U.S. ARMY RDECOM® ARL

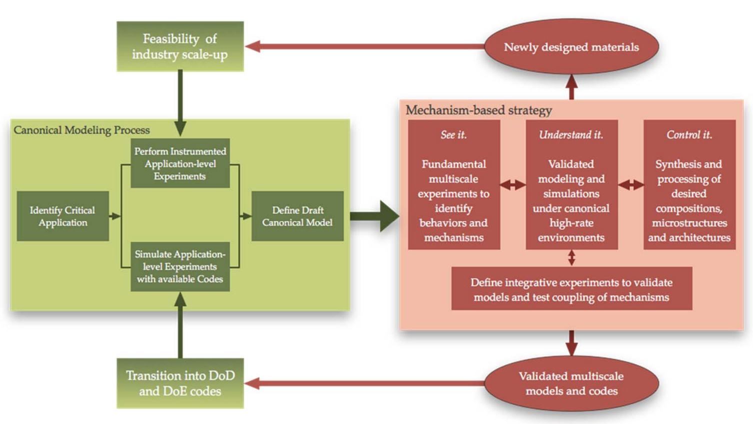
Meso-Mechanical Modeling of Canonical Perforation Experiments

Christopher S. Meyer (UD/CCM, ARL), Bazle Z. (Gama) Haque (UD/CCM), John W. Gillespie, Jr. (UD/CCM), Daniel J. O'Brien (ARL), Bradley D. Lawrence (ARL), Jennifer M. Sietins (ARL), Enoch Bonyi (MSU), Kadir Aslan (MSU)

Enterprise for Multi-scale Research of Materials

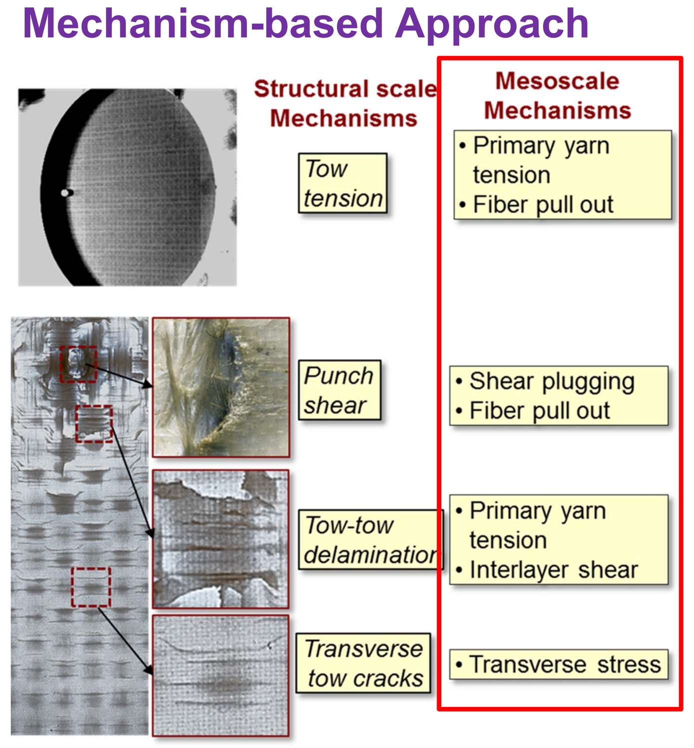
How We Fit

Materials-by-Design Process



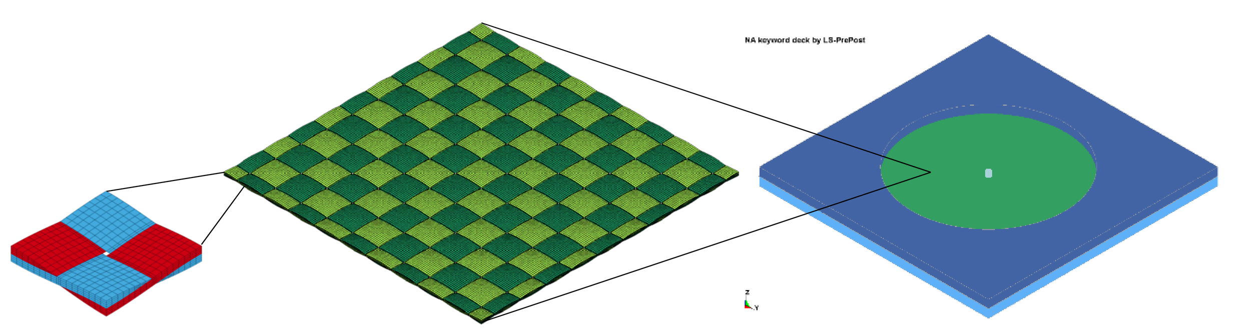
- Experiments to see mesoscale damage mechanisms: matrix cracking, tow-tow debonding, tension-shear tow failure
- Modeling & simulation to understand mesoscale damage mechanisms

Mechanism-based Approach



- Meso-mechanical model to capture mechanisms occurring at mesoscale:
  - Axial wave speed
  - Transverse cone wave speed
  - Transverse tow cracking
  - Tow-matrix and tow-tow debonding
- Model damage and failure modes from understanding of mechanisms

Key Goals



Collaboration:

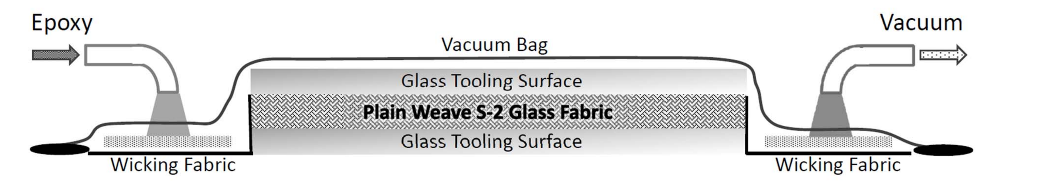
- Experiments (tension, compression, punch-shear, impact): ARL, UD/CCM
- Damage mapping, characterization, visualization: MSU, ARL, UD/CCM
- Microscale modeling and material/constitutive inputs: JHU, UD/CCM

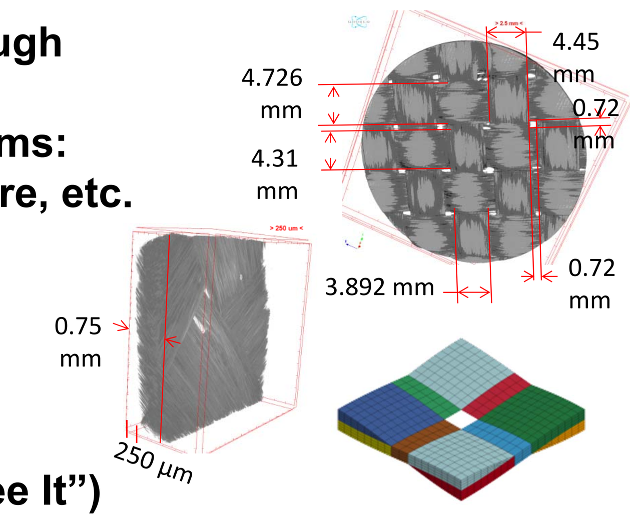
Meso-mechanical modeling:

- Tensile and punch-shear damage modes and energy dissipation as model input and validation
- Characterize elastic wave propagation and effect on mesoscale damage modes and energy dissipation
- Build and validate mesoscale model to predict energy dissipation and damage:
  - Tension (e.g., matrix cracking)
  - Punch-shear (e.g., punch-shear damage mode)
  - Tow pull-out (e.g., traction-separation, tow-tow debonding)
  - Impact (e.g., elastic wave propagation, back-face deflection, perforation)
- In materials-by-design framework, use model to evaluate novel composite material systems and lead to enhanced soldier protection and lethality

Technical Approach

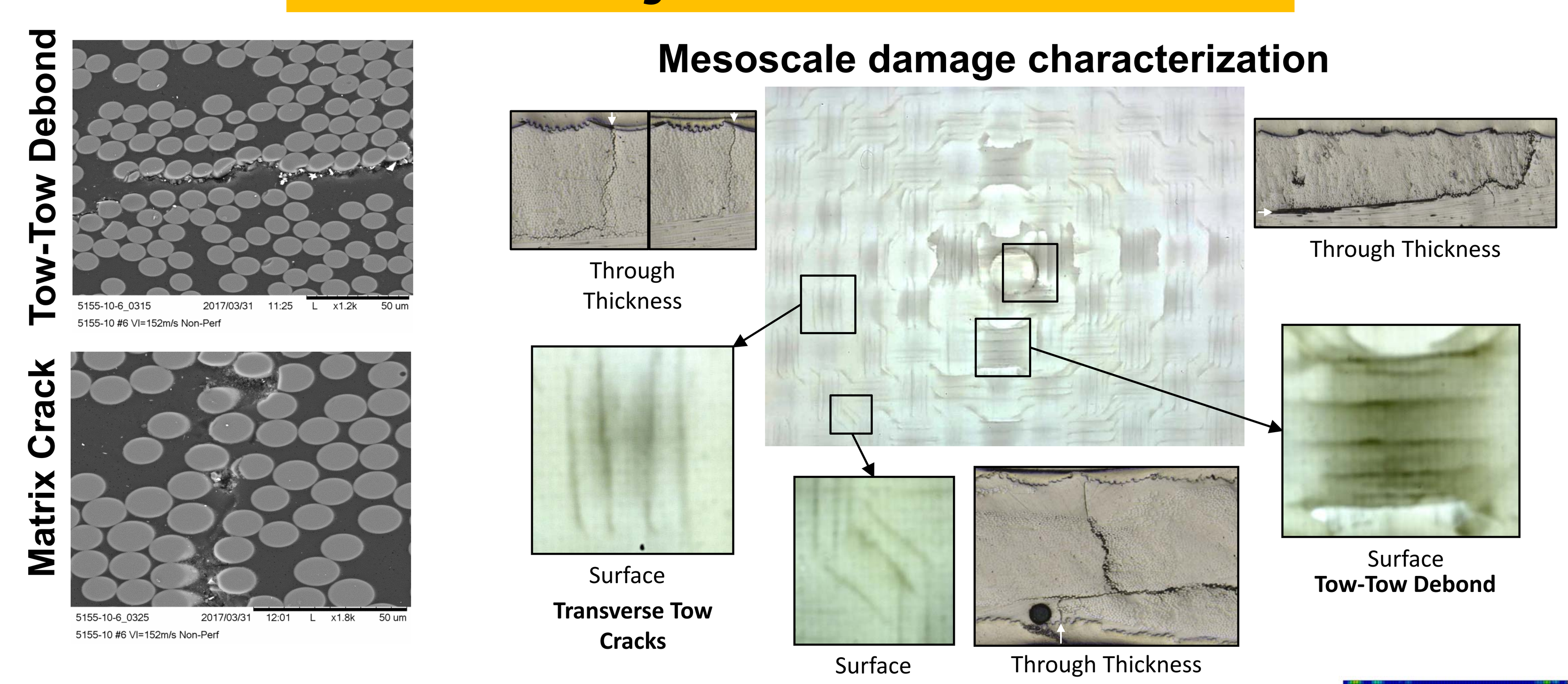
- Macroscopic damage modes dissipate energy through
  - Elastic strain energy (wave motion, vibration)
  - Meso-I and micro-mechanical damage mechanisms:
    - Matrix cracking, debonding, tensile fiber fracture, etc.

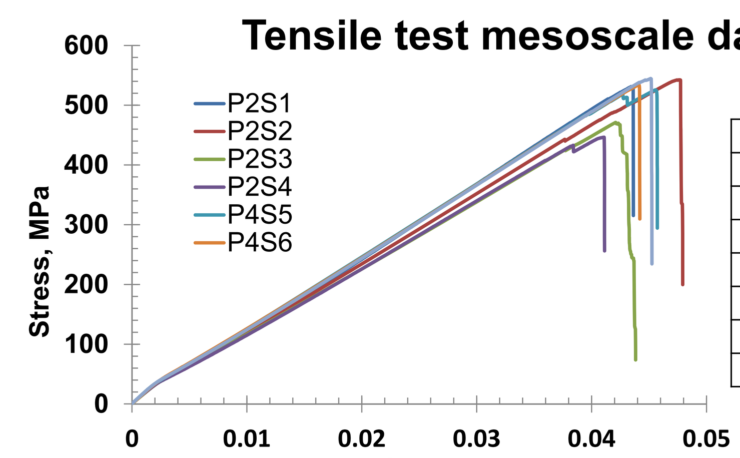




- Isolate mechanisms that lead to damage modes ("See It")
  - Single layer eliminates delamination mode, interlaminar stress field, nesting
  - Focus on perforation phase (eliminate penetration and transition)
  - Isolate and characterize tension and shear damage modes and energy dissipation
  - Characterize elastic wave propagation and effect on mesoscale damage modes and energy dissipation
- Systematically build up complexity of models ("Understand It")
  - Homogenized continuum plain weave properties
  - Meso-mechanical plain weave model geometry with cohesive zone elements bonding constituents

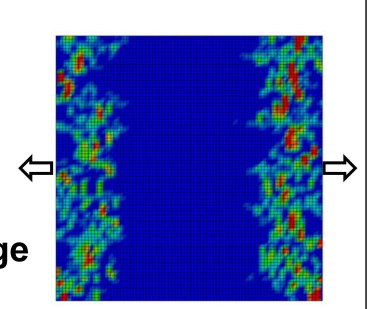
Major Results



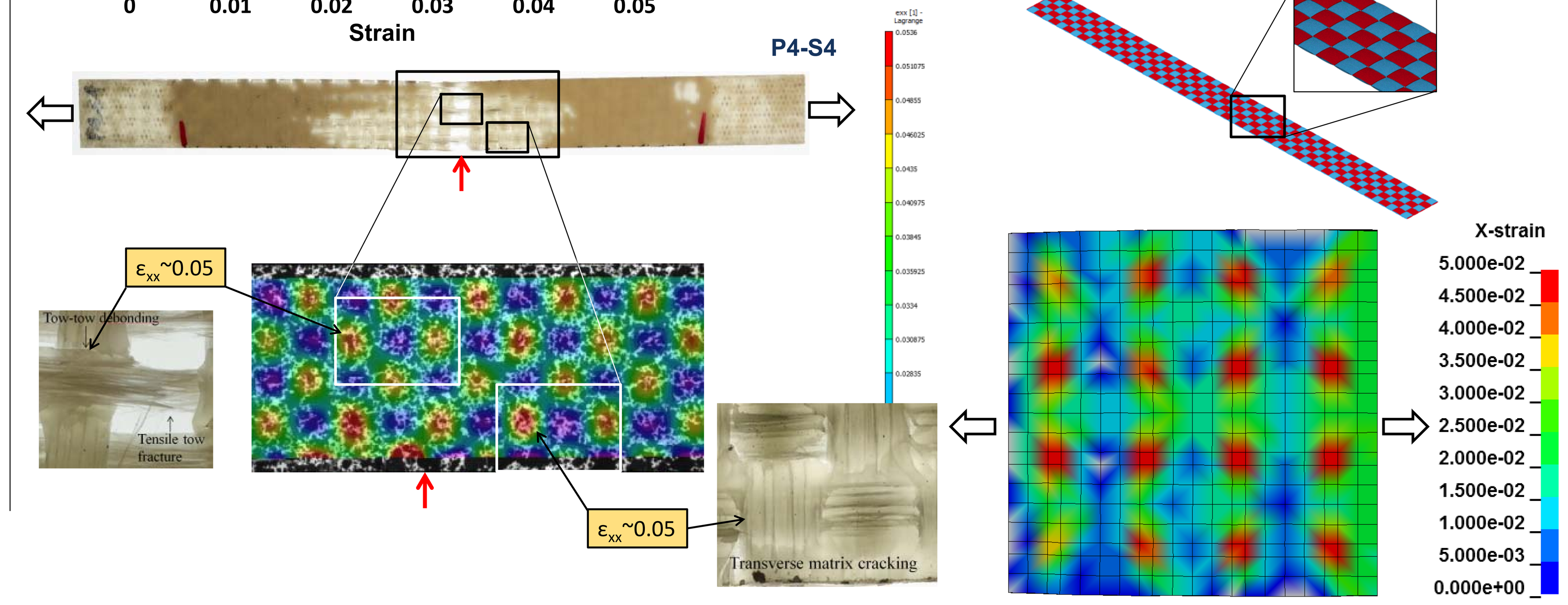


Spcmn	Width (in)	E_1 (GPa)
P2S1	1	12.477
P2S2	3	13.194
P2S3	3	13.650
P2S4	1	13.282
P4S5	2	13.543
P4S6	2	14.720
P4S7	2	13.887

Homogenized continuum model cannot capture mesoscale damage

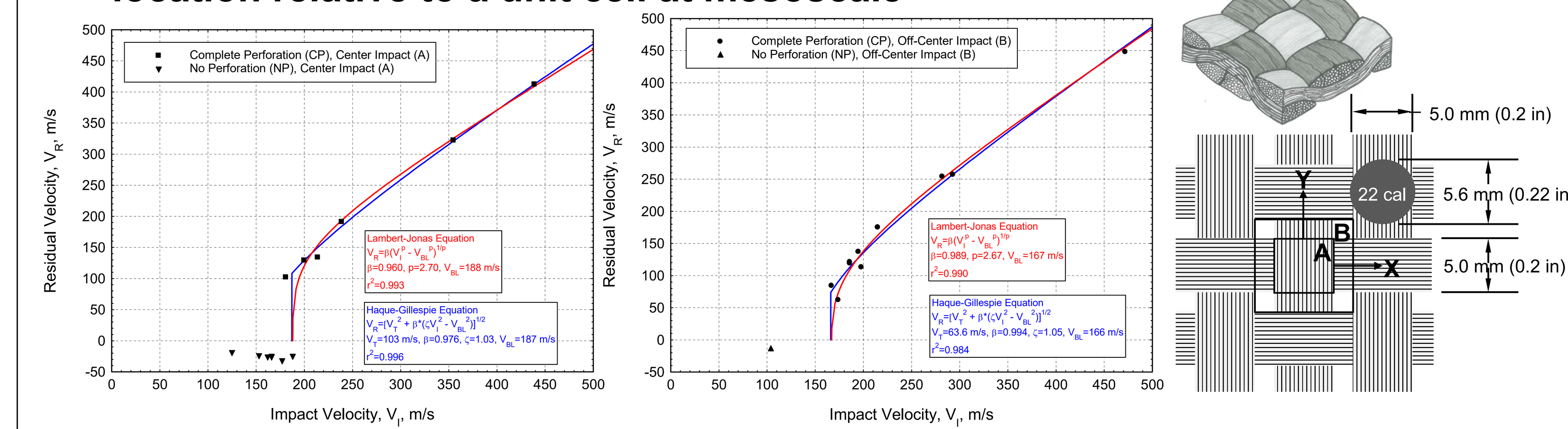


Meso-mechanical model: realistic woven geometry based on CT scans



Key Accomplishments

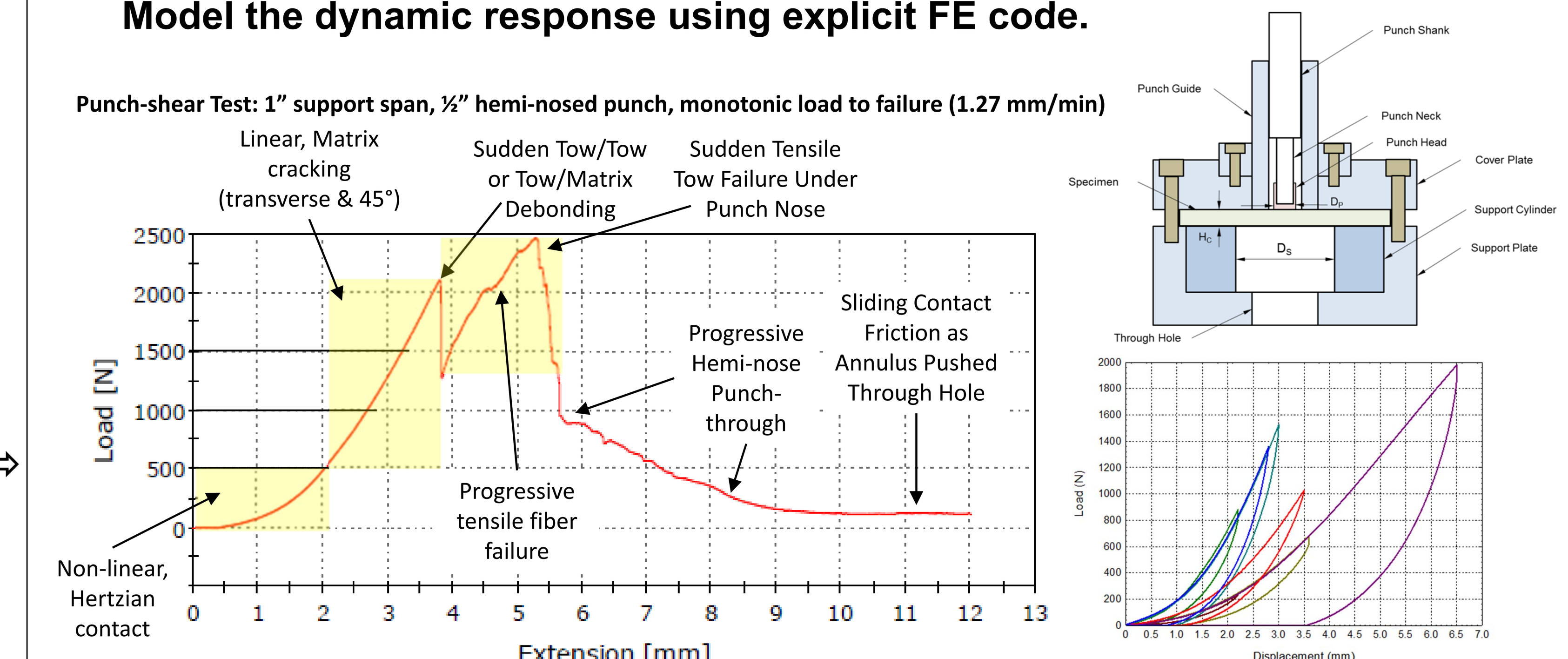
- Demonstrated perforation energy difference depending on impact location relative to a unit cell at mesoscale



- Damage characterization using CT scanning, confocal microscopy, and SEM showed how damage evolves from transverse matrix cracks to tow-tow debonding

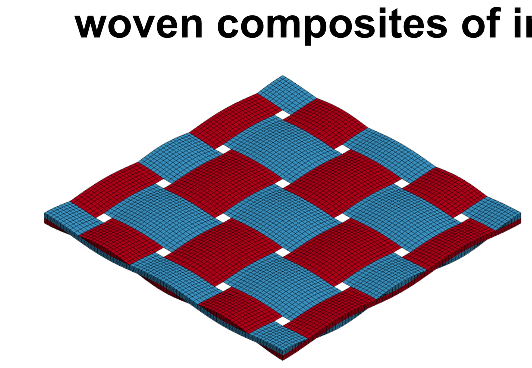
Future Directions in 2018

- Refine model in terms of delamination response and transverse matrix cracking by evaluating/optimizing cohesive zone formulation, bilinear traction-displacement behavior, and predefined fracture planes.
- Conduct tension testing of 1, 2, and 3 inch wide PW tensile specimens, determine quasi-static tensile response of single-layer PW composite and using DIC identify strain levels at which transverse matrix cracks initiate and proliferate. Evaluate model tensile response in explicit FE code.
- Conduct quasi-static punch-shear testing of single-layer PW specimens at load levels increasing to failure to quantify damage and energy dissipation due to transverse punch-shear loading.
- Conduct low velocity impact experiments of single-layer PW specimens. Model the dynamic response using explicit FE code.



Impact

- Validated meso-mechanical plain weave composite model will be applied to woven composites of interest to the Army



- In materials-by-design framework, model will be used to evaluate novel composite material systems in ballistic impact
- Used in developing advanced composite armor systems for personnel and light vehicles, model will lead to enhanced protection for the soldier

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