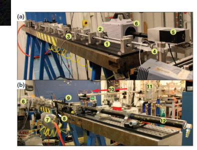


S-glass/epoxy cruciform

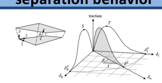








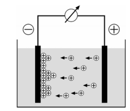
Validate MD prediction interphase traction separation behavior

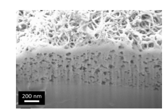


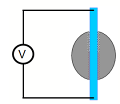
Visualization of damage in interphase

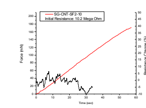
Key Accomplishments

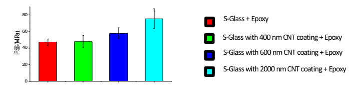
- Developed HSR Kolsky bar experimental technique for composite interphase characterization at the micromechanical length scale: measure traction separation laws
- Modeling methodology to determine interfacial traction separation laws
- Carbon nanotubes (CNTS) as non-invasive sensor for crack monitoring





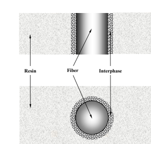


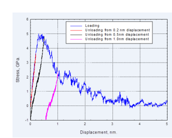




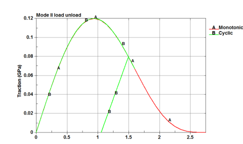
Future Directions in 2017

- Validate interphase mechanisms to maximize energy absorption during impact
- Interphase characterization under mixed mode HSR loading conditions using Drexel resins
- Validate MD traction laws and bridge length scales for composite RVE models
- Visualize damage in model composite

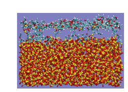


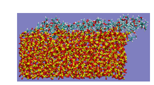


MD cyclic loading of interface



PPR potential based model



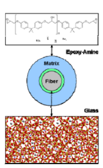


Key Goals

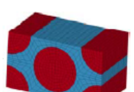
- Establish high strain rate mixed mode traction separation laws for glass fiber/epoxy interphases
- Design interphase for maximum energy absorption from both resin plasticity and interphase debonding mechanisms

Develop high strain rate mixed-mode traction-separation laws for glass fiber/epoxy interface

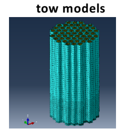
Validate traction laws predicted by MD models



Input to unit cell composite models

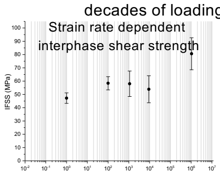


Input to fiber-level impregnated tow models



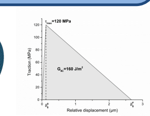
Major Results

HSR S-glass/epoxy interphase characterization covering six decades of loading (up to $1.5 \times 10^7\ s^{-1}$)



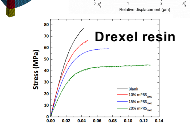
FE modeling the QS and HSR microdroplet test method
Cohesive zone modeling of the interphase between fiber/matrix

Mechanisms
Mixed mode damage initiation followed by mode II dominated crack propagation
Progressive interfacial debonding, frictional sliding



Traction separation laws

Sizing		Experimental IFSS (MPa)	Traction separation law	
Silane	Film former		Peak traction (MPa)	Critical energy release rate (J/m²)
γ-GPS + γ-PTMO	DGEBA epoxy	62	120	160
γ-APS	Silylated polyazamide	110	180	450
Commercial sizing γ-GPS, epoxy		47	120	110



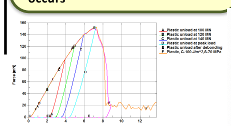
Methodology considering resin plasticity

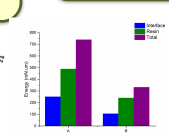
Experimental:
- ✓Load-unload total energy absorption until peak load ($E_{resin} + E_{interface}$)
- ✓Load at which crack initiation occurs

Traction law:
- ✓Initial guess G_{IIC} from elastic analytical solution
- ✓Peak traction $\tau_{IFSS} < S < \tau_{resin}$

Correlate:
- ✓Energy absorption until peak load
- ✓Load at which crack initiation occurs

Validate:
- ✓Traction law determined from above steps with different droplet lengths to predict experimental results





Impact

- Improved understanding of energy absorbing mechanisms will have broad applications in composites
- Critical element of materials-by-design framework for composite materials under high rate loading
- Will lead to improved protection materials while decreasing the cost and time for development of new lightweight energy absorbing composite materials

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