U.S. ARMY RDECOM

Mapping "Defects" and Linking Failure modes at Multiple Length Scales in UHMWPE Filaments

ARL

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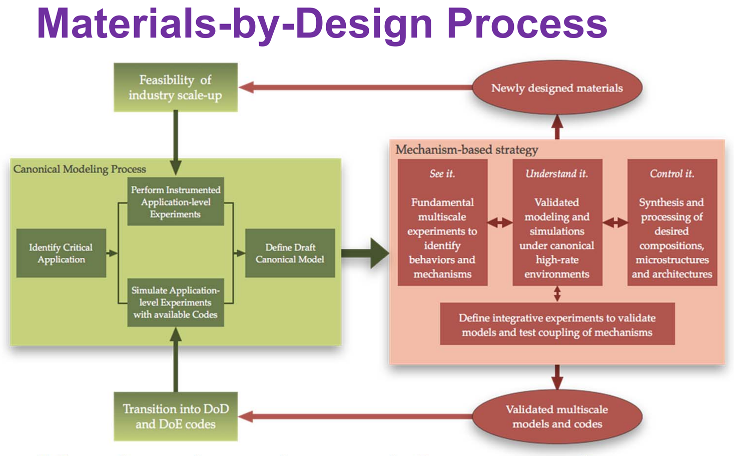
Enterprise for Multi-scale Research of Materials

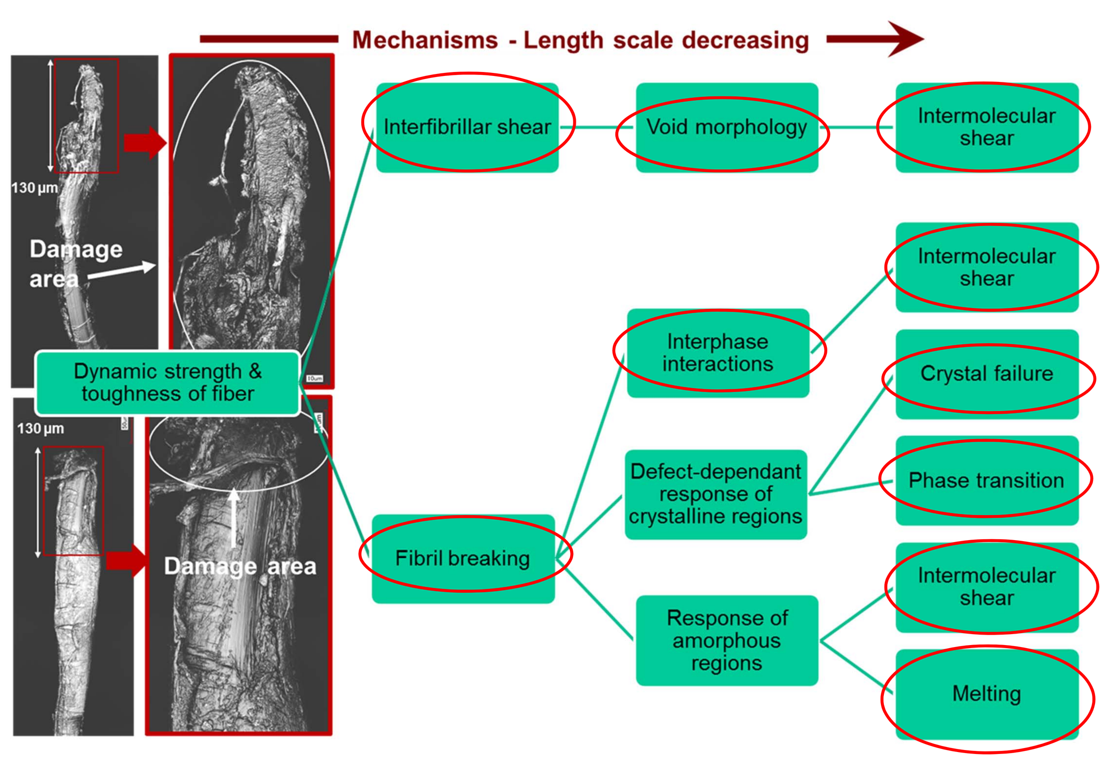
How We Fit

Materials-by-Design Process



Mechanism-based Approach

- "See It": Quantification of morphological features and their spatial distribution within a single filament.
- "Understand It": Quantification of failure modes, mechanical properties and energies of interaction between morphological elements in a single filament to provide parmeters to be used in modelling efforts
- "Control It": Correlation between process history, morphology and mechanical properties to provide as feedback to fiber processing efforts



Key Goals

Motivation

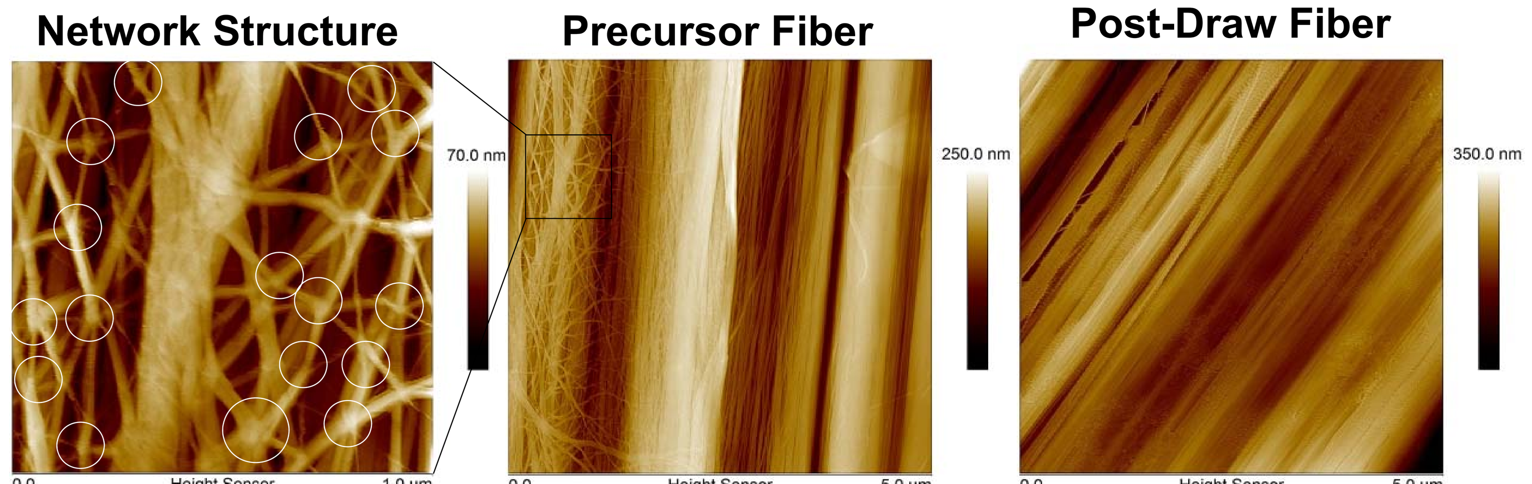
- Design of high performance UHMW PE fibers with optimized Meso/Nanoscale structure for strength, modulus and energy dissipation.

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.

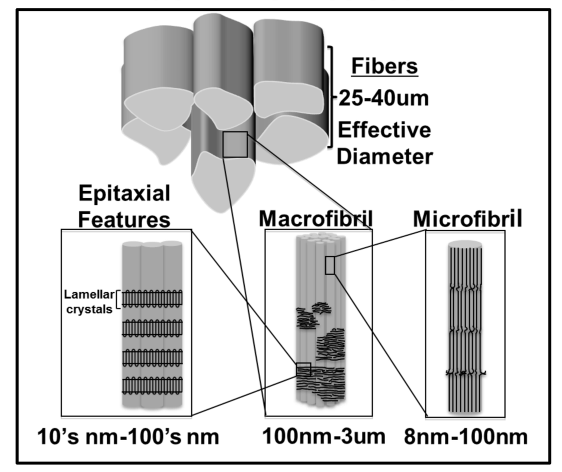
Information ultimately used to determine how load is transferred in the fiber and develop accurate constitutive models describing mechanical behavior

Network Structure | Precursor Fiber | Post-Draw Fiber



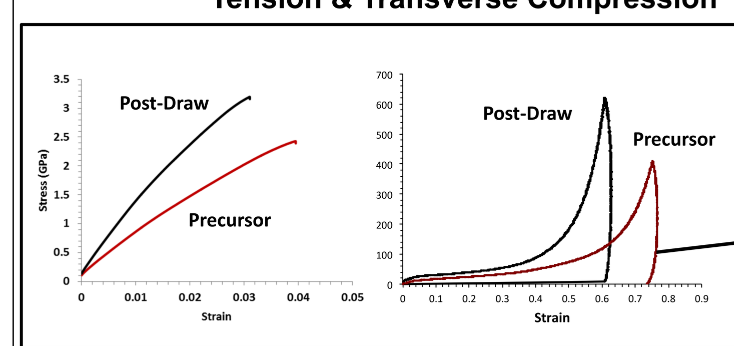
Technical Approach

Fiber Architecture



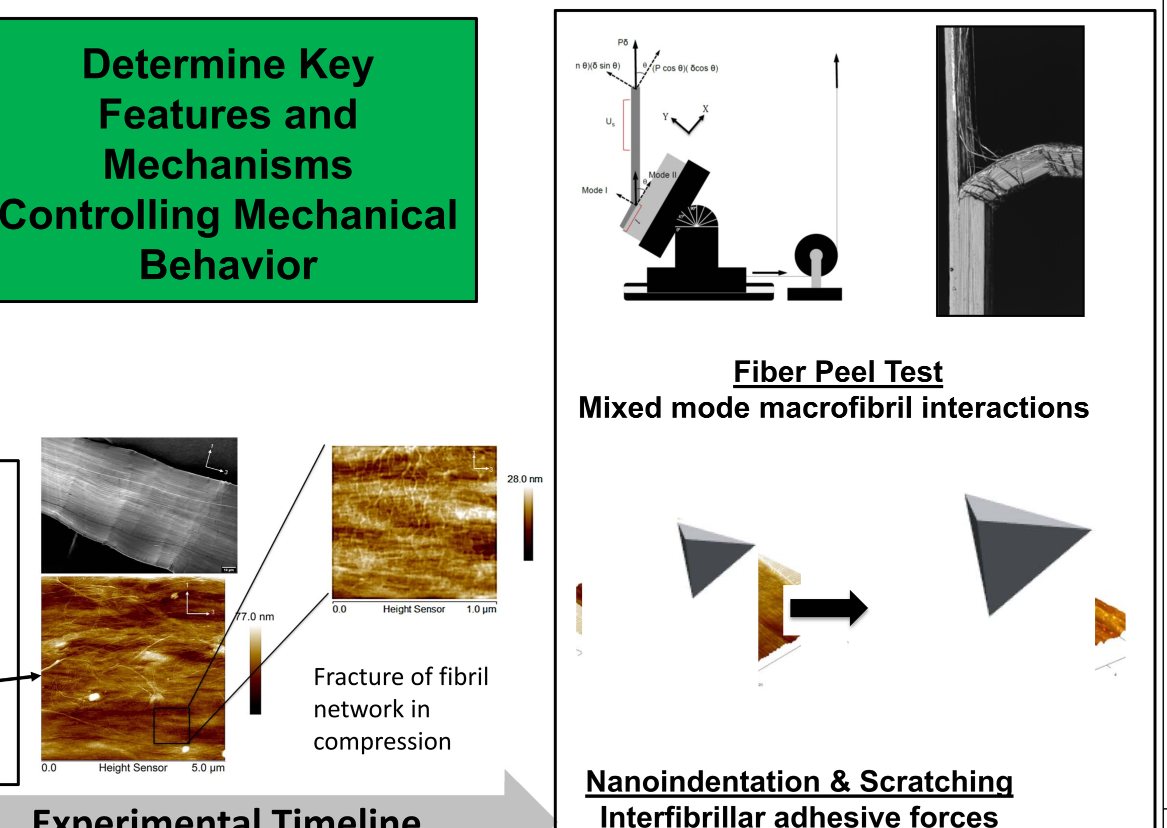
Determine Key Features and Mechanisms Controlling Mechanical Behavior

Mechanical Response
Tension & Transverse Compression



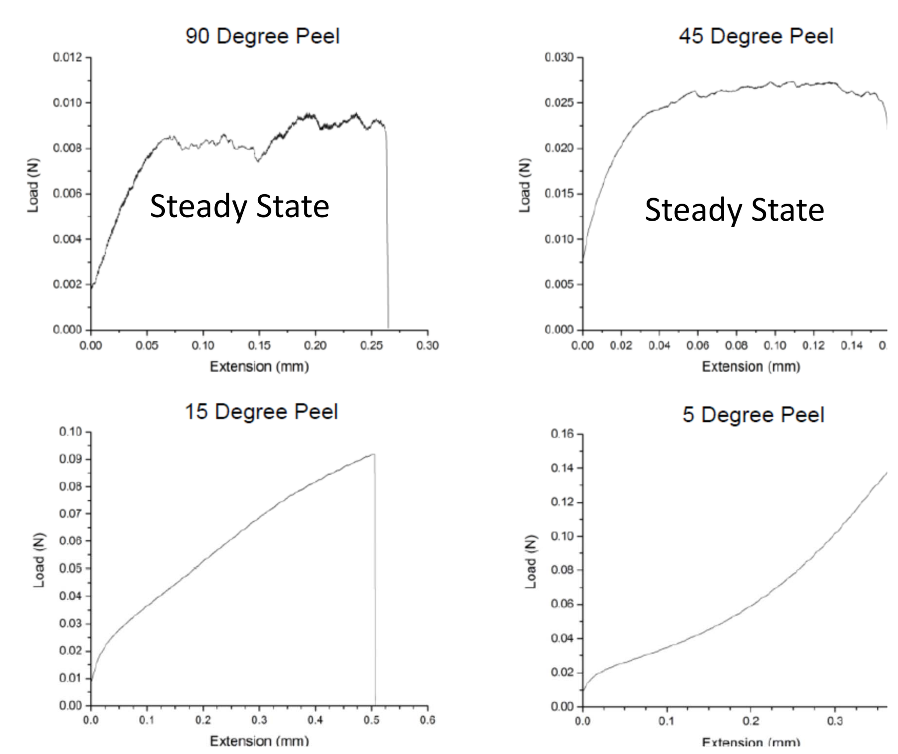
Experimental Timeline

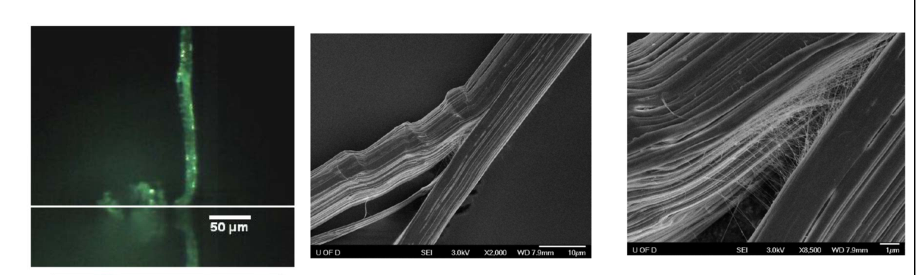
Experiments To Quantify Interactions and Mechanisms at All Length Scales



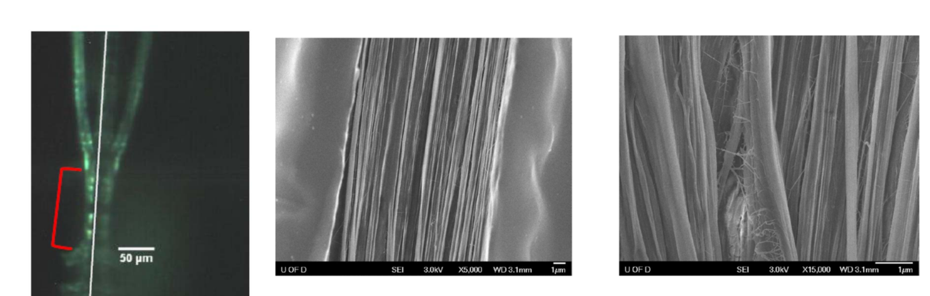
Major Results

Single Filament Peel Test



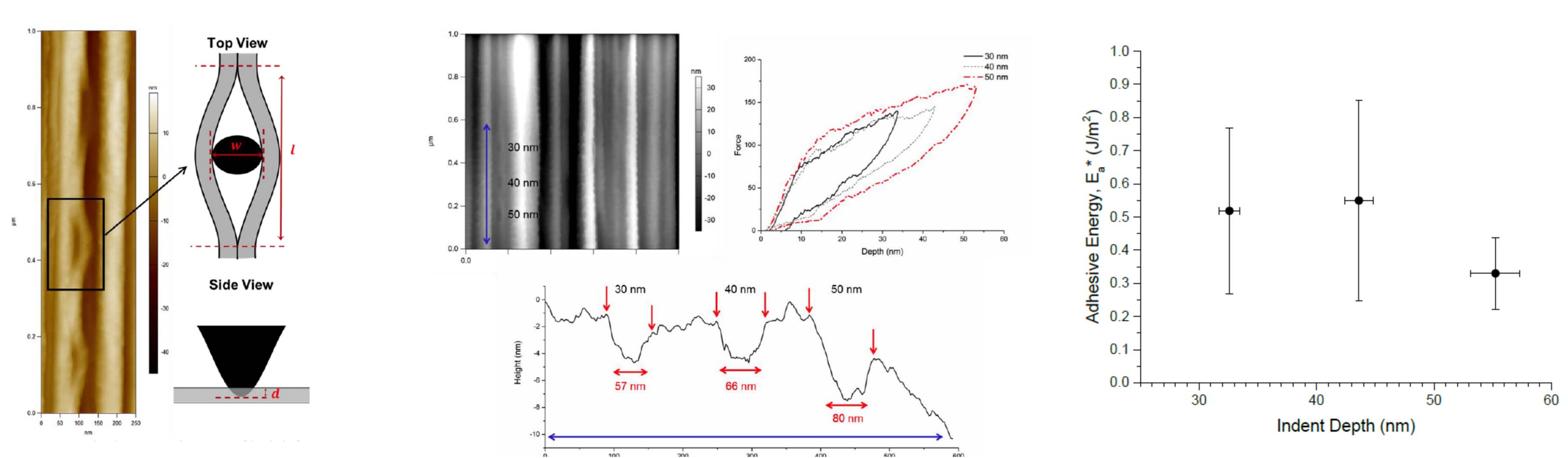


Peel Angle 90°(Mode I Dominant)



Peel Angle 5° | Peel Angle 0° (Mode II dominant)

Interfibril Adhesion Measurement (In collaboration with ARL)



Polyethylene C-C bond Fracture	van der Waals Adhesive Energy	Adhesive Energy (E_a*)	Average Interface Area	Chains Fractured	Chain Pullout Energy	Chains pulled out
6.41 E-19 J	0.13 J/m²	0.55 J/m²	2900.40 nm²	0.65/nm²	1.89 E-19 J	2.22/nm²

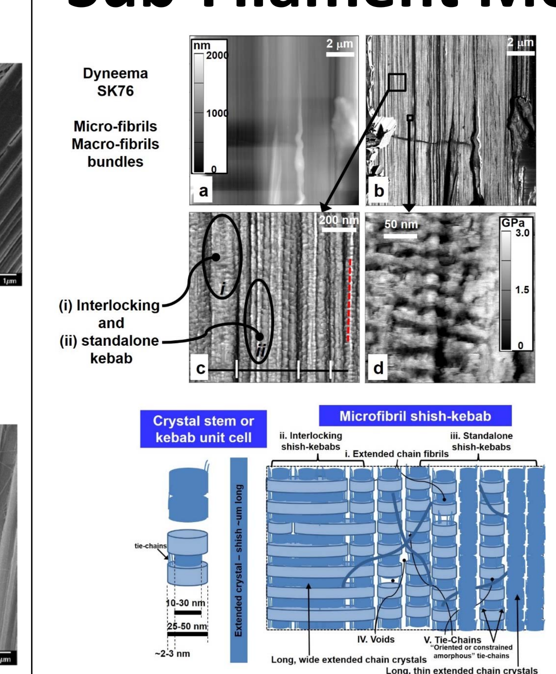
*Energy of chain pull out comes from JHU MD simulation efforts

Key Accomplishments

- **Quantified size and distribution of meso/nanostructural features through high resolution AFM imaging**
  - Nanofibril dimeter distribution and bundle size
  - First time identification of a 3D fibril network and determination of average length between network junctions
- **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**
  - Single Fiber Peel Test developed to study interfibril interactions
    - Identified change in failure mode as we shift from Mode I to Mode II loading.
    - Fibrils bridging shear plane shift from pull out to tension failure
  - With ARL, developed and validated nanomechanical method to measure localized interfibril adhesion (1st TIME!)
    - Energy of adhesion is shown to be greater than that attributable to van der Waals forces alone.
    - Clear morphological evidence of material bridging microfibrils

Transitions to ARL, within CMRG and to other CMRGs

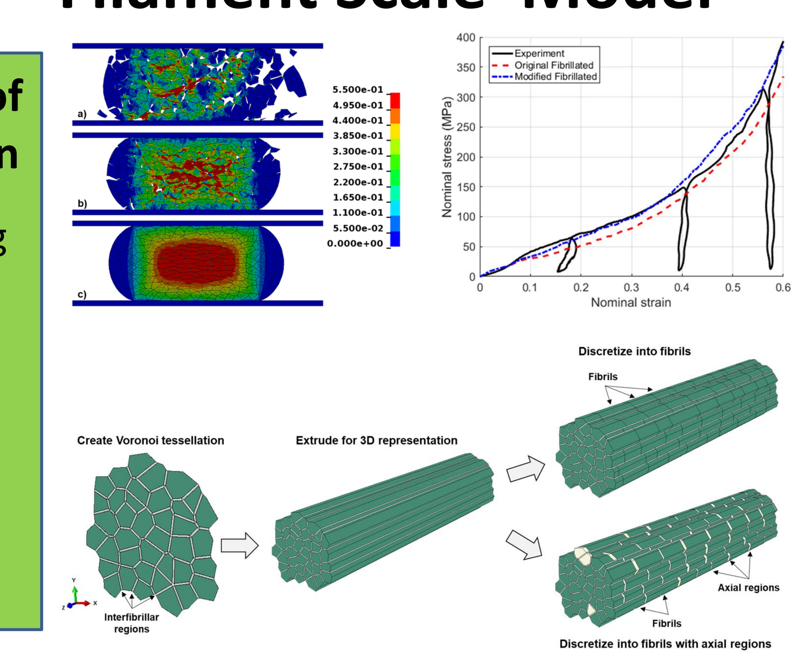
Sub-Filament Model



Mechanisms of Fiber Cohesion

Crystals bridging Microfibrils → Microfibrils bridging Macrofibrils

Filament 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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