Multi-scale Experimental Framework to Understand Rate Dependent Fiber-based Material Response

S&T Campaign: Sciences for Lethality & Protection
Rate Dependent *Multi-scale Experimental Mechanics*

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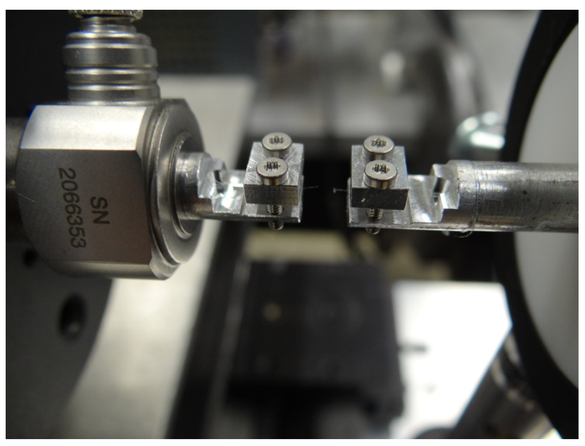
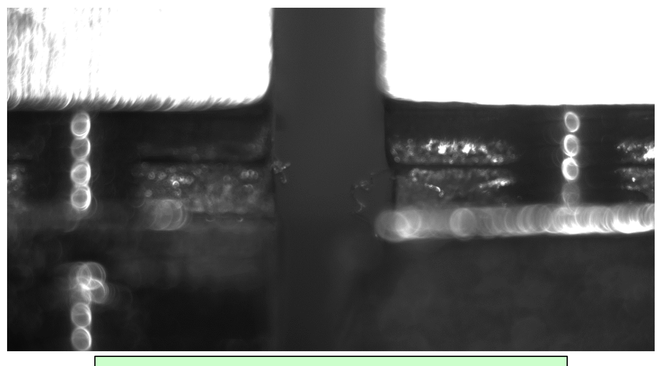
Research Objective

- **Goal: Understand the mechanical response of fiber-based materials via fiber and sub-fiber response**
- **Currently, constitutive response models are based solely on the uniaxial tensile behavior of single fibers. In reality, the stress-state of a fiber during impact is *multiaxial*. While the fiber is *primarily* loaded in uniaxial tension, the fiber is also subjected to transverse compression.**
- **Multiaxial response of the fiber must be incorporated into mathematical models**

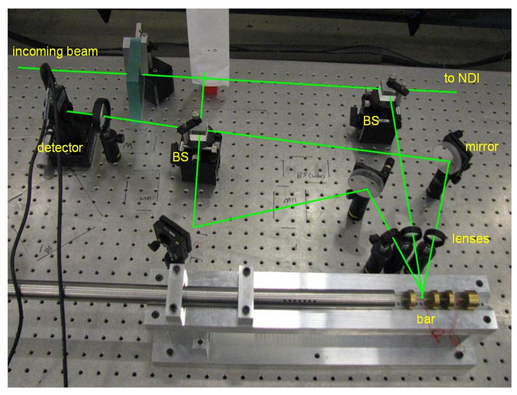


Gripping Method

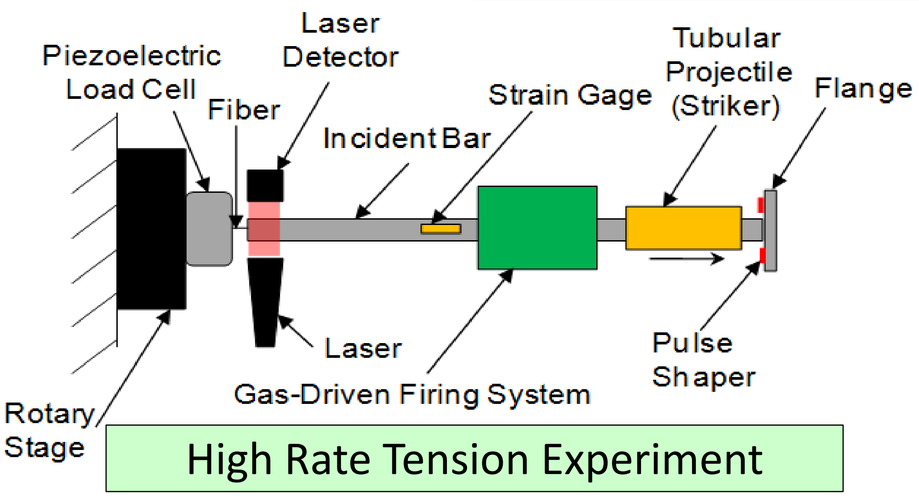
High-Rate Micro Tensile Experimentation



Post-Failure Recoil



High-Rate Micro Compression



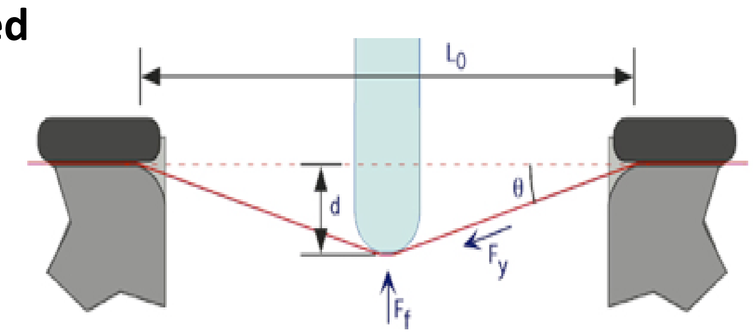
High Rate Tension Experiment

Challenges

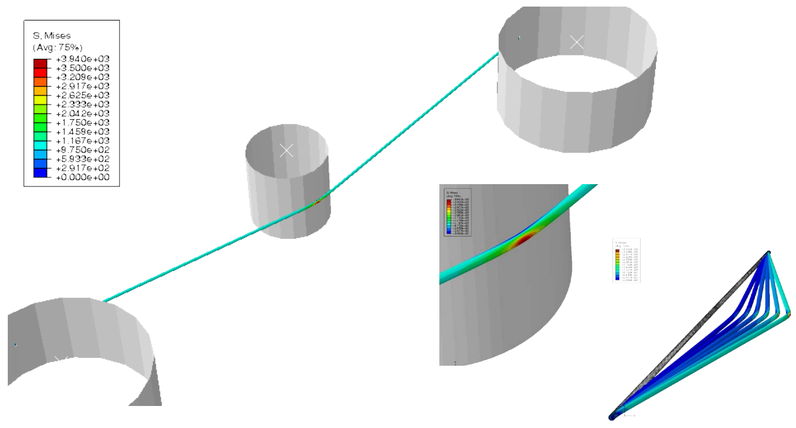
- **Experimental methods to subject single fibers to both axial tension and transverse compression do not exist**
- ***Combined loading* must be modeled to extract material behavior**
- ***Dynamic* transverse *compression* of single fibers has not been studied**
- ***Failure process* of single fibers is not well understood**

ARL Facilities and Capabilities Available to Support Collaborative Research

- **ARL has the ability to conduct tensile experiments on PPTA [1] and UHMWPE [2] single fibers from low to high strain rates**
- **Currently developing experimental capabilities to conduct transverse compression of single fibers at high rate**
- **Exploring ways to subject single fibers to both axial tension and transverse compression simultaneously**
- **In situ SAXS/WAXS loading experimentations are being developed**



Schematic of multiaxial loading setup



Initial simulation of mixed mode loading experiment

Complementary Expertise/Facilities/ Capabilities Sought in Collaboration

- **Develop a *constitutive relationship* of the transverse compressive response**
- **Model the *anisotropic* multi-axial behavior of single fibers**
- **Model the macro behavior of fiber-based armor using *micro-mechanistic* relationships from the single fiber scale**
- **Investigate failure mechanisms and the failure processes of single fibers through *in situ* microscopy (AFM, SEM, TEM, SAXS/WAXS)**
- **Micro-mechanistic modeling of fiber substructure – combined crystalline/amorphous regions**
- **Validation of sub-fiber modeling via single fiber response**
- **Synchrotron-based diffraction investigation of failure process to complement SAXS/WAXS studies**

- **[1] B. Sanborn, T. Weerasooriya. Quantifying Damage at Multiple Loading Rates to Kevlar KM2 Fibers Due to Weaving, Finishing, and Pre-Twist. *International Journal of Impact Engineering,* 71:50-59, 2014.**
- **[2] B. Sanborn, A.M. DiLeonardi, T. Weerasooriya. Tensile Properties of Dyneema SK76 Single Fibers at Multiple Loading Rates Using a Direct Gripping Method. *Journal of Dynamic Behavior of Materials*, In Review.**

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