U.S. ARMY RDECOM

Micromechanical Modeling of Progressive Punch-Shear Behavior of Unidirectional Composites

ARL

Enterprise for Multi-scale Research of Materials

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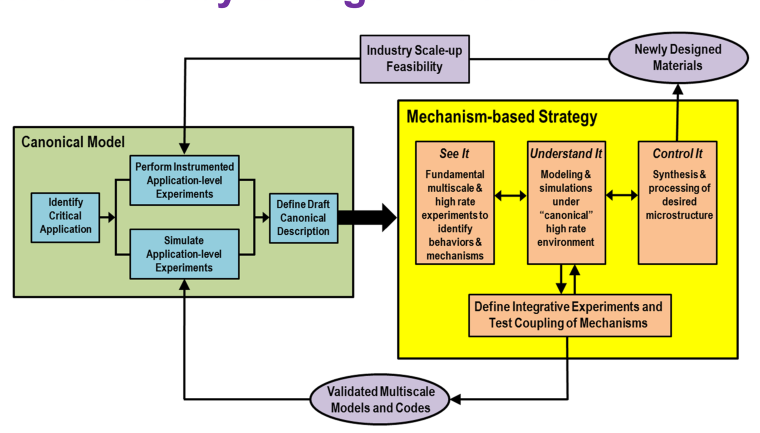
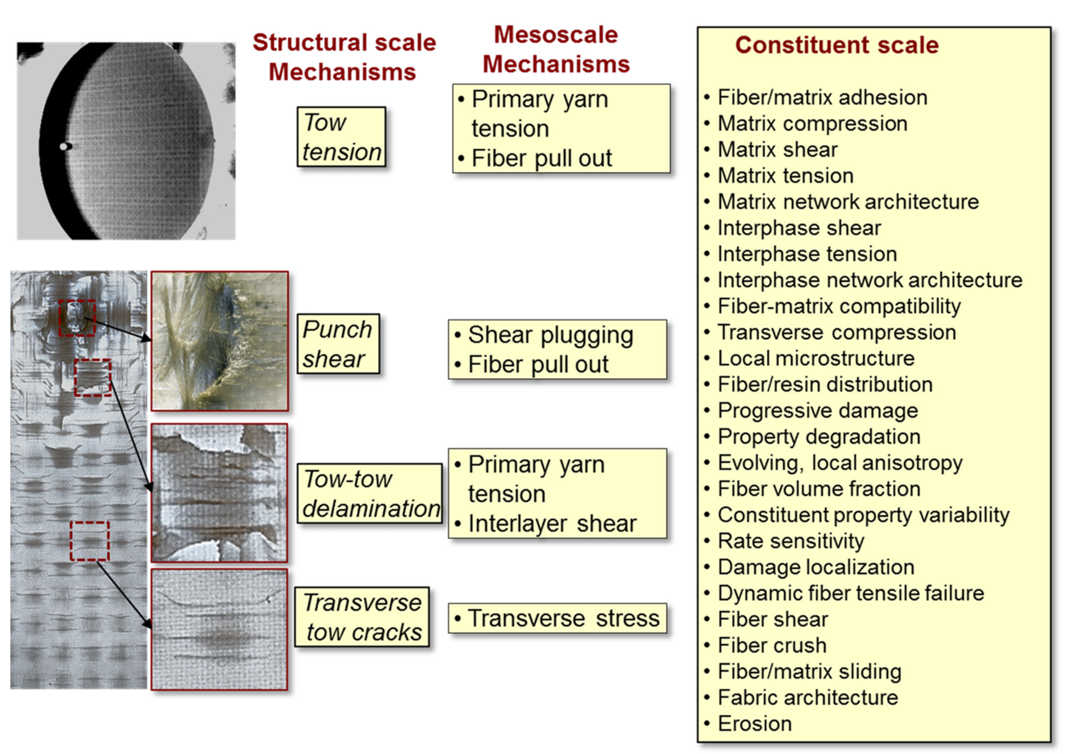
How We Fit

Materials-by-Design Process



Mechanism-based Approach



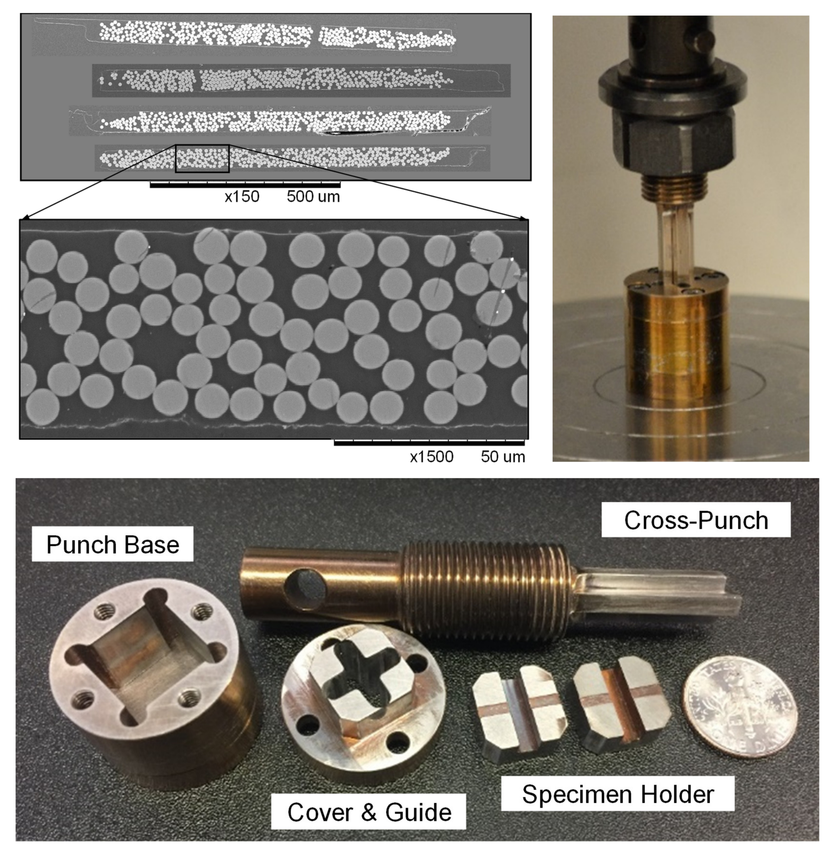
- ❑ Conducting high rate punch shear experiments to understand the energy dissipating damage mechanisms as a function of rate of loading
- ❑ Developing micro-scale punch shear models to understand the evolution of damage mechanisms leading to model based prediction of material properties
- ❑ Structural scale punch shear damage mechanisms
- ❑ Meso-scale fracture of fiber bundles, fragment lengths, & transverse tow cracks
- ❑ Micro-scale fiber fracture, interface debonding, and matrix cracking

Technical Approach

- ❖ Micromechanical modeling of Punch Shear & Crush considering each Fibers, Fiber-Fracture, F-M Debonding, & Matrix Plasticity
- ❖ Prediction of MAT162 Input Properties

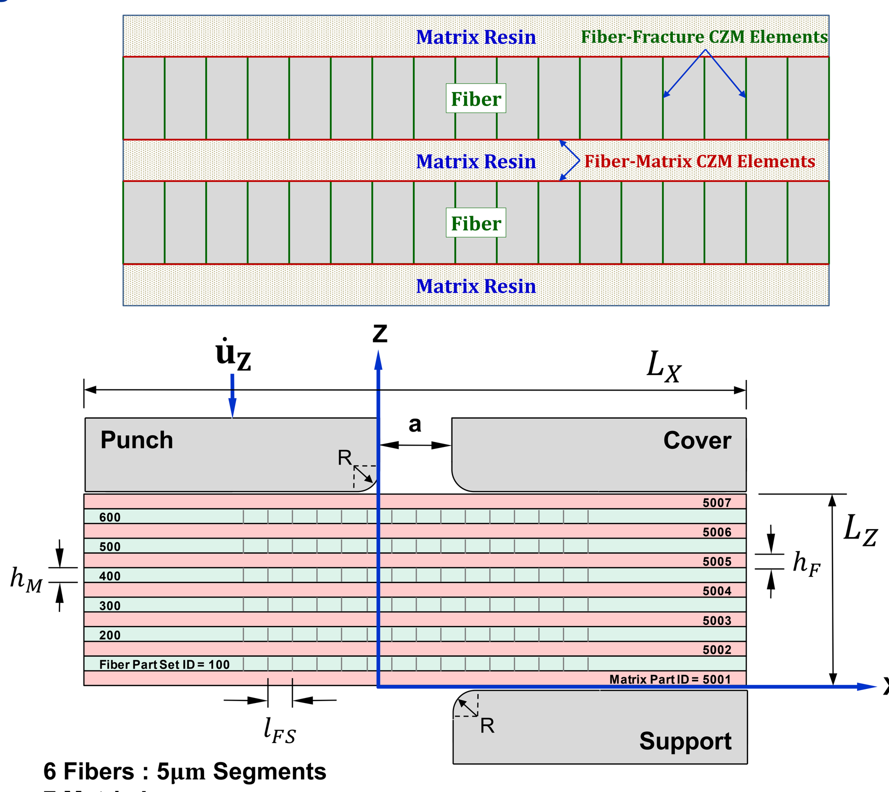
Micro Punch Shear Experimental Methodology

1. Fabricate unidirectional composite ribbons
2. Develop micro punch shear experiments to test the UD composite ribbons
3. Develop data reduction and damage evaluation methodology



Micromechanical Modeling of Micro Punch Shear

1. Develop 2D Finite Element Model of Micro Punch Shear Experiments Modeling Each Fiber of the UD ribbon
2. Use Cohesive Elements for Fiber-Fracture with Bi-Modal Weibull Distribution & Fiber-Matrix Debonding from Microdroplet Experiments & Simulations
3. Use Elastic-Plastic Matrix Deformation form Experiments

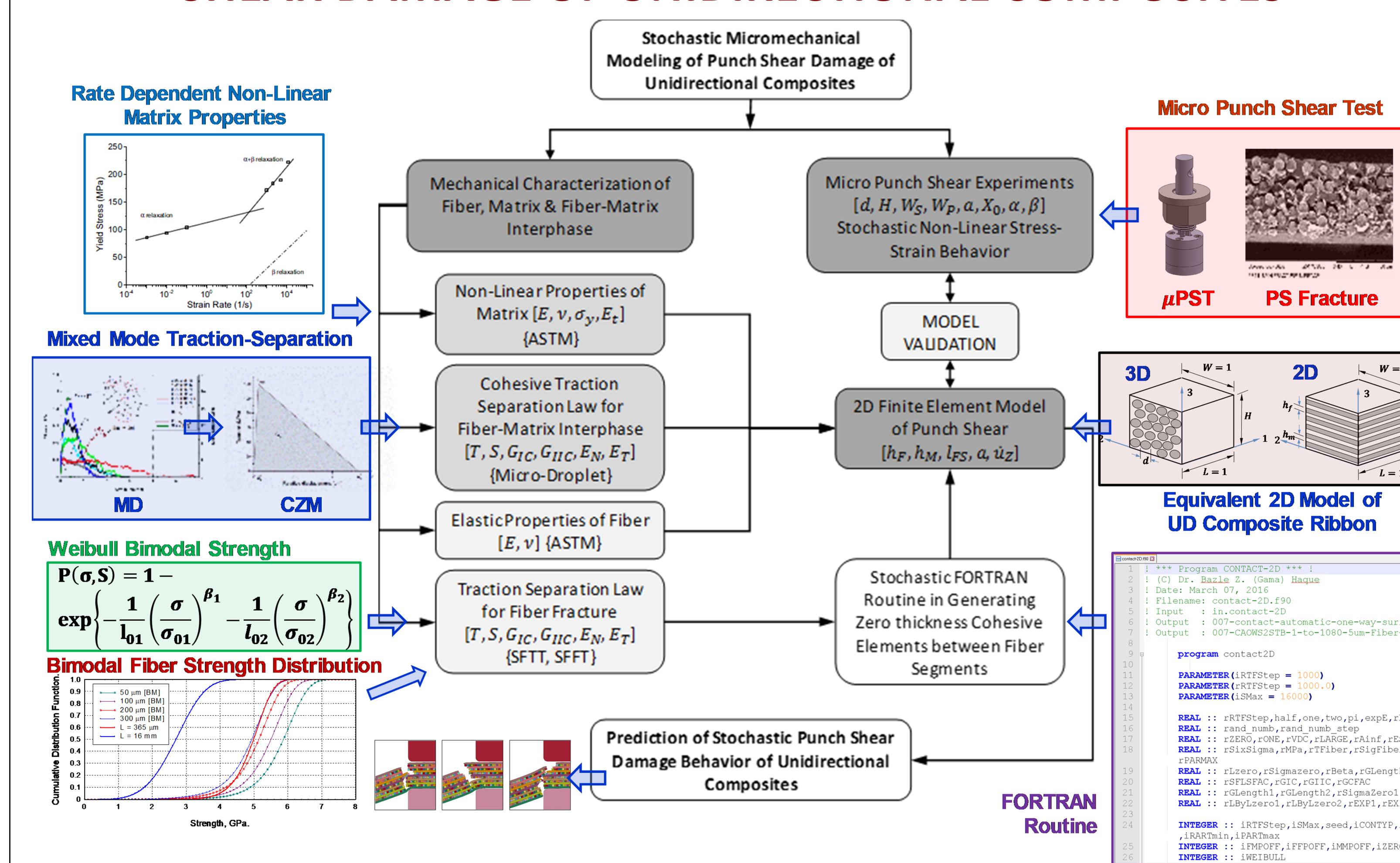


6 Fibers : 5μm Segments
7 Matrix Layers
Mesh Size : 1μm × 0.50μm
$L_X \times LZ$ = 360μm × 65μm
$h_M = h_F$ = 5 μm
Punch Radius, R = 10 μm
Annulus Width, a = 150 μm
Disp. Rate, $\dot{u}_Z = 1\ \mu m/\mu s$

Total No. of Nodes = 301k
Total No. of Solid Elements = 129k
Total No. of Fiber Segments = 1080
No. of Processors = 60
Total Solution Time = 100 μs
Total Computational Time = 22 hours

Key Accomplishments

STOCHASTIC MICROMECHANICAL MODELING OF PUNCH SHEAR DAMAGE OF UNIDIRECTIONAL COMPOSITES

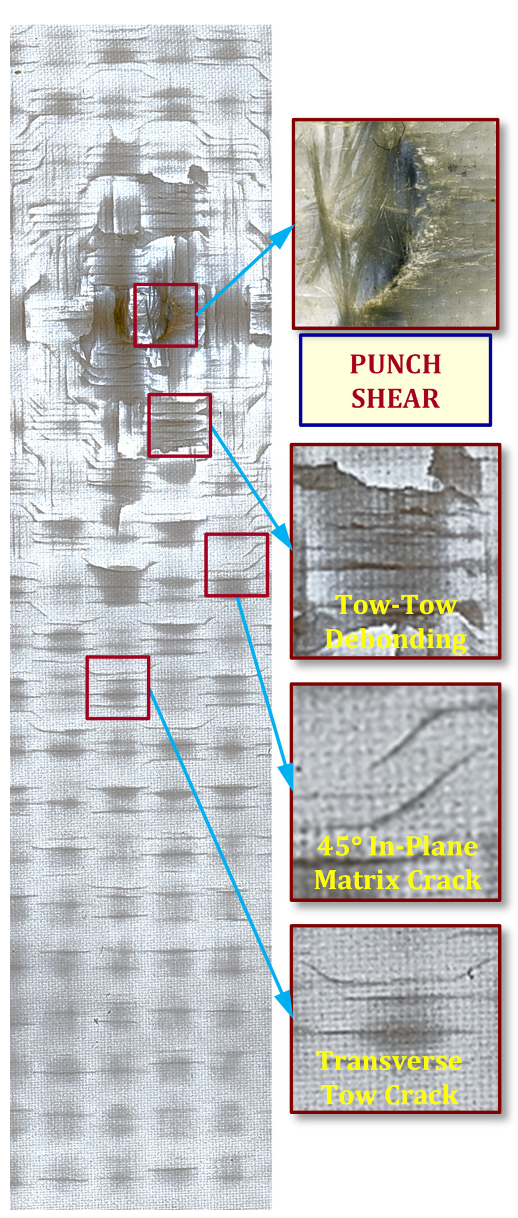


Transition to ARL, within CMRG and to other CMRGs

Following Items are Ready to be Transitioned to ARL:

- ❑ The Micro Punch Shear Experimental Methodology
- ❑ The 2D Finite Element LS-DYNA Model of Micro Punch Shear Test
- ❑ LS-DYNA Keyword Programs in Building the Array of Fiber Segments
- ❑ FORTRAN Code to Generate Zero Thickness Tie Break Cohesive Surfaces for the Array of Fiber Segments
- ❑ The 3D Finite Element LS-DYNA Model of UD Composite Ribbon

Key Goals



LONG TERM RESEARCH GOALS

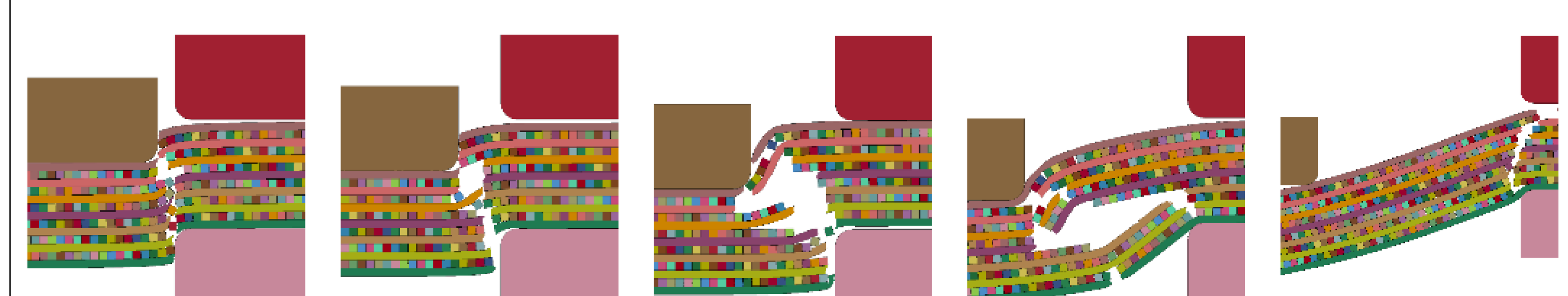
- ❑ Predict the PUNCH SHEAR Damage Mechanisms of Uni-Directional Composites found in ARL Canonical Perforation Experiments
- ❑ Micro-Mechanical Mechanisms of Progressive Punch Shear Damage
  - ❑ Tension-Shear Fiber Fracture
  - ❑ Mixed-Mode Debonding of Fiber-Matrix Interphase
  - ❑ Large Non-Linear Deformation of Matrix Resin
- ❑ Predict MAT162 Punch-Shear Parameters Capturing all Micro-Mechanical Damage Modes described above
  - ❑ Under Dynamic Loading Conditions using Developed Direct-Impact Punch-Shear Tests (DI-PST)

IMPORTANCE & SCIENCE OBJECTIVES

- ❑ ARL-CDM-UMAT in LS-DYNA uses PUNCH-SHEAR & PUNCH-CRUSH Strengths, which are experimentally Determined
- ❑ Micro-Mechanical Modeling of PUNCH-SHEAR Experiments with Individual Fibers, Matrix, and Fiber-Matrix Interphase will provide
  - ❑ Fundamental Understanding of PUNCH-SHEAR Damage Mechanisms

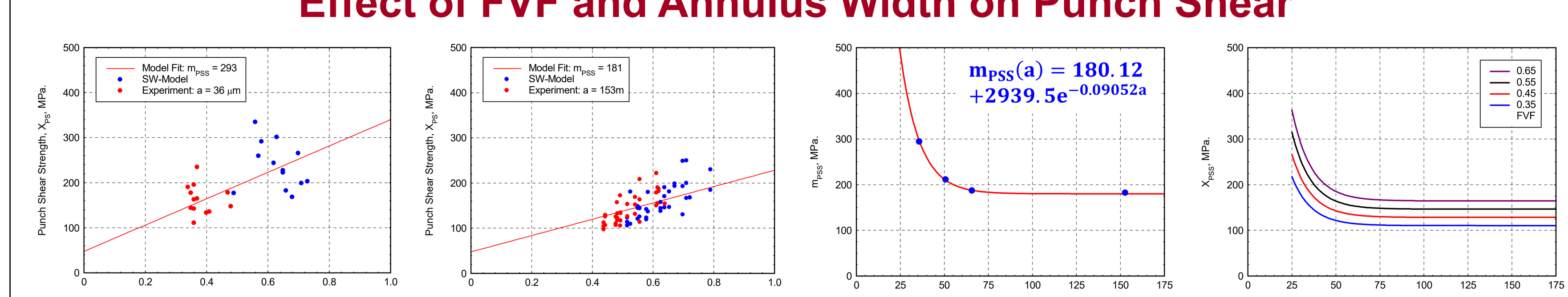
Major Results

EFFECT OF ANNULUS WIDTH ON PUNCH SHEAR

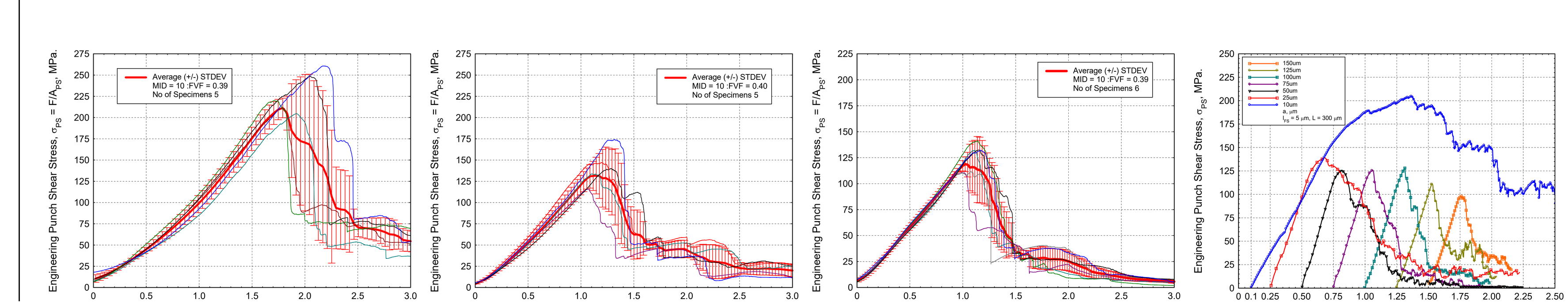


a = 10μm 25μm 50μm 100μm 150μm

Effect of FVF and Annulus Width on Punch Shear



XPS vs FVF (a = 33μm) | XPS vs FVF (a = 153μm) | m vs a | $X_{PS} = X_M + v_f[180.12 + 2939.5e^{-0.09052a}]$



EXPT: Stress-Strain (a = 35μm) | Stress-Strain (a = 51μm) | Stress-Strain (a = 66μm) | SIMULATION: Stress-Strain

Impact

This Project will:

- ➢ Provide fundamental understanding of punch-shear and punch-crush damage mechanisms under dynamic loading conditions
- ➢ Predict the MAT162/ARL-CDM-UMAT punch-shear/crush modeling parameters (SFS, AM2, AM4, C1, C3, EEXPN, SFC, ECRSH)
- ➢ Direct impact punch-shear and crush experiments at mm-length scale will provide model-validating rate-dependent data
- ➢ Predict computational damage surfaces under HSR multi-axial dynamic loading conditions for which experiments are difficult
- ➢ Properties predicted at micromechanical length scale can then be used to model continuum damage mechanics models.

CMEDE CENTER FOR MATERIALS IN EXTREME DYNAMIC ENVIRONMENTS

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