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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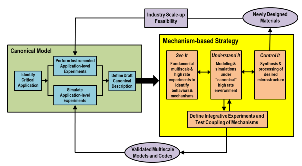
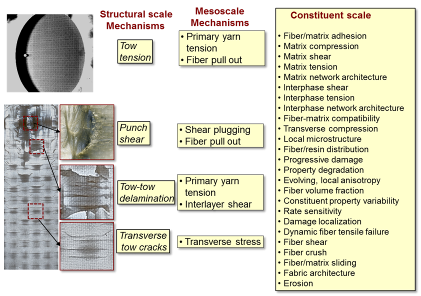
How We Fit

Materials-by-Design Process



- 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

Mechanism-based Approach



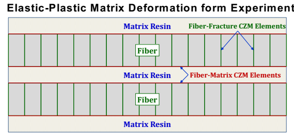
- Structural scale punch shear damage mechanisms
- Meso-scale fracture of fiber bundles, fragment lengths, & transverse tow cracks
- Micro-scale fiber fracture, interface debonding, and matrix cracking

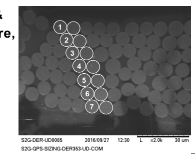
Technical Approach

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

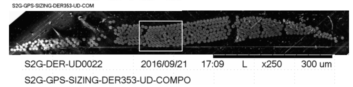
2D FE Model of UD Composites

1. Cohesive Elements for Fiber-Fracture with Weibull Distribution & Fiber-Matrix Debonding from Microdroplet Experiments & Simulations
2. Elastic-Plastic Matrix Deformation form Experiments



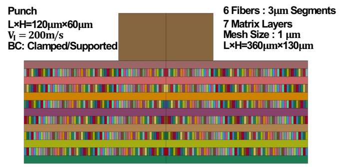


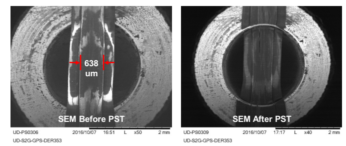
Unidirectional Single Tow Composite
S-2 Glass GPS Fibers
DER 353 Epoxy Resin
Width = 600~800 um
Thickness = 95 um
Total 407 Fibers
7 Fibers Through-Thickness
100 Fibers Across Width



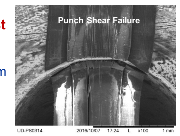
Dynamic Punch-Shear & Crush Loading

1. Understand the Fundamental Physics of Punch-Shear and Crush Damage Mechanisms
2. Design Punch Shear Experiments by Simulations





Micro Punch Shear Test
Tow Width = 638 um
Tow Thickness = 95 um
Support Dia – $D_S = 2.60$ mm
Punch Dia – $D_P = 2.58$ mm
Load Cell : 500 N
Load Rate : 0.100 mm/min



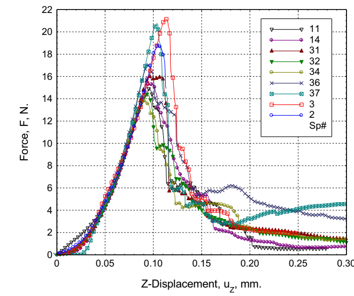
Key Accomplishments

EXPERIMENTS

- Infusion of UD tows with 7 TT fibers into Ribbon
- Quasi-static punch shear testing of UD ribbons
- New concepts for PST Experiments

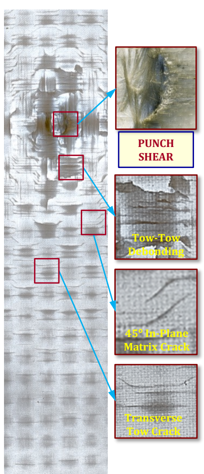
MODELING

- 2D Plain-Strain FEM of 6 Fibers and 7 Resin Blocks with CZM fractures of Fiber-Fiber & Fiber-Matrix Interfaces
- Numerical Simulations of Punch Shear and Punch Crush
- Identification of Key Damage Mechanisms of Punch Shear and Crush



Force-Displacement Plots of Micro Punch Shear Tests Conducted on S-2 Glass/DER353 Epoxy UD Composite Ribbon Specimens

Key Goals



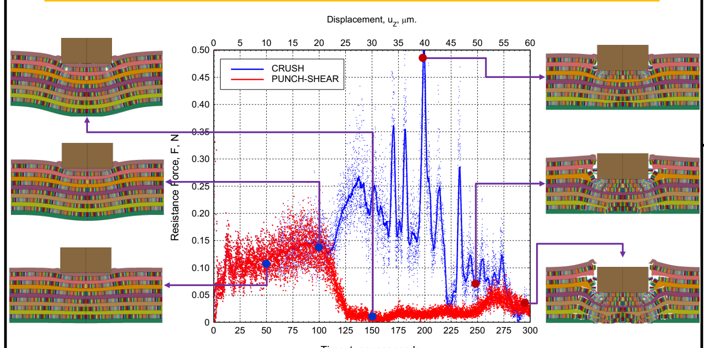
LONG TERM RESEARCH GOALS

- 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 Developed Direct-Impact Punch-Shear Tests (DI-PSDamage 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

Micromechanical Modeling of 2D Punch-SHEAR & Punch-CRUSH



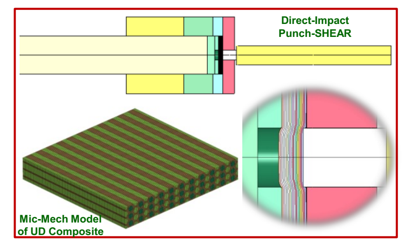
PUNCH-SHEAR

- Punch shear damage occurs in a shear-cone under the punch
- Transverse fiber fracture occurs under mixed mode loading
- Peak punch force occurs before any visible crack opening

PUNCH-CRUSH

- Identical punch shear damage occurs before the punch crush damage
- Transverse fiber fracture leads to fiber crush with large deformation around the punch periphery
- Debonding and pull out mechanisms appear at large deformation

Future Directions in 2017



- Dynamic punch shear experiments will be conducted on UD ribbon specimens
- 3D solid model with CZM fiber fracture and fiber-matrix debonding will be developed to study the 3D damage mechanism under high strain rate loading

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.

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