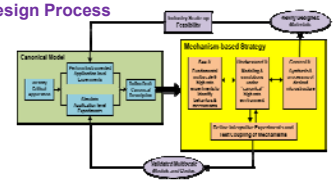
Relating Meso/Nano-Scale Structure to Mechanical Properties and Failure Mechanisms in Fibers

P. McDaniel, J. Deitzel and J. Gillespie (UDel); T. Bogetti, K. Strawhecker and T. Weerasooriya (ARL)

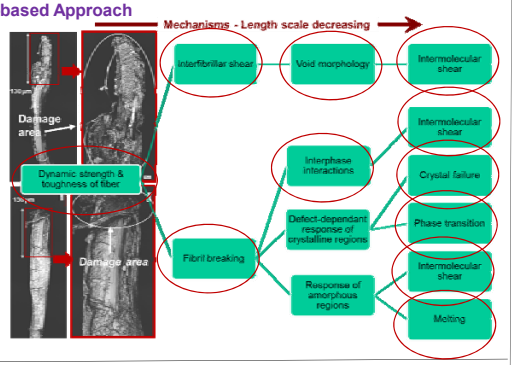
Enterprise for Multi-scale Research of Materials

How We Fit

Materials-by-Design Process



Mechanism-based Approach



Goals and Motivation

Motivation

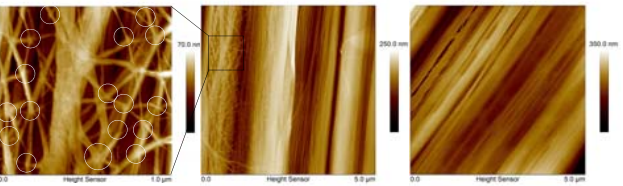
- Design of high performance UHMW PE fibers with optimized Meso/Nanoscale structure for strength, modulus and energy dissipation.

Goals

- Relate Processing -Structure-Properties
- Identify critical modes of failure at Meso/Nanoscale for different loading conditions
- Provide experimentally determined input parameters needed for physics-based models across all scales
- Validation of Model predictions across all scales
- Provide feedback regarding changes in sub-filament structure with processing conditions.

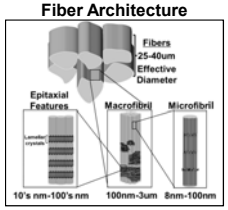
Information ultimately used to determine how load is transferred in the fiber and develop accurate constitutive models describing mechanical behavior

Network Structure | Precursor Fiber | Post-Draw Fiber



Technical Approach

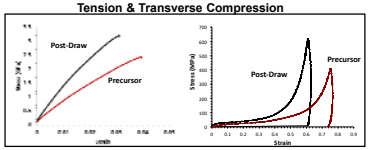
Fiber Architecture



Determine Key Features and Mechanisms Controlling Mechanical Behavior

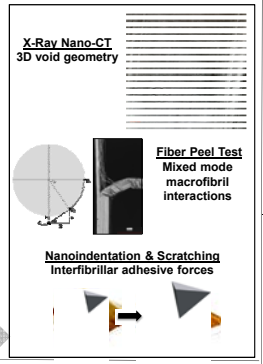
Mechanical Response

Tension & Transverse Compression



Experimental Timeline

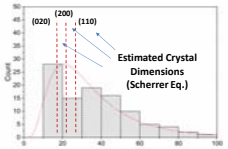
Experiments To Quantify Interactions and Mechanisms at All Length Scales



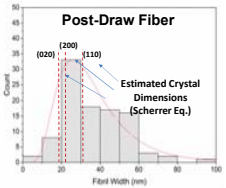
Major Results

AFM Fibril Diameter Distributions

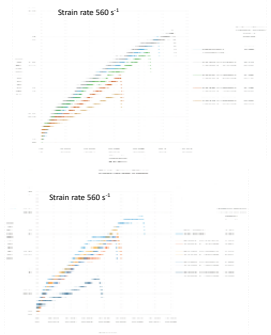
Precursor Fiber



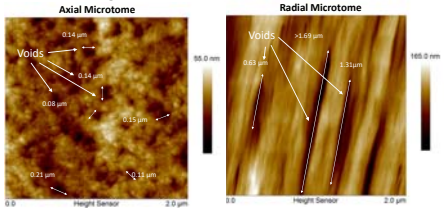
Post-Draw Fiber



Effect of Shear Strain on Failure Stress



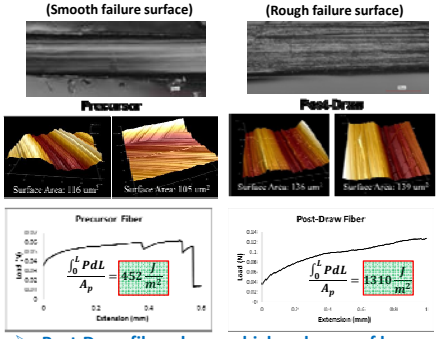
AFM Images of Microtomed Post-Draw Fibers



➢ Drawing at elevated temperatures leads to consolidation of microfibrils into bundles and consolidation of void spaces

Fracture Energy From Single Fiber Peel Test

Precursor fiber (Smooth failure surface) | Post-Drawn fiber (Rough failure surface)



➢ Post-Draw fiber shows a higher degree of large scale deformation of microfibril bundles, increasing fracture energy!

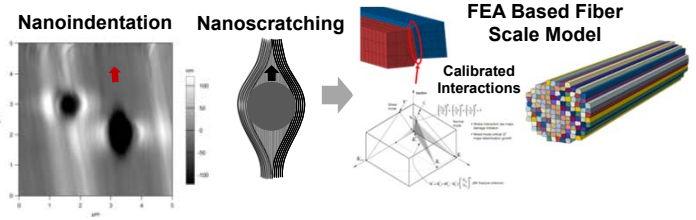
Key Accomplishments

- Quantified size and distribution of meso/nanostructural features through high resolution AFM imaging
  - First time identification of a 3D fibrillar network
  - Critical for building 3D model of filament internal structure
- Identified changes in meso/nanoscale features with processing correlating to increased mechanical properties
- Developed new test methods and state-of-the-art characterization techniques to study the fibers
  - Awarded beamtime for X-ray nanotomography studies at Argonne National Lab Center for Nanoscale Materials to study nanoscale voids
  - Single Fiber Peel Test developed to study interfibrillar interactions

Future Directions

- Direct measurement of microfibril properties and interactions
- Nanotomagraphy to determine spatial and size distributions of voids
- Development of computational models of a single fiber based on measurements of meso/nanoscale structure and properties
- Quantification of phase domain size and spatial distribution within a single microfibril (WAXD/SAXS/Dynamic TEM)
- Identify failure modes in fibers subjected to dynamic testing

Nanoindentation | Nanoscratching | FEA Based Fiber Scale Model



Impact

- Provided quantitative insight into the relationship between processing conditions and meso/nanoscale structure in UHMWPE fibers
- Demonstrate how changes in Meso/Nanoscale structures influence macroscopic mechanical properties
- This information is critical to developing accurate material models at all length scales that currently do not exist
- Tools developed in this study will be translatable to other ballistic fibers 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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