# MATERIALS IN EXTREME DYNAMIC ENVIRONMENTS (MEDE) CAPSTONE: MAXIMUM PENETRATION RESISTANCE

University of Delaware | Center for Composite Materials


**Prof. John W. Gillespie, Jr.[1], Dr. Daniel J. O'Brien[2]**
University of Delaware | Center for Composite Materials[1] | DEVCOM Army Research Laboratory[2]


❖ ***Army Relevance***: Application-specific, materials for personnel/vehicle protection. Maximum $V_{50}$ of composite

❖ ***Key Mechanisms***: Penetration: punch-shear, crush and perforation: in-plane tension

❖ ***Materials-by-Design Process***: Meso-scale models identify key energy absorption and failure mechanisms, constituent models used to design matrix/interface for max performance

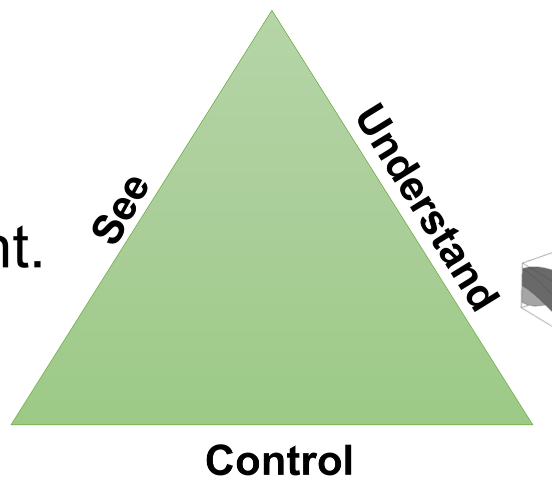
❖ ***New Designer Materials***: High toughness matrix materials through designed network topology; tailored silane interphases

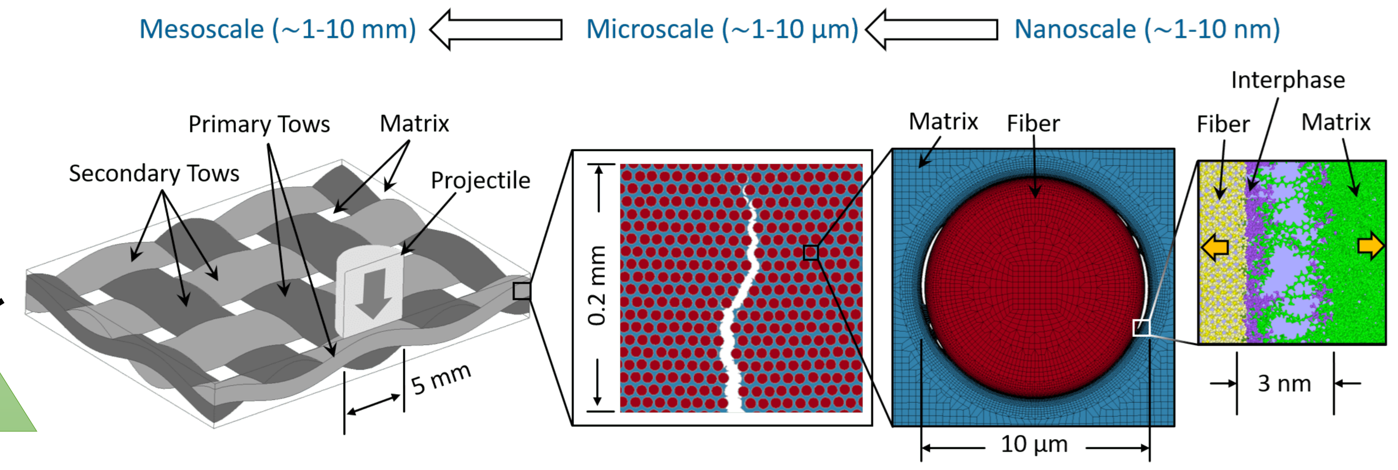
❖ ***Demonstration***: Functionally graded laminate (FGM) designed for penetration punch shear at strike face, max tensile strength at back face

❖ ***Transitions to industry***: +epoxy resins formulations, +scale up of custom sizing

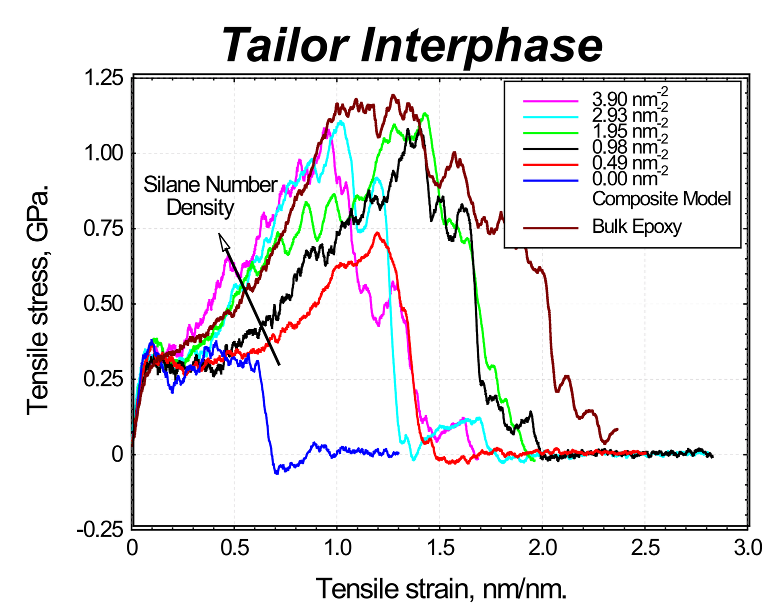
## I. Materials-By-Design

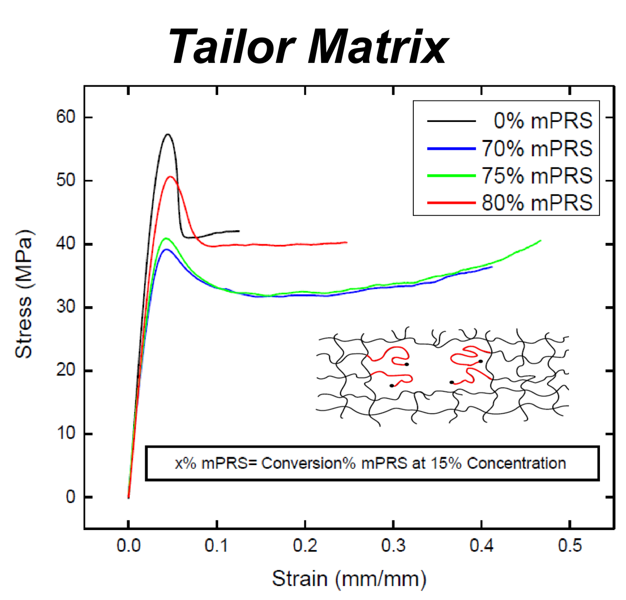
- Mechanism-Based See It- Understand It – Control It Paradigm:
  - **See It:** Observe mechanisms through testing in extreme environment.
  - **Understand It:** Computational models to understand mechanisms
  - **Control It:** Synthesis & Processing to control mechanisms.
- All Working together for targeted design of new materials.



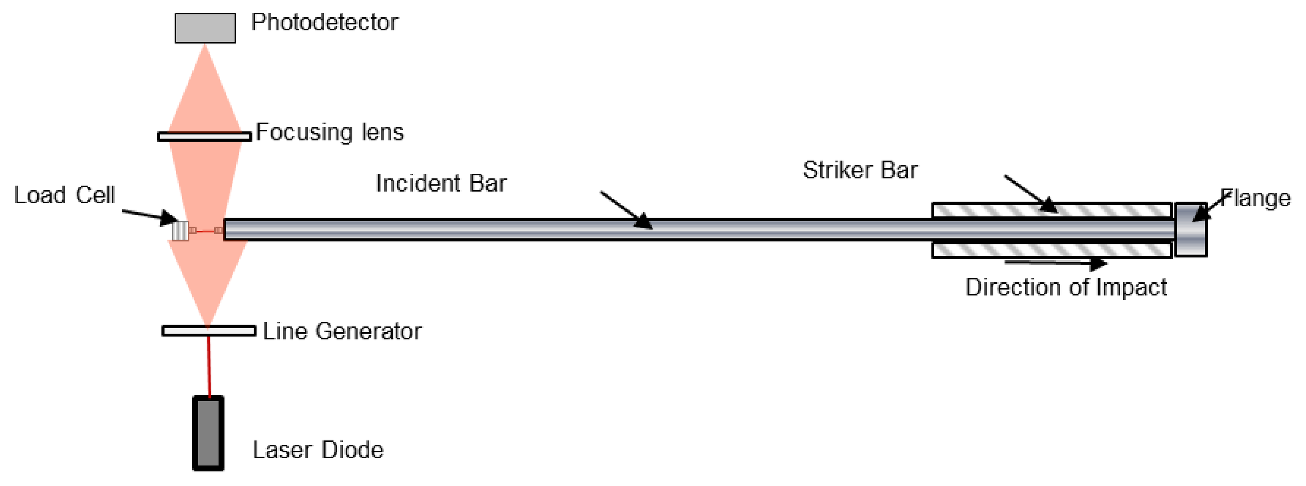




## II. Constituents - Novel Processing / Characterization

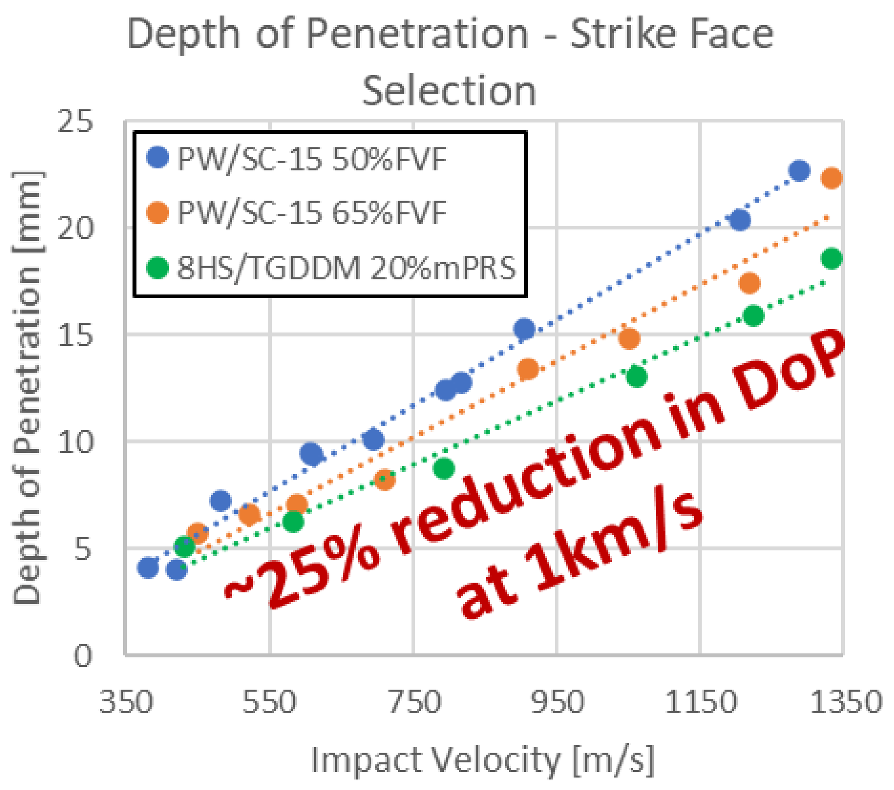



**Process Scale-up**



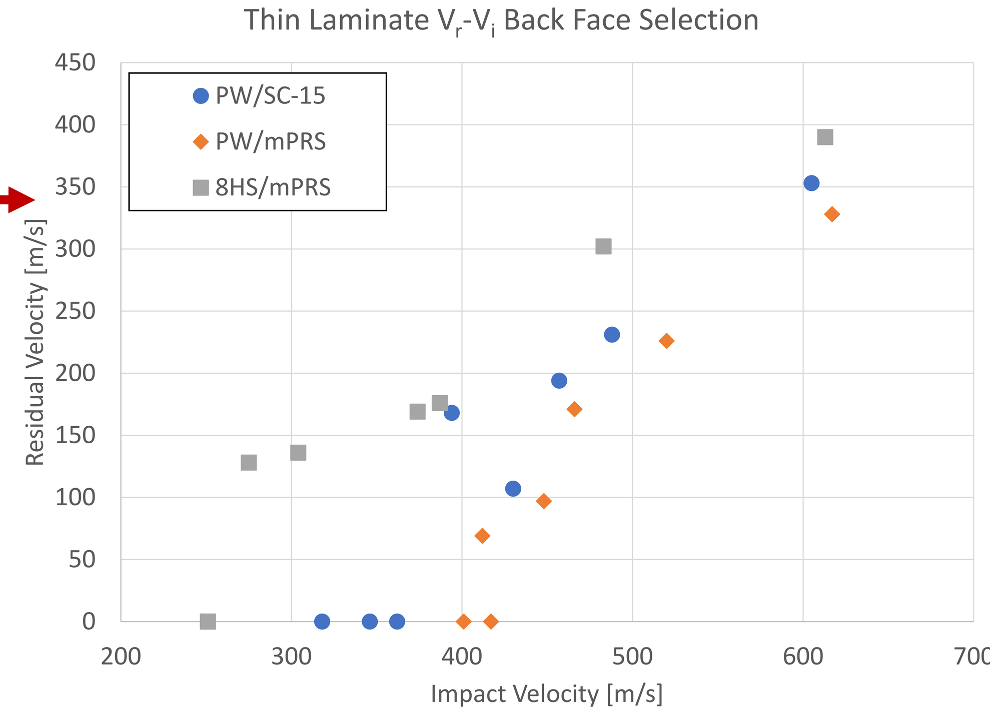

## III. Demonstration - Tailor Laminate Local Architecture For Maximum Performance





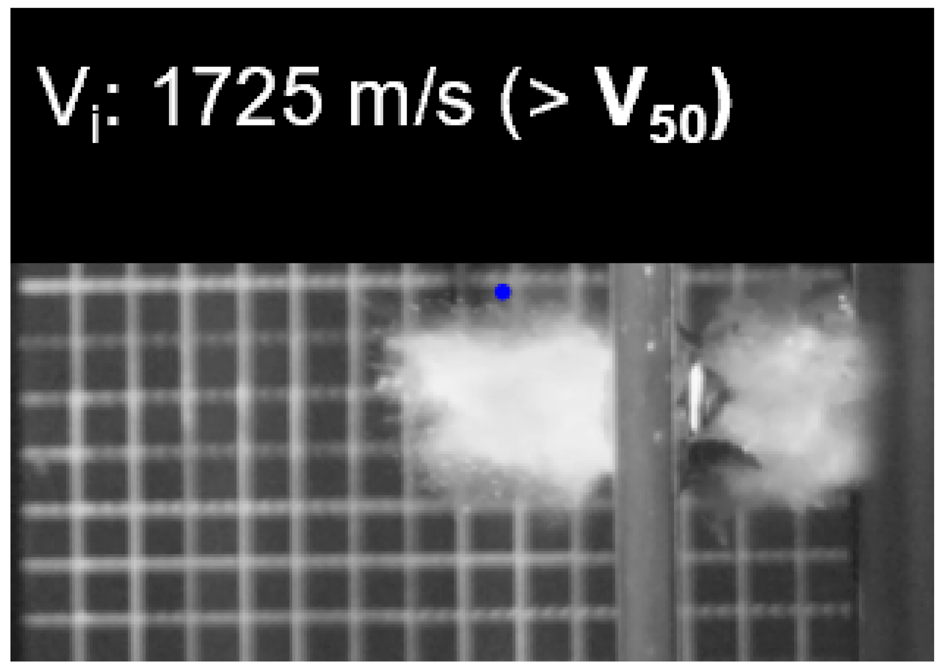
MIN DoP

MIN Perforation

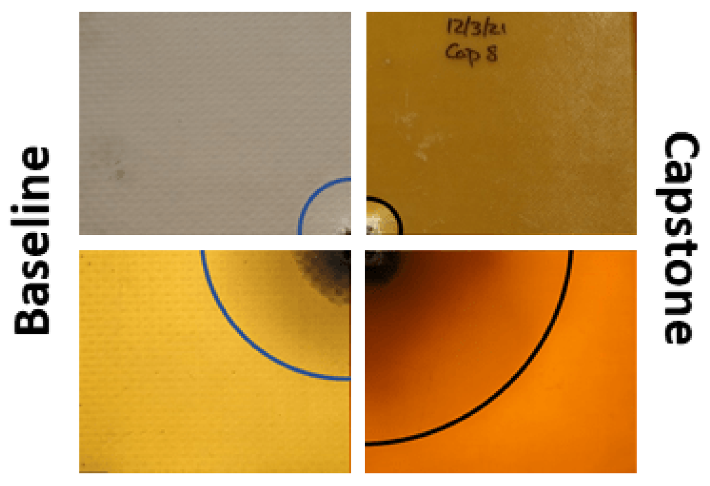



**$V_{50}$ = +16%**
**Energy absorption = +34%**
**Weight = -14%**
**Thickness = -23%**

Capstone Panel: Side View




Strike Face




Back Face

## IV. Transition to Industry: Sizing via CVD batch process of silane on Tows and Fabrics

agy strength in materials

FABRIC DEVELOPMENT INC.

CMEDE CENTER FOR MATERIALS IN EXTREME DYNAMIC ENVIRONMENTS

U.S. ARMY

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❖***Army Relevance***: Application-specific, materials design for personnel/vehicle protection. Multi-hit/durability of laminated armors

❖***Key Mechanisms***: Transverse shear Delamination: interlaminar shear

❖***Materials-by-Design Process***: Laminate analysis to limit interlayer shear stress; minimize ply-level progressive damage across length scales

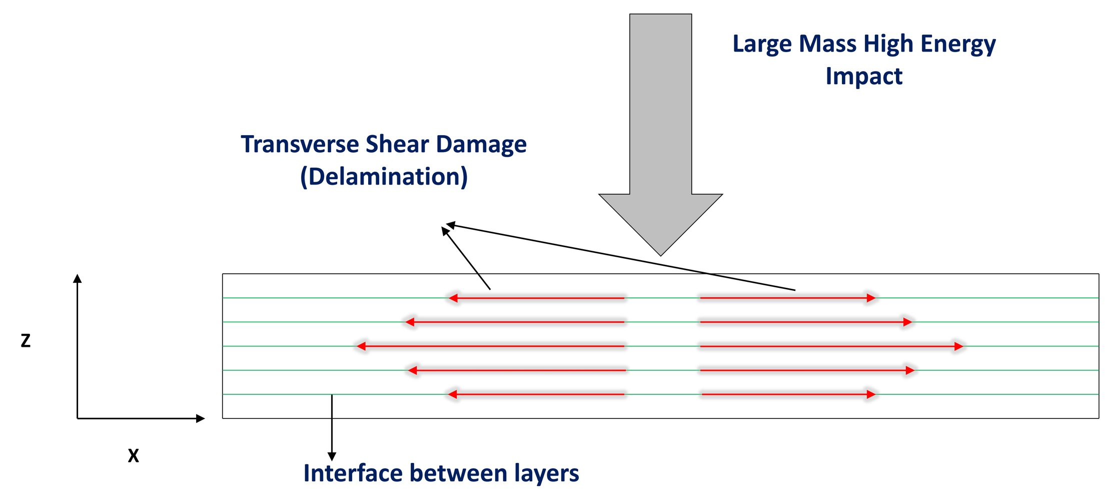
❖***Materials processing***: Co-consolidation of high toughness interlayers; high toughness matrix materials

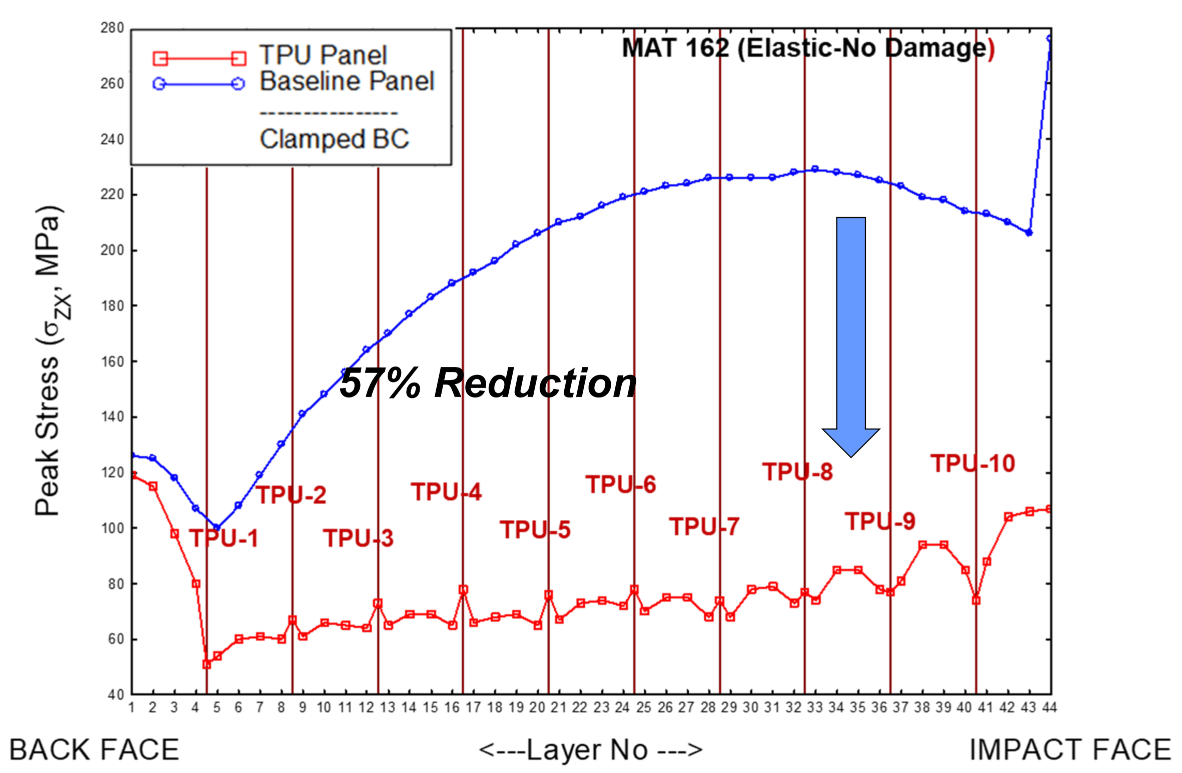
❖***Demonstration***: Drop tower – High energy, low velocity impact, with pre/post-mortem stiffness and damage characterization

❖***Transitions:*** Experimental databases, constituent/microscale test methods, materials and continuum models across length scales

## I. Materials-by-Design

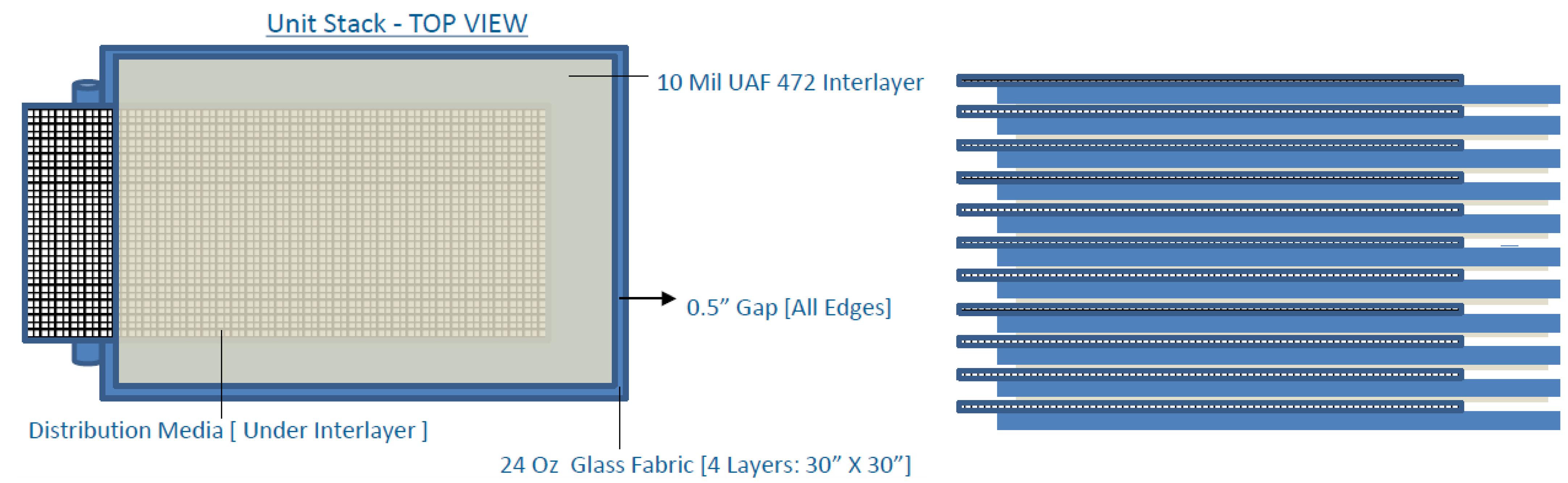
Interlayer Design Limits Damage and Reduction of Stiffness

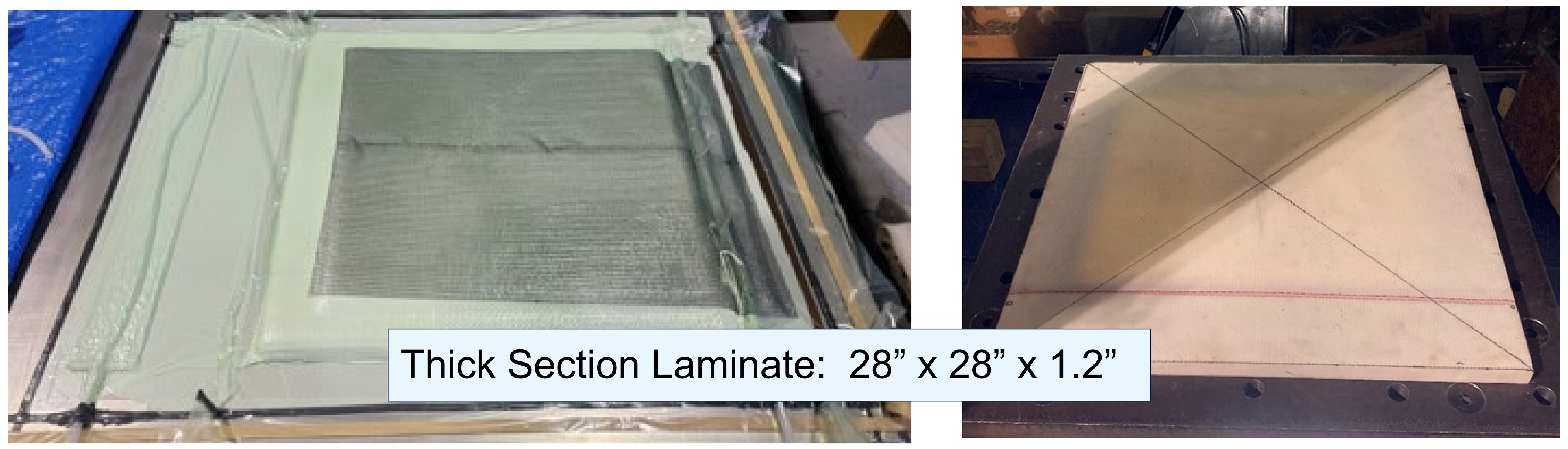



## II. Processing

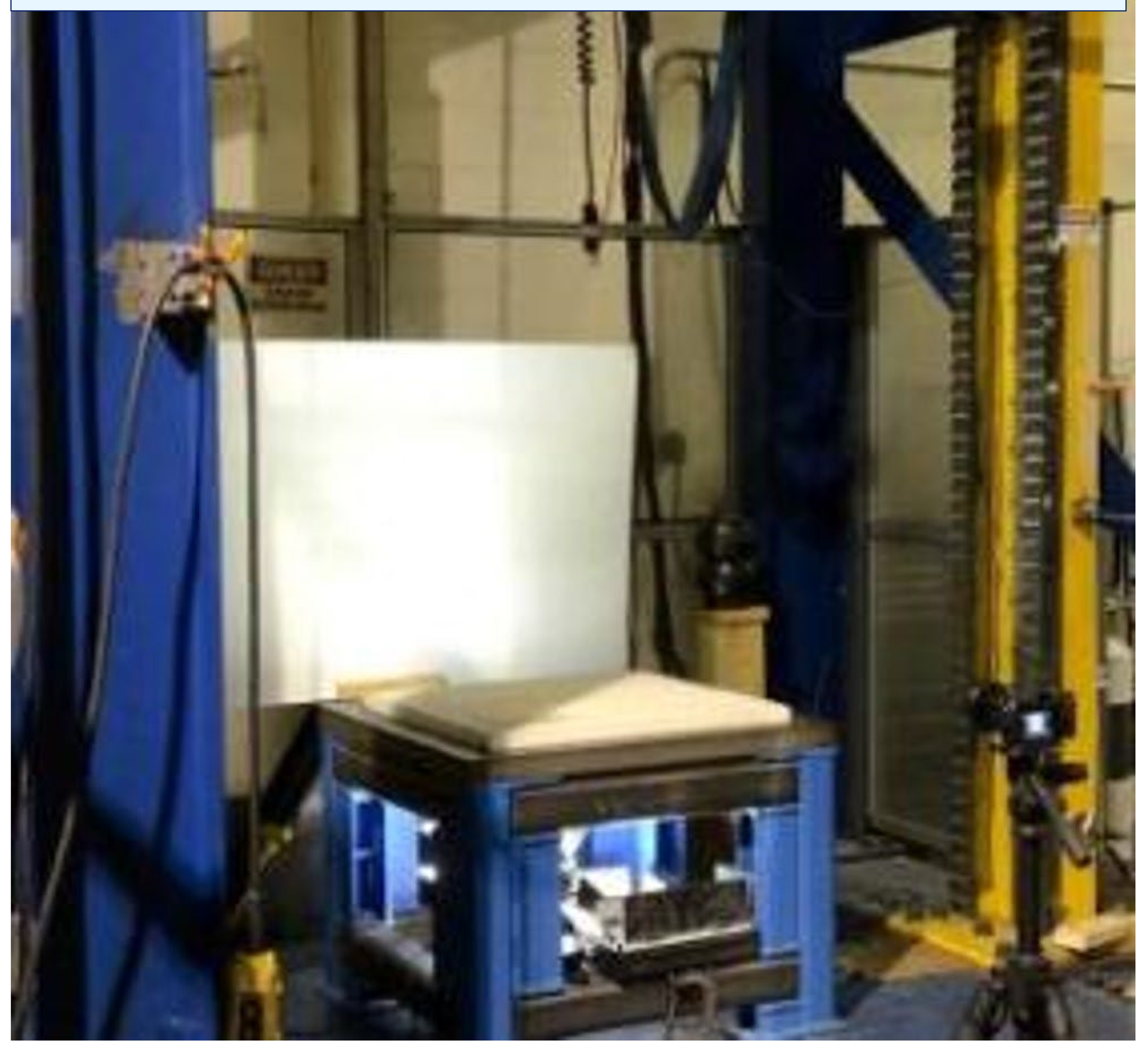
Co-consolidation with High Toughness Interlayer



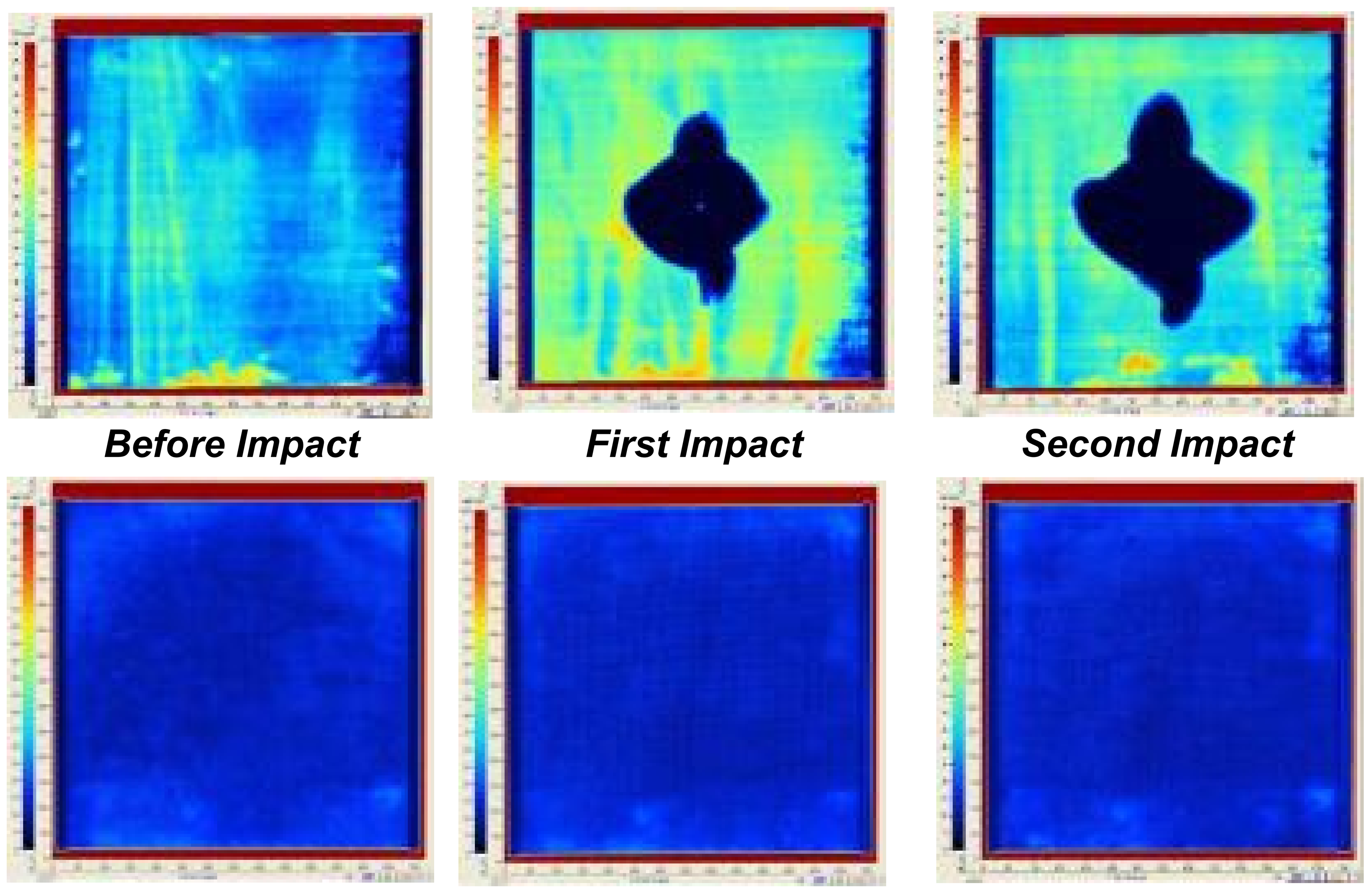




## III. Demonstration

High energy (7.4kJ), low velocity impact



**Damage Evolution**



***Before Impact*** ***First Impact*** ***Second Impact***

**Baseline Panel**
**44%**
**Stiffness Retention**
14" Delamination

**MEDE Panel**
**91%**
**Stiffness Retention**
NO Delamination

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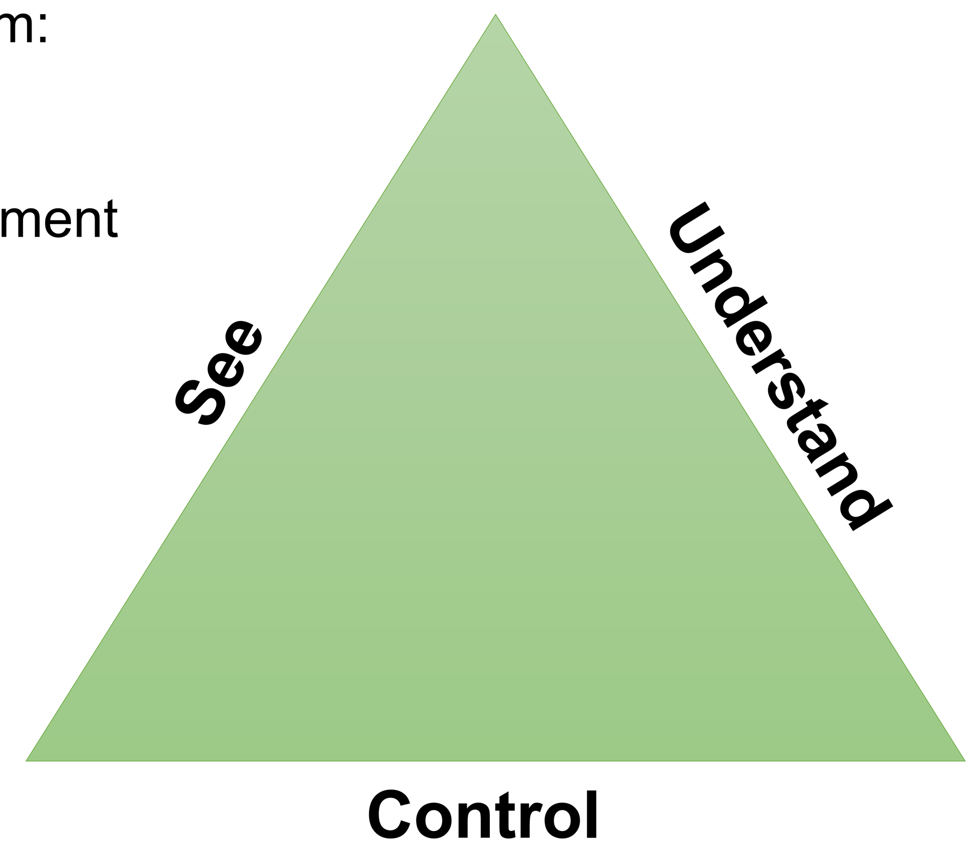



## Journal Publications (2012 – 2021)

| CMRG | Journal Articles* | Journal Article Citations |
|---|---|---|
| Ceramics | 133 | 1,885 |
| Composites & Polymers | 181 | 2,977 |
| Integrative | 27 | 425 |
| Metals | 137 | 2,808 |
| TOTAL | 478 | 8,095 |

* submitted, accepted or published

...and many communications not fully tracked:
- 100's of conference proceedings
- 1000's of conference presentations
- Lectures, keynote talks, ...

**Comparison to Similar Programs:**
- MEDE: 8.4 papers/$1M
- Other Case: 7.8 papers/$1M

## Legacy Special Issue:

Composite Materials in Extreme Dynamic Environments (MEDE)

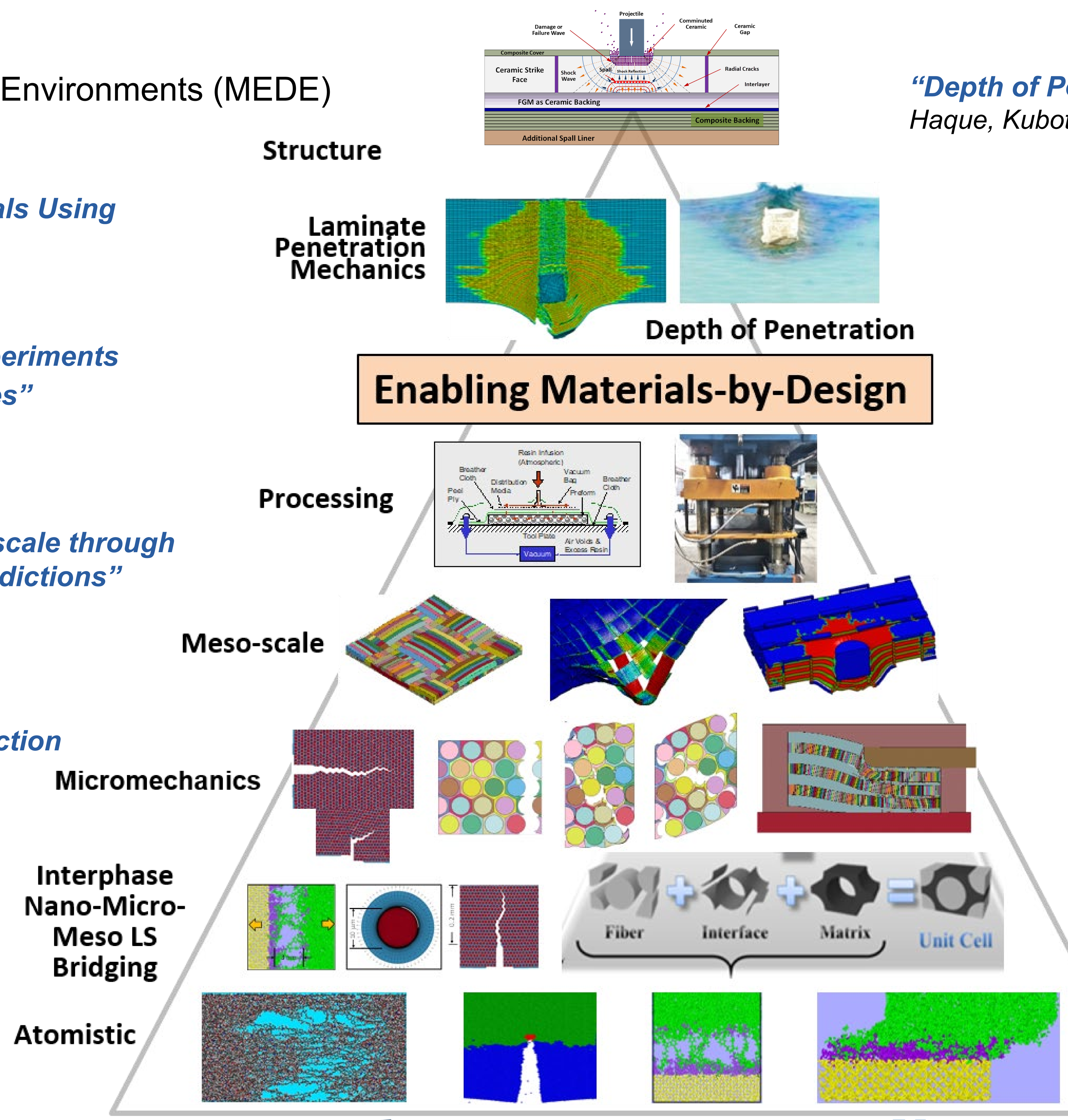
***"Stress Field Prediction in Composite Materials Using Deep Learning"***
*Bhaduri, Gupta and Graham-Brady*

***"Mesoscale Modeling of Ballistic Impact Experiments On a Single Layer of Plain Weave Composites"***
*Meyer, O'Brien, Haque, and Gillespie Jr.*

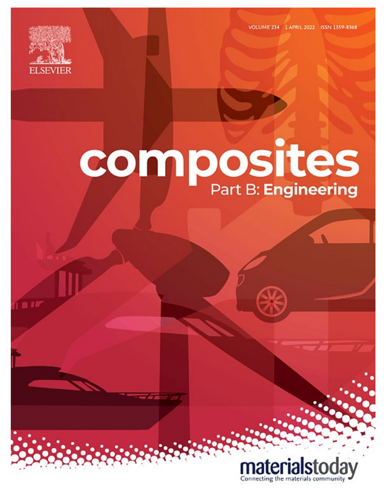
***"Bridging Length Scales from Micro to Mesoscale through Rate-Dependent Traction-Separation Law Predictions"***
*Meyer, Haque, and Gillespie Jr.*

***"Strain-Rate Dependent Mode I Cohesive Traction Laws for Glass Fiber-Epoxy Interphase using Molecular Dynamics Simulations"***
*Chowdhury and Gillespie Jr.*

***"Mechanical Properties and Damage Analysis of S-Glass Fiber: A Reactive Molecular Dynamics Study"***
*Yeon, Chowdhury and Gillespie Jr.*




***"Depth of Penetration Experiments of S-2 Glass/Epoxy Composites"***
*Haque, Kubota, and Gillespie Jr.*




Elsevier Composites Part B;
Impact Factor: 9.0;
Ranking in Engineering, Multidisciplinary: 1 out of 91

***"Impact Damage Modeling in Woven Composites with Two-Level Parametrically-Upscaled Continuum Damage Mechanics (PHCDM) Models"***
*Zhang, Xiao, Meyers, O'Brien, and Ghosh*

***"Dynamic Fracture of Glass Fiber-Reinforced Ductile Polymer Matrix Composites and the Loading Rate Effect on their Fracture Toughness"***
*Gao, Kedir, Kirk, Hernandez, Gao, Horn, Kid, Fezzaa, Shevchenko, Tallman, Palmese, Sterkenburg, and Chen*

***"Synergistic Fracture Toughness Enchancement of Epoxy-Amine Matrices via Combination of Network Toplogy Modifications and Silica Nanoparticle Reinforcement"***
*Gao, Kashcooli, Palmese, Gillespie Jr., O'Brien, Patterson*

***"Modeling Sizing Emulsion Droplet Deposition onto Silica using All – Atom Molecular Dynamics Simulations"***
*Zarrini and Abrams*

DEVCOM Army Research Laboratory | Drexel University | Johns Hopkins University | Purdue University | University of Delaware Center for Composite Materials | CMEDE Center for Materials in Extreme Dynamic Environments | U.S. Army | DEVCOM Army Research Laboratory