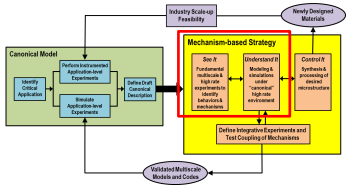
Meso-Mechanical Modeling of Canonical Perforation Experiments

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

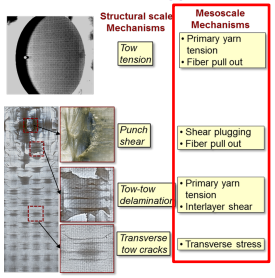
How We Fit

Materials-by-Design Process



- Experiments to see mesoscale damage mechanisms
- Modeling & simulation to understand mesoscale damage mechanisms

Mechanism-based Approach



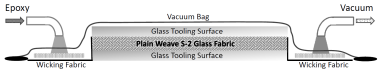
- Meso-mechanical model to capture mechanisms occurring at mesoscale:
  - Axial wave speed
  - Transverse cone wave speed
  - Transverse tow cracking
  - Tow-matrix and tow-tow debonding
- Model damage and failure modes from understanding of mechanisms

Technical Approach

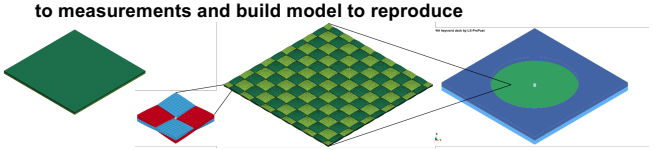
- Macroscopic damage modes dissipate energy through
  - Elastic strain energy (wave motion, vibration)
  - Meso-mechanical and micro-mechanical damage mechanisms

Mesoscale mechanisms pass information up to macoscale damage modes

Meso-Mechanical Damage Mechanisms:	Macroscopic Damage Modes:
Progressive matrix cracking	Crush
Debonding (tow-tow, tow-matrix)	Transverse matrix cracking
Tow fracture	In-plane matrix cracking
Frictional sliding	Tension-shear
	Compression-shear
	Punch-shear
	Delamination



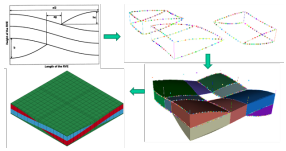
- Isolate mechanisms that lead to damage modes ("See It")
  - Single layer eliminates delamination mode and interlaminar stress field
  - Focus on perforation phase (eliminate penetration and transition)
  - Conduct experiments to isolate damage mechanisms and relate them to measurements and build model to reproduce



- 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

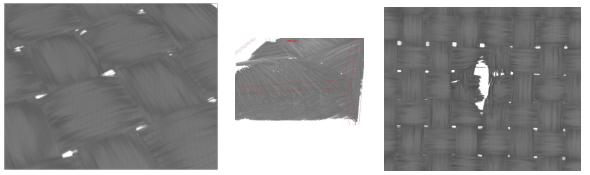
Key Accomplishments

- Meso-mechanical model built, scripted with Cubit for easy geometry and finite element mesh modification (C. Key)

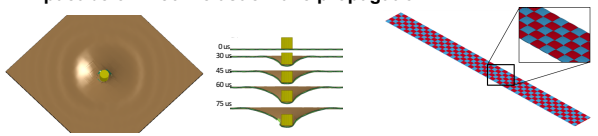


Future Directions in 2017

- CT Scan single layer plain weave composite samples to get accurate geometry and build FEM model to reproduce geometry

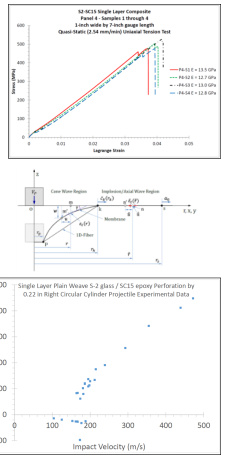


- Model tensile testing – compare load-displacement curve to progressive matrix cracking, tow-two debonding, & tow fracture
- Model punch-shear testing – compare load-displacement curve to quasi-static work of perforation
- Traction-separation behavior of tow-tow bond
- Impact below V50 – elastic wave propagation



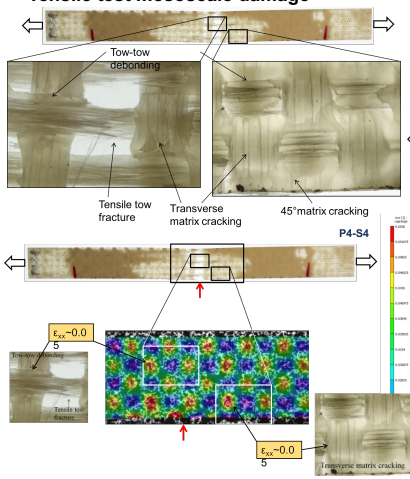
Key Goals

- Develop model with plain weave mesoscale geometry
- Systematically conduct testing and use experimental data to validate model and to refine model to capture
  - Tensile, compression, and punch-shear behavior
    - Load-displacement
    - Mesoscale damage mechanisms:
      - Matrix cracking
      - Tow-tow debonding
      - Tensile tow failure
  - Elastic wave propagation behavior
    - Axial (implosion) and transverse cone wave speeds
    - Back-face deflection
- Use validated model to simulate canonical ballistic penetration experiments and reproduce VI-VR and V50

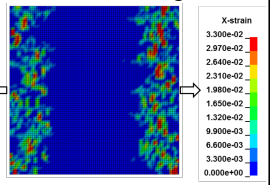


Major Results

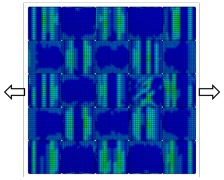
- Tensile test mesoscale damage



- Homogenized continuum model cannot capture mesoscale damage



- Meso-mechanical model



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
- Used in evaluating weapon systems against composite armor will lead to enhanced lethality for soldier

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