



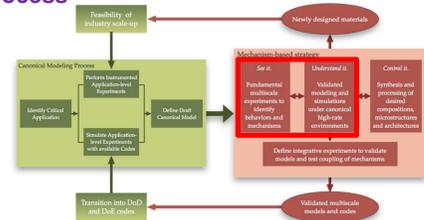
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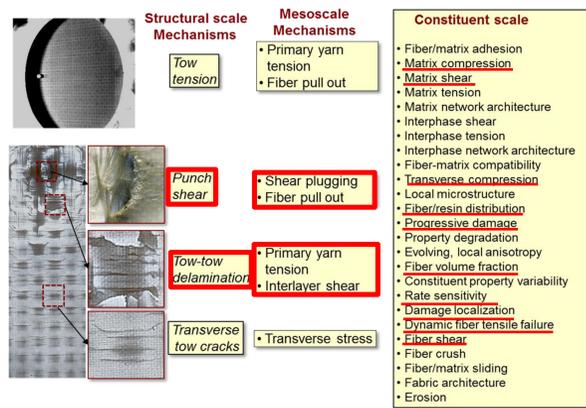
Enterprise for Multi-scale  
Research of Materials

### How We Fit

#### Materials-by-Design Process

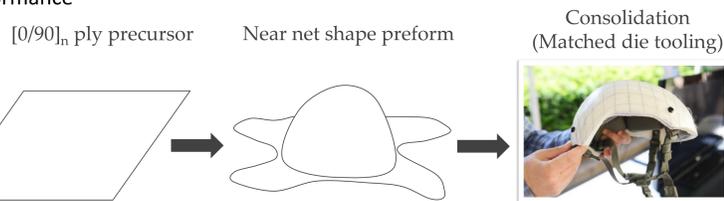


#### Mechanism-based Approach



### Key Goals

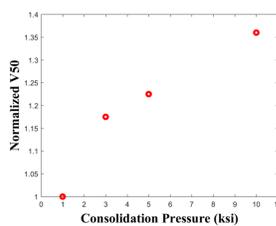
**Background:** Processing induced variations in composite microstructure lead to variability in armor performance



- ❖ Preforming induces local variations in ply thickness and fiber orientation
- ❖ Thickness variations can lead to nonuniform pressure during consolidation
- ❖ This leads to variations in microstructure throughout the finished item

#### As a consequence this research seeks to:

- ❖ Understand how microstructure affects failure mechanisms and damage evolution in UHMWPE composites under dynamic loading
- ❖ Develop a model to couple the work ARL and NSRDEC is undertaking on process modeling with the work being done within the CMRG on ballistic modelling of composites



V<sub>50</sub> of Dyneema® HB80 as a function of consolidation pressure.

### Technical Approach

#### Material:

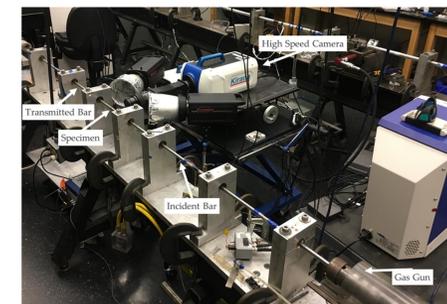
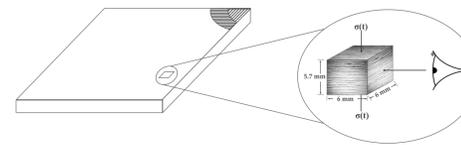
- ❖ Dyneema HB80 is processed at varying consolidation pressures
- ❖ Samples are sectioned into cubed specimens
- ❖ One side is polished for optical imaging

#### Experiment:

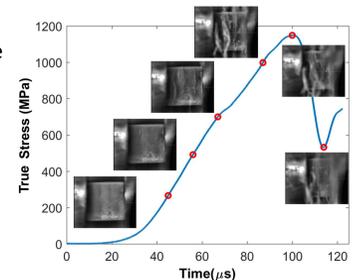
- ❖ Samples are tested in a Kolsky bar in out-of-plane-compression
- ❖ Cross-section is imaged at 1M fps to track damage evolution in-situ

#### Future Work:

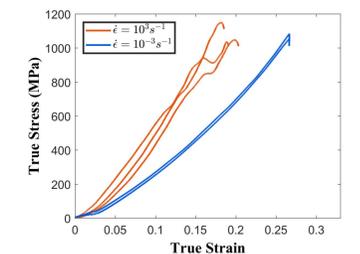
- ❖ Characterize microstructure with Micro CT
- ❖ Strain recovery to determine microstructure evolution
- ❖ DIC to view strain localizations
- ❖ High Strain-rate interlaminar shear experiment



True stress vs. time plot along with selected images from the high speed video. Strain-rate was on the order of  $10^3 \text{ s}^{-1}$ . At a stress of 700 MPa, fibers are extruded from the specimen and there is a reduction in hardening. At 1.15 GPa an entire ply ruptures, it can be seen exiting the specimen at 117  $\mu\text{s}$ .

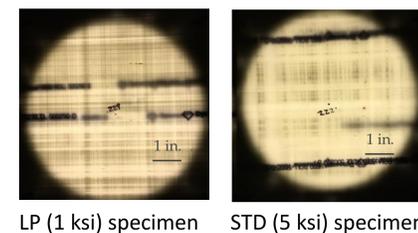


True Stress-strain curves for specimens from STD sample loaded dynamically in CKB and quasi-statically. Specimens loaded at both strain-rates displayed similar strength, however modulus was higher and strain-to-failure was lower in the specimens tested at high strain-rate. This is likely do to the strain-rate sensitivity of the matrix, UHMWPE fibers have been shown to exhibit little strain-rate dependence [1], while polyurethanes (matrix) display significant strain rate sensitivity [2].

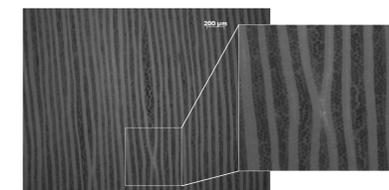


### Major Results

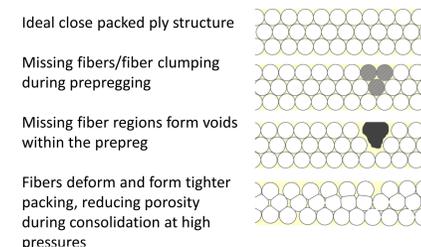
**Microstructure:** Backlit images of the LP (1 ksi) and STD (5 ksi) specimens. The opaque regions are from light attenuation caused by the presence of elongated voids. These voids are from missing fibers. Some of these voids have been consolidated in the STD sample.



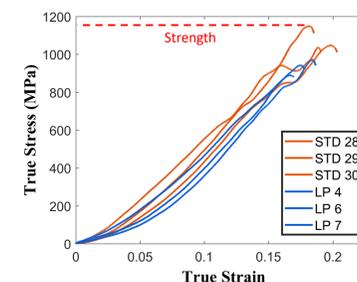
Optical micrograph of a STD (5 ksi) specimen imaged at 10x magnification. There is a ply in which the fibers clumped together during the prepregging operation leading to a region next to it in which this ply is missing fibers. The void has been consolidated from the high consolidation pressure.



Missing fibers during prepregging can lead to voids within the prepreg. During consolidation at high pressures fibers are transversely deformed and packed tighter within the ply. This packing removes many of these voids leading to higher volume fraction of fibers being uniformly loaded during out-of-plane compression.



**Test results:** True stress vs. true strain plot comparing the STD (5ksi) specimens and LP (1 ksi) specimens. Strain-rate was on the order of  $10^3 \text{ s}^{-1}$ . There is variation in strength among the various specimens. The dynamic strength of all of the STD specimens are greater than those of the LP specimens.



### Key Accomplishments

- ❖ First in-situ observation of damage evolution in UHMWPE composites during dynamic out-of-plane compressive loading

### Transitions to ARL, within CMRG and to other CMRGs

- ❖ Development of imaging techniques which CMRG can utilize
- ❖ ARL is transitioning expertise on microstructure characterization
- ❖ Development of a model the Army (NSRDEC and ARL) can utilize to link processing to performance of UHMWPE composites

### Impact

This work has the potential to couple work ARL and NSRDEC is undertaking on process modeling with the work being done within the CMRG on ballistic modelling of composites. This will allow the Army to optimize the processing of protective items and ultimately reduce the weight burden to the Soldier and law enforcement personnel.

### Acknowledgements

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- ❖ DoD SMART scholarship for service program
- ❖ U.S. Army Research Laboratory (Travis Bogetti, Daniel O'Brien, Jason Cain, and Jennifer Sietins)

#### References:

- [1] Russell, B. P., et al. "The high strain rate response of ultra high molecular-weight polyethylene: from fibre to laminate." *International Journal of Impact Engineering* 60 (2013): 1-9.
- [2] Sarva, Sai S., et al. "Stress-strain behavior of a polyurea and a polyurethane from low to high strain rates." *Polymer* 48.8 (2007): 2208-2213.

