U.S. ARMY RDECOM

Relating Meso/Nano-Scale Structure to Mechanical Properties and Failure Mechanisms in Fibers

ARL

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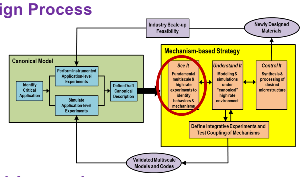
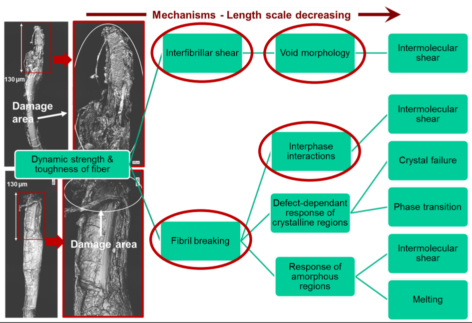
Enterprise for Multi-scale Research of Materials

How We Fit

Materials-by-Design Process

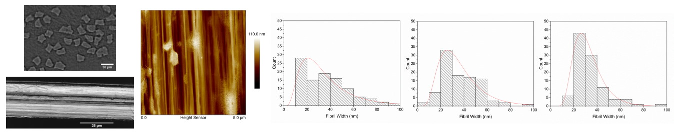


Mechanism-based Approach



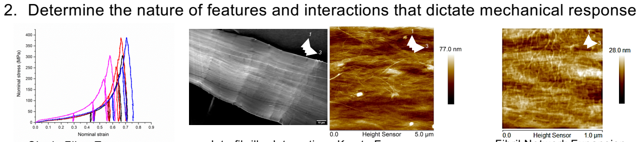
Technical Approach

1. Understand fiber architecture through high resolution imaging techniques



Microscale (10^{-6}m) Mesoscale (10^{-7}m) Nanoscale (10^{-9}m)

2. Determine the nature of features and interactions that dictate mechanical response

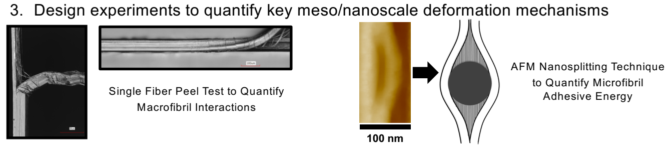


Single Fiber Transverse Compression

Interfibrillar Interactions Key to Energy Absorbtion

Fibril Network Expansion

3. Design experiments to quantify key meso/nanoscale deformation mechanisms

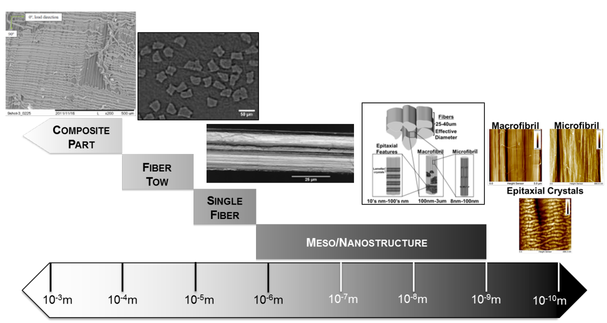


Single Fiber Peel Test to Quantify Macrofibril Interactions

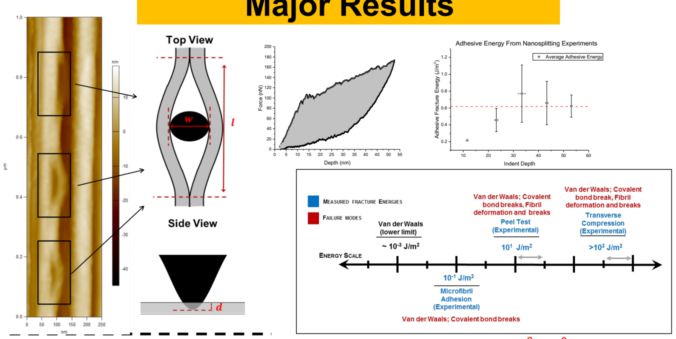
AFM Nanosplitting Technique to Quantify Microfibril Adhesive Energy

Key Goals

- Goal: The focus of this experimental work is to quantify the size and spatial distributions of nano/mesoscale features, and the mechanical properties associated with these features, as well as identifying critical modes of failure for different loading conditions. This information is key to determining how load is translated throughout the fber and development of accurate constitutive models describing macroscopic behavior.



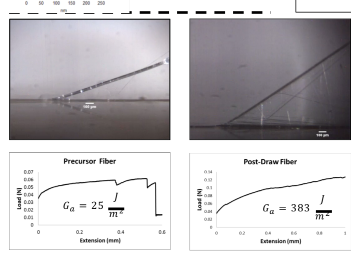
Major Results



$$G_a = \frac{1}{b}\left(\frac{dU_{ext}}{da} - \cancel{\frac{dU_s}{da}} - \cancel{\frac{dU_{dt}}{da}} - \frac{dU_{db}}{da}\right)$$

Adhesive Energy, External Work, Stored Strain Energy (0), Energy of Tensile Deformation (0), Bending Energy

$$G_a = \left[\frac{P}{b}(1 - \cos\theta)\right] - (1-\alpha)\left[\frac{k_0^2}{3} + \frac{2(1-\alpha)^2}{3k_0} - 1\right]\frac{1}{2}(E\varepsilon_y^2 h)$$



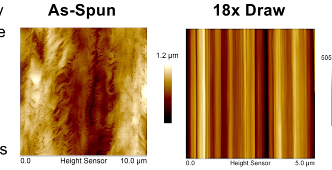
P: force
b: sample width
θ: peel angle
α: work hardening parameter
k_0: root rotation parameter
E: Young's modulus
ε_y: yield strain of peel arm
h: thickness of peel arm

Key Accomplishments

1. Identification and mapping out of key structural features in UHMWPE fibers
2. Observation of the changes in meso/nanostructure corresponding to changes in processing that result in increased strength and stiffness
3. Studied the nonlinear inelastic transverse compressive behavior of fibers and the meso/nanoscale deformation mechanisms that influence this response
   I. Discovered that voids appear to play a role in the compliant response at early levels of strain
   II. Fibrillation occurs first at the macrofibril scale and at increasing strains continues until separation into constitutive microfibrils
4. Developed novel characterization techniques to quantify energy of failure at multiple length scales in the fiber
   I. Single Fiber Peel Test to quantify Mode I and Mode II failure at the fiber level
   II. AFM Nanoindentation based technique to quantify the adhesive energy between two nanoscale microfibrils

Future Directions in 2017

1. Working alongside Drexel University to understand fibers optimized at the meso/nanoscale for tailored performance at the macroscale
2. Probing the thermodynamic basis for the formation of the fundamental fibril structures in the fiber
3. Working alongside ARL Researchers to provide inputs for fibril level mechanical models



Gel spun fibers from Drexel showing an evolution in meso/nanostructure with increasing draw

Impact

To date, this program has provided quantitative insight into the role that processing conditions play in determining meso/nano scale structure in UHMW PE fibers, and how changes in this structure affects failure modes and macroscopic properties under different loading conditions (Quasi-static and Dynamic Tensile, Mixed Mode Peel). Future efforts will focus on developing experimental techniques to quantify thermal and mechanical properties of nanoscale phase domains and microfibril tensile and adhesion. This information is critical to the development and validation of accurate material models at all scales and currently DOES NOT EXIST.

Working in close conjunction with the Modelling and Processing efforts, this work will provide the necessary computational and experimental tools needed to predict produce and optimize fiber performance at all critical length and time scales. The tools developed in this program will be translatable to other ballistic fiber materials of interest. The benefit to the Soldier will be a revolutionary capability to design superior ballistic fibers and textiles for use in Personnel protection applications.

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