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CMEDE | CENTER FOR MATERIALS IN EXTREME DYNAMIC ENVIRONMENTS

2018 HIGHLIGHTS

WHAT IS CMEDE?

THE CENTER FOR MATERIALS IN EXTREME DYNAMIC ENVIRONMENTS IS A MULTI-INSTITUTION COLLABORATIVE RESEARCH CENTER LOCATED WITHIN THE HOPKINS EXTREME MATERIALS INSTITUTE AT JOHNS HOPKINS UNIVERSITY.

The Center brings together academia, government, and industry to advance the state of the art for materials in extreme dynamic environments.

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CONSORTIUM MANAGEMENT COMMITTEE

FROM THE CMEDE DIRECTOR:

Welcome to the fourth edition of the Center for Materials in Extreme Dynamic Environments (CMEDE) highlights. 2018 has been an exciting year for us! We continue our extensive collaborative research activities across three materials groups (ceramics, composites, and metals) and have made exciting scientific advances as we cultivate the future materials-by-design workforce.

A few significant events occurred in 2018 for the MEDE program. In January, we underwent a Research Management Board review that was co-chaired by the ARL Director and the Director of Basic Research of ASA(ALT). This review provided senior Army Science and Technology (S&T) leaders the opportunity to assess the MEDE program and to see the first generation of newly designed protection materials. We also hosted several visits throughout the year, including one with Congressional legislative assistants. Their continued interest in the MEDE program has led to a substantial upgrade in experimental and processing facilities across the Consortium.

Our academic programs have further increased our research and workforce footprint. The Army Educational Outreach Program awarded internships for high school and undergraduate students engaged on MEDE research projects. The Extreme Science Internship program with Morgan State University continued to excel in the depth and breadth of research experiences for minority students. Finally, MEDE's development of a materials-by-design workforce was highlighted at the Army S&T Symposium and Showcase in August.

As always, we are thankful for the continued support from the U.S. Army and the Department of Defense, as well as the support within the Enterprise for Multiscale Research of Materials and the partners in the MEDE CRA, without whom none of this would be possible.

K.T. RAMESH
Director, CMEDE

Alonzo G. Decker Jr. Professor
of Science and Engineering

Professor, Department of
Mechanical Engineering, Earth
and Planetary Sciences, Materials
Science and Engineering
Johns Hopkins University

JOHN H. BEATTY

Cooperative Agreement Manager
MEDE CRA
U.S. Army Research Laboratory

KAUSHIK BHATTACHARYA

Howell N. Tyson, Sr.,
Professor of Mechanics and
Materials Science

Professor of Materials Science
California Institute of Technology

JOHN W. GILLESPIE, JR.

Donald C. Phillips Professor of Civil
and Environmental Engineering

Professor, Mechanical Engineering,
Materials Science and Engineering
University of Delaware

RICHARD HABER

Professor, Materials Science
and Engineering
Rutgers University

ABOUT US

In 2010, two National Research Council boards established a committee to examine opportunities in protection materials science and technology for future Army applications. This committee recommended that the Department of Defense establish an initiative for protection materials by design. This initiative would include a combination of computational, experimental, and materials testing, characterization, and processing research to be conducted by academia, government, and industry.

In response to the committee's recommendation, in April 2012 the Army Research Laboratory (ARL) established a framework to integrate the Army's multiscale basic research in materials into one coordinated enterprise. Called the Enterprise for Multiscale Research of Materials (EMRM), the focus of the program is to develop a materials-by-design capability for the U.S. Army using validated multiscale and multidisciplinary modeling capabilities to predict material structure, properties, and performance.

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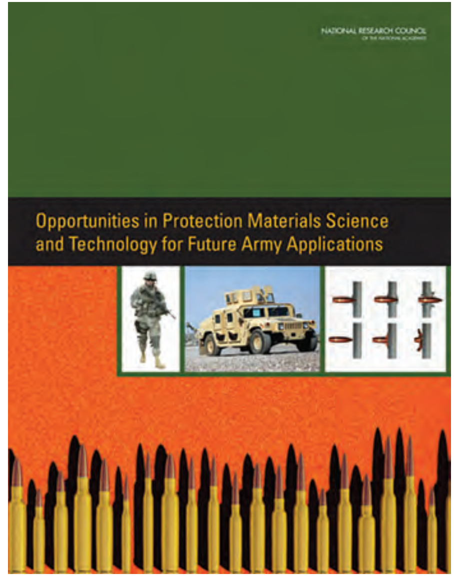
The EMRM enables ARL to coordinate its in-house activities with extramural research efforts. The EMRM is organized into four major areas: protection materials, energetic materials, electronic materials, and cross-cutting computational science.

To launch the protection materials research component of EMRM, ARL competitively awarded and then signed the Materials in Extreme Dynamic Environments cooperative research agreement with Johns Hopkins University (JHU), the California Institute of Technology (Caltech), the University of Delaware (Delaware) and Rutgers University. The agreement allowed JHU, which is the lead research organization within the consortium of university and research partners, to establish the Center for Materials in Extreme Dynamic



National Research Council report

Environments, or CMEDE. CMEDE is a center within the Hopkins Extreme Materials Institute, and focuses on advancing the fundamental understanding of materials in high-stress and high-strain-rate regimes, with the goal of developing a materials-by-design capability for these extreme environments. This 10-year agreement, valued up to $90 million, represents a significant investment and demonstrates the importance of the design of protection materials to the U.S. Army.

The MEDE program also supports the Presidential Materials Genome Initiative (MGI) for Global Competitiveness. Established in June 2011, MGI aims to double the speed at which materials are discovered, developed, and deployed. The MEDE program represents one of the Department of Defense's largest investments in extramural basic research in support of the MGI.

"MEDE leads the way towards designing new materials based on desired performance through techniques that span from the atomic to continuum levels. I look forward to revolutionary electronic, energetic, and protection materials realized through the pioneering approaches being created through the MEDE CRA."

- DR. KIMBERLY SABLON
Director, Basic Research
Office of the Assistant Secretary of the Army
(Acquisition, Logistics and Technology)

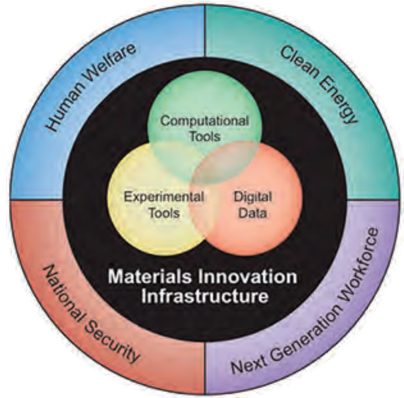


Figure 1: *Materials Genome Initiative: MEDE focuses on developing the experimental and computational tools needed to develop protection materials for national security.*

ORGANIZATION

The MEDE Collaborative Research Alliance (CRA) is composed of a consortium of university and research partners and the Army Research Laboratory. The MEDE consortium members include:

- **Johns Hopkins University (Lead)**
- **California Institute of Technology**
- **University of Delaware**
- **Rutgers University**
- **Drexel University**
- **Ernst Mach Institut**
- **ETH Zürich**
- **Lehigh University**
- **Morgan State University**
- **New Mexico Institute for Mining and Technology**
- **North Carolina Agricultural and Technical State University**
- **Purdue University**
- **Southwest Research Institute**
- **Texas A&M University**
- **University of Houston**
- **University of North Carolina at Charlotte**

Additionally, through government agreements, the MEDE CRA collaboratively works with the Defence Science and Technology Laboratory of the United Kingdom.

The MEDE CRA is composed of a consortium of university and research partners and the Army Research Laboratory. It also works internationally with the Defence Science and Technology Laboratory of the United Kingdom.

JOHNS HOPKINS UNIVERSITY

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Caltech

NORTH CAROLINA AGRICULTURAL AND TECHNICAL STATE UNIVERSITY

UNIVERSITY OF DELAWARE

PURDUE UNIVERSITY

LEHIGH UNIVERSITY

SwRI

RUTGERS

TEXAS A&M UNIVERSITY

Drexel UNIVERSITY

UNIVERSITY of HOUSTON

MORGAN STATE UNIVERSITY

UNC CHARLOTTE

ARL

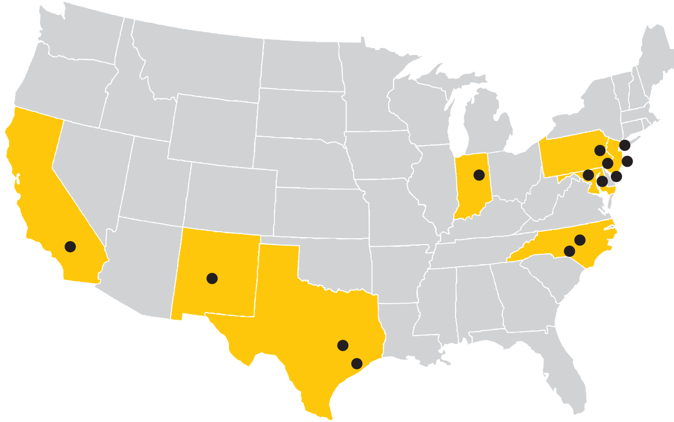


Figure 2: *MEDE Collaborative Research Alliance*

United Kingdom

[dstl]

Germany

Fraunhofer EMI

Switzerland

ETH zürich

STRUCTURE

- The CMEDE Director is located within CMEDE at Johns Hopkins University, the lead research organization for the MEDE CRA.
- The MEDE Science Advisory Board complements ARL's Technical Advisory Board. It provides important scientific insight, oversight, and expertise to the CMEDE consortium. The Board reports to the CMEDE Director.
- The Consortium Management Committee (CMC) is composed of a senior representative from the four major consortium partners and the ARL Cooperative Agreement Manager. The CMC is the final decision authority for the MEDE CRA.
- A Collaborative Materials Research Group (CMRG) coordinates all research activities for each material type. Each CMRG is co-led by a consortium principal investigator and an ARL researcher.
- Within each CMRG, there are multiple technical areas, separated by scale or mechanism. The CMRGs are highly integrated with a consortium PI and an ARL researcher co-leading each major effort.

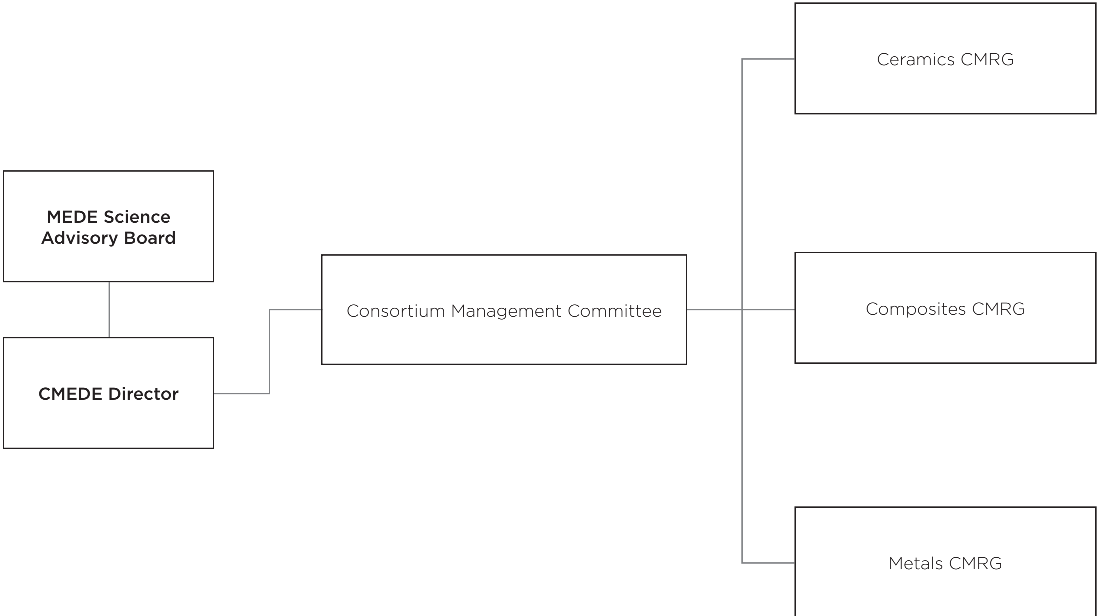


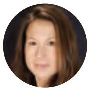
Figure 3: *MEDE organizational structure*

Members of the MEDE Science Advisory Board with Prof. KT Ramesh (JHU) and Dr. John Beatty (ARL). From left: Prof. KT Ramesh, Dr. Charles Anderson, Dr. Douglas Templeton, Prof. Steven McKnight, Dr. John Beatty.

MEDE SCIENCE ADVISORY BOARD MEMBERS

Dr. Donald Shockey
SRI International (Chair)

Dr. Charles E. Anderson, Jr.
CEA Consulting



Professor Irene Beyerlein
University of California, Santa Barbara

Professor Horacio Espinosa
Northwestern University

Professor David McDowell
Georgia Institute of Technology

Professor Steve McKnight
Virginia Polytechnic Institute

Professor Marc Meyers
University of California, San Diego

Professor Anthony Rollett
Carnegie Mellon University

Professor Thomas Russell
University of Massachusetts Amherst

Professor Susan Sinnott
Pennsylvania State University

Professor Nancy Sottos
University of Illinois at Urbana-Champaign

Dr. Douglas Templeton
DWT Consulting

RESEARCH STRATEGY

The objective of the MEDE program is to develop the technical and workforce capability to design, create, and optimize novel material systems that exhibit revolutionary performance in extreme dynamic environments. Achieving this objective requires a new paradigm for materials research and workforce development. One cannot use the classical materials science structure-properties-performance approach because path-dependent and time-dependent failure processes are involved in these dynamic environments, and optimal solutions may not exist in the traditional design space. Instead, we must design with knowledge of the dynamic failure processes (mechanisms) that are involved in the actual application.

The objective is not necessarily to produce a specific material system that is optimized for a specific range of applications, but rather to produce a way of thinking that will allow the design of lightweight protective material systems that can be used for extreme dynamic environments.

To achieve the MEDE program objectives, research activities are focused on a materials-by-design process involving a canonical model and a mechanism-based strategy as shown in Figure 5. We have established a canonical model for each model material under investigation. A canonical model is defined as: "A simplified description of the system or process, accepted as being accurate and authoritative, and developed to assist calculations and predictions."

Typically such a canonical model defines key variables and their ranges, defines critical mechanisms, and then prioritizes the variables and mechanisms. Beginning with a canonical model allows a large group of researchers to ensure that efforts are relevant in terms of both science and application.

Once the canonical description is established, researchers can then proceed with the mechanism-based strategy. Researchers seek to see the mechanisms during the extreme dynamic event, to understand them through multiscale models, and to control them through synthesis and processing. Understanding the mechanisms through multiscale models provides the capability to define integrative experiments and to test the coupling of mechanisms. This information leads to validated models and codes, which feed back into the canonical model, by transitioning into Department of Defense (DoD) and Department of Energy (DoE) codes. Similarly, controlling the mechanism through synthesis and processing leads to newly designed materials for the canonical environment. Industry helps to determine the scale-up feasibility of these newly designed materials, which are then fed back to the experiments in the canonical modeling effort.

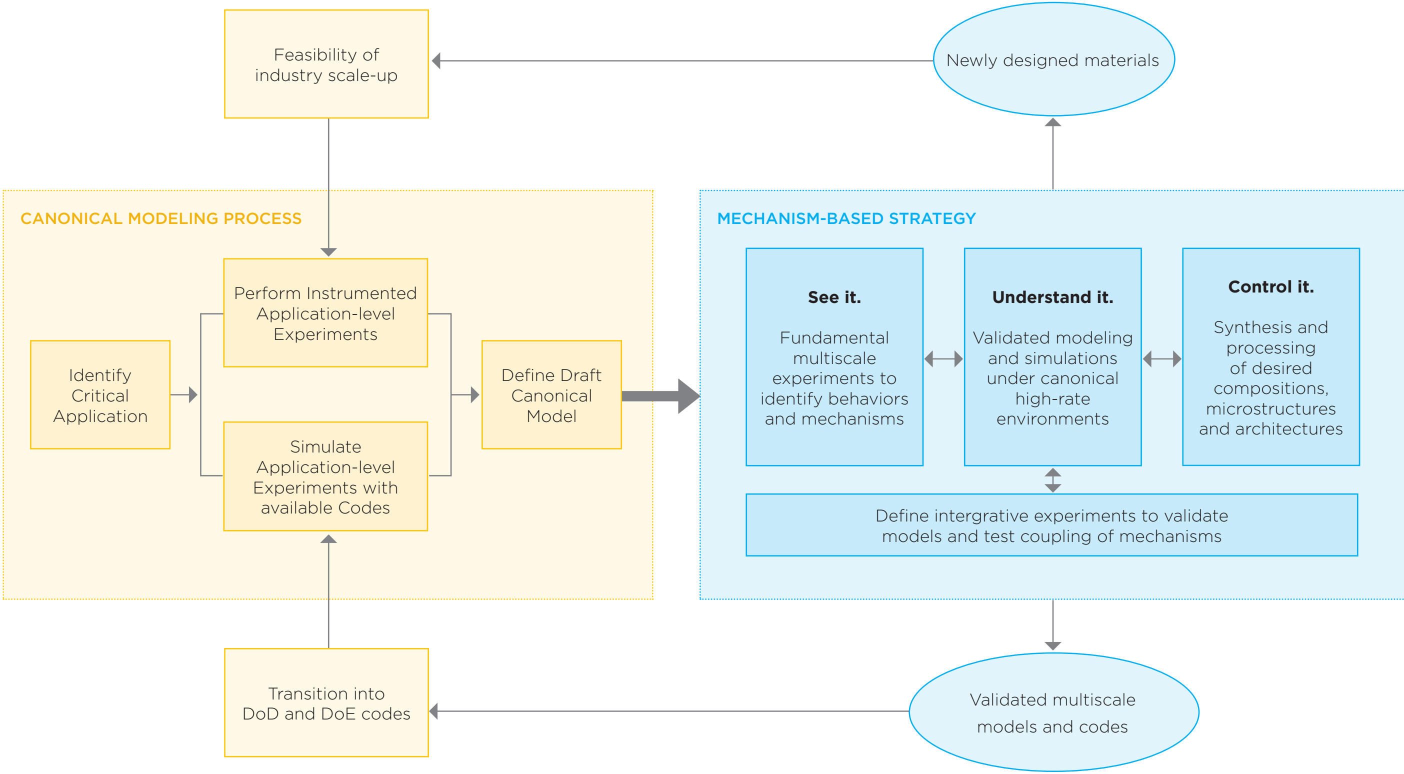


Figure 4: *Overall design strategy for protection materials. Left hand boxes are driven by ARL, while right hand boxes are driven by the MEDE Consortium.*

RESEARCH ACTIVITIES

The MEDE program examines one model material in each of the following four material classes: ceramics, composites, and metals. The discoveries and insights developed can be used for other materials in the same class.

Ceramics: Boron Carbide

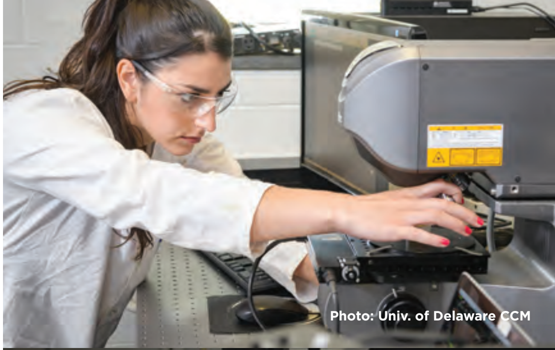
Boron carbide is the model material for the Ceramics CMRG because it has the unrealized potential of dramatic improvements in ballistic performance for vehicular protection at very low weight. The Ceramics CMRG seeks to understand and control the dynamic failure processes in this protective ceramic material and to improve its dynamic performance by controlling mechanisms at the atomic and microstructural levels through multiscale modeling, advanced powder synthesis, control of polytypes, and microstructural improvements.

Application: Boron carbide is one of the component materials used to protect soldiers and military vehicles from blast and ballistic threats.

Composites: S-2 Glass/Epoxy

Composite materials subjected to dynamic loads are essential examples of high performance systems in the conventional sense. In order to focus on the complexities raised by the interfaces and architectures, S-2 Glass/Epoxy is the model system for the Composites CMRG. The Composites CMRG develops the fundamental understanding of the role of interfaces, component interactions, and composite architecture over the full range of length scales and time scales that are manifested in the system during the dynamic event.

Application: S-2 Glass/Epoxy provides a strong, structural backing system to support protective plates for military vehicles.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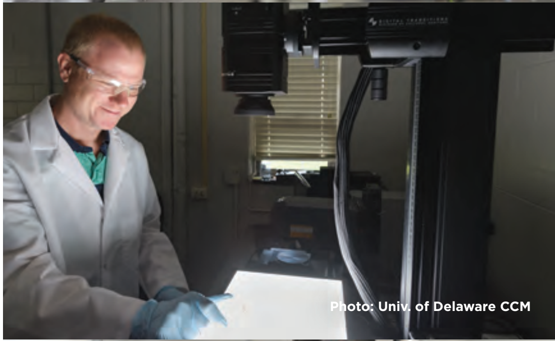


Photo: Univ. of Delaware CCM


Photo: Univ. of Delaware CCM

Metals: Magnesium

The magnesium alloy system is the model material for the Metals CMRG because it is the lightest-weight structural metal that offers the potential of approaching steel-like ballistic performance while using conventional low-cost and time-tested processing techniques. We are enhancing the dynamic performance of this hexagonally-close-packed metal using experimentally validated modeling and alloy design to control dynamic strengthening and failure mechanisms, including deformation twinning.

Application: The U.S. Army's Stryker vehicle incorporates magnesium in its structure. In comparison to steel, magnesium offers the potential for a lightweight metal system that could enhance the deployability and protection of military vehicles.

CMEDE RESEARCH ACTIVITIES ADDRESS THE FOLLOWING FIVE CORE ELEMENTS:

- **Advanced Experimental Techniques:** developing experimental methodologies to interrogate and characterize the in-situ materials response to extreme dynamic environments at critical length and time scales.

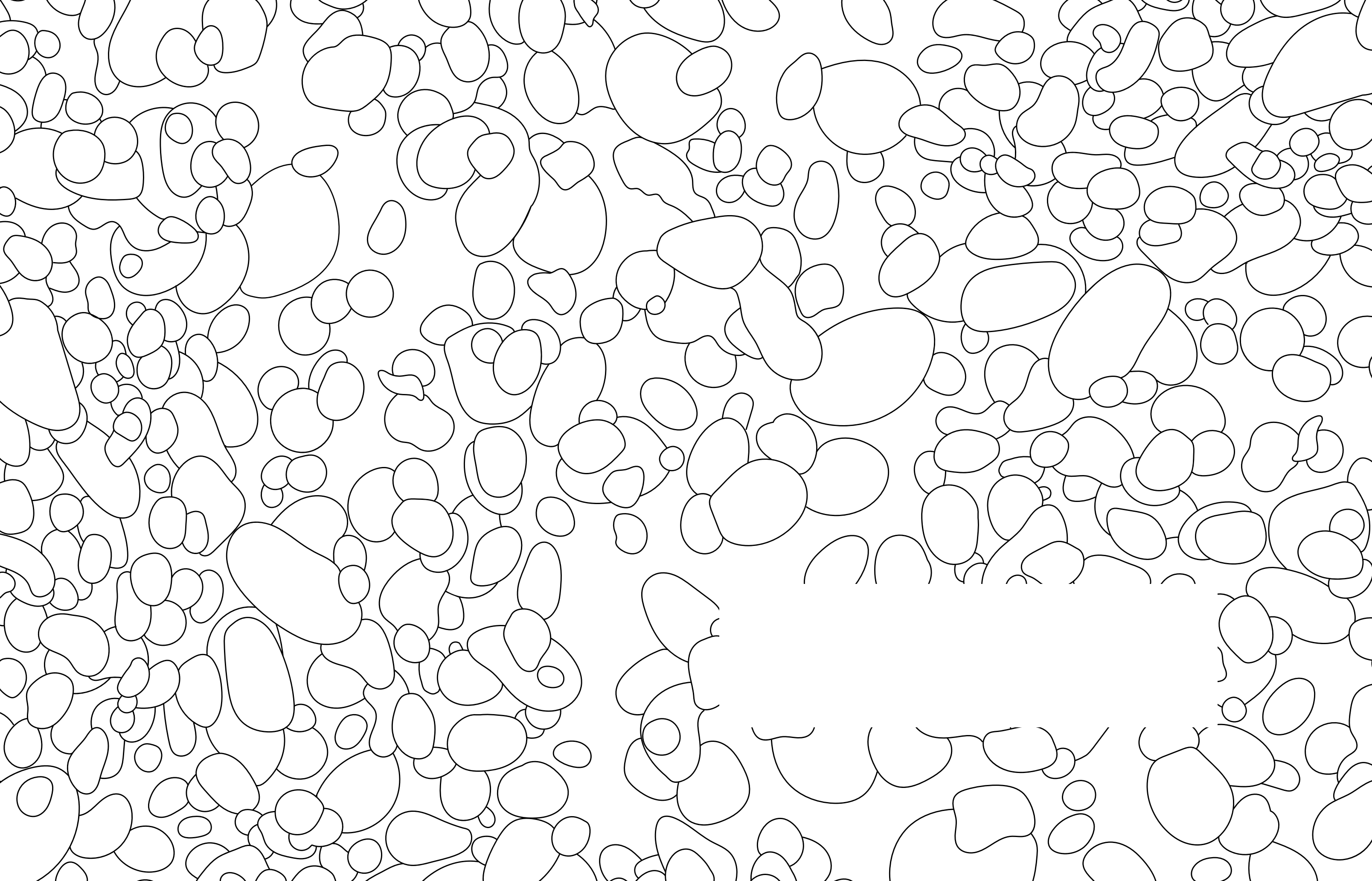
- **Modeling and Simulation:** developing computational approaches to predict the materials response to extreme dynamic environments at critical length and time scales.

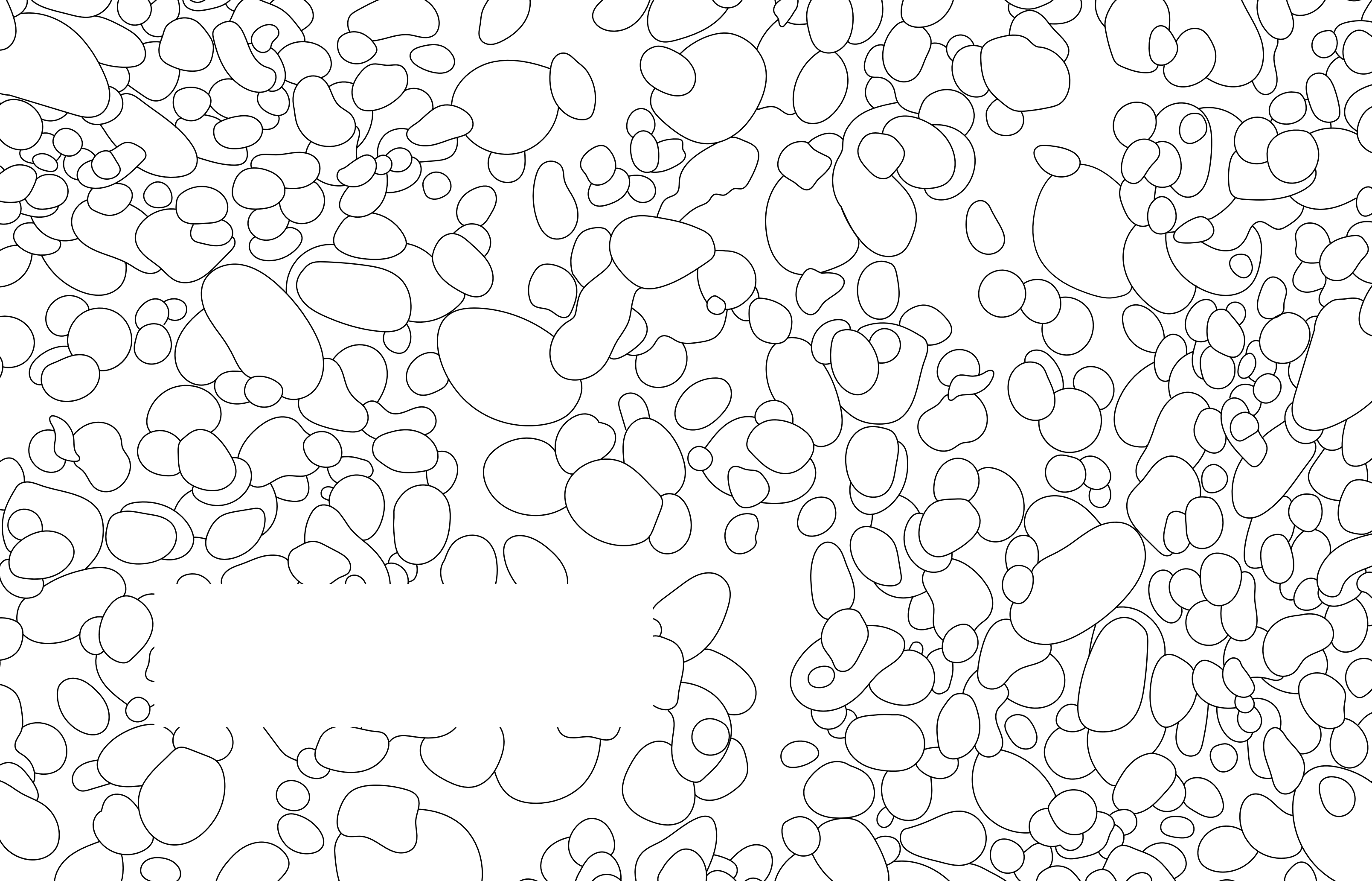
- **Bridging the Scales:** developing physical and mathematical constructs necessary to bridge critical length and time scales.

- **Material Characteristics and Properties at Multiple Scales:** utilize existing and novel experimental methodologies to identify the comprehensive set of material characteristics, microstructural features, and dynamic properties that govern high rate deformation and failure phenomena, and to validate computational approaches in order to bridge the characteristic length and time scales.

- **Synthesis and Processing:** incorporate research discoveries to enable the synthesis of novel materials and the processing of final products with critical material characteristics and resulting properties.

Artistic rendering of the atomic-level view of boron carbide as seen through a transmission electron microscope.





CERAMICS

Consortium Lead - Prof. Richard Haber (Rutgers)

ARL Lead - Dr. Jerry LaSalvia

Ceramics CMRG

CONSORTIUM INVESTIGATORS

Prof. MVS Chandrashekhar, South Carolina

Dr. Vladislav Domnich, Rutgers

Prof. Lori Graham-Brady, JHU

Prof. Rich Haber, Rutgers

Prof. Martin Harmer, Lehigh

Prof. Kevin Hemker, JHU

Prof. Todd Hufnagel, JHU

Prof. Ryan Hurley, JHU

Dr. Chris Marvel, Lehigh

Prof. K.T. Ramesh, JHU

Prof. Mark Robbins, JHU

Prof. Michael Spencer, Morgan State

ARL COLLABORATORS

Dr. Brady Aydelotte

Dr. Richard Becker

Dr. Kristopher Behler

Dr. Shawn Coleman

Dr. George Gazonas

Dr. Jerry LaSalvia

Mr. Brian Leavy

Dr. Jonathan Ligda

Dr. Bryan Love

Dr. James McCauley

Dr. Jason McDonald

Dr. Sikhanda Satapathy

Dr. Brian Schuster

Dr. Jeffrey Swab

Dr. Jennifer Synowczynski-Dunn

Dr. Andrew Tonge

Dr. Scott Walck

CONSORTIUM RESEARCH TASKS

- Fracture and Fragmentation (Graham-Brady, Ramesh, Hufnagel and Robbins, JHU)
- Granular Flow (Ramesh, Graham-Brady, and Hurley, JHU)
- Integrated Modeling (Ramesh, JHU)
- Quasi-Plasticity (Haber and Domnich, Rutgers; Ramesh and Hemker, JHU)
- Synthesis and Processing (Haber, Rutgers; Harmer and Marvel, Lehigh; Spencer, Morgan State; Chandrashekhar, South Carolina)

Locating Si atoms in Si-Doped Boron Carbide

Dr. Atta U. Khan
Rutgers University

Dr. Anthony Etzold
Rutgers University

Dr. Vlad Domnich
Rutgers University

Dr. Qi An
University of Nevada, Reno

Dr. Kris Behler
U.S. Army Research Laboratory

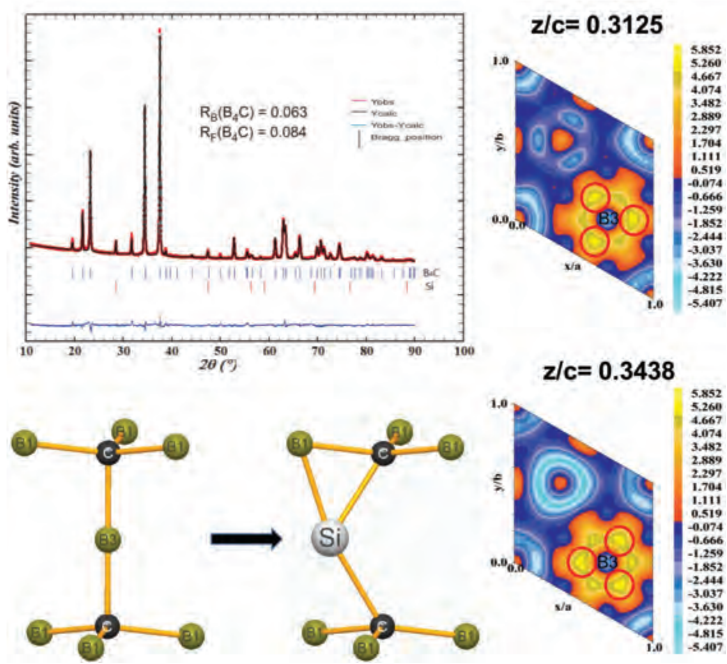
Dr. Jerry LaSalvia
U.S. Army Research Laboratory

Professor Richard Haber
Rutgers University

Boron carbide is a well-known compound owing to its high hardness, low density and exceptional resistance to wear, making it a prime candidate for armor materials. However, its low fracture toughness is detrimental for its use as a material for multi-impact armor. At Rutgers, we have enhanced the properties of boron carbide powders through Rapid Carbothermal Reduction processing, giving rise to a carbon particulate free material, which has had an immediate impact on the hardness and strength of armor plates. While these measures solve some macroscopic issues, silicon addition has helped in mitigating the amorphization of boron carbide. As amorphization is a key component in the failure of boron carbide, this reduction signifies advancement in toughening the material for use in armor. However, it is very important to understand the mechanism, by which silicon addition to boron carbide reduces the amorphization under impact. The very first step in solving the mechanism puzzle is the resolution of the crystal structure, including the location of the silicon atoms in the boron carbide lattice.

A suitable sample for Rietveld refinement was synthesized by mixing boron carbide and SiB_6 powders and sintered in SPS for an extended period. Presence of liquid aided in achieving thermodynamic equilibrium. X-ray powder diffraction pattern obtained from this sample confirmed a homogenized sample. Rietveld refinement of this pattern coupled with electron density difference Fourier maps shows the silicon atoms being present in the void between the 3-atomic chain and the icosahedra, resulting in a kinked 3-atomic C-Si-C chain. These silicon atoms lie close to the icosahedra and seem to have bonding with the nearest boron atom of the icosahedra, possibly further stabilizing the icosahedra. This location of Si atoms also bridges the bond between the chain end atom and the icosahedra. As it is reported in the literature that the icosahedra disintegrates first in the event of amorphization, this additional stabilization may have led to the observed reduced amorphization. Moreover, DFT simulations by Dr. Qi An, confirmed the location of Si atoms and these calculations fully support our findings.

Figure 5: *Rietveld refinement of the XRD pattern (top left) and the difference electron density Fourier maps for Si-doped boron carbide phase in hexagonal setting (on the right). Variation in electron density concentration along z-axis clearly depicts that the three possible Si atom locations are slightly above the z/3 position and the other three, slightly below the z/3 position. Lower left corner shows the alteration of chain with Si incorporation.*



A Continuum Constitutive Model for Amorphization in Boron Carbide

Dr. Qinglei Zeng
Johns Hopkins University

Dr. Andrew L. Tonge
U.S. Army Research Laboratory

Professor K. T. Ramesh
Johns Hopkins University

Boron carbide is well known as the third hardest material in nature. Benefitting from its high Hugoniot elastic limit (HEL), low density and high thermal stability, it should be an ideal candidate as protection material. However, boron carbide was found to lose shear strength under high impact velocities, which has been attributed to the formation of amorphization bands observed in different experiments (e.g. ballistic impact, indentation, diamond anvil cell). In this work, we proposed a continuum constitutive model for amorphization in boron carbide and implemented it in the integrative model based on Tonge-Ramesh model.

The proposed model comprises the onset of amorphization bands and the subsequent sliding along these bands. We define an equivalent amorphization stress as the initiation criterion for amorphization, which combines the contribution from shear stress and hydrostatic pressure. There's compaction deformation inside amorphization bands. When the shear stress reaches a critical shear resistance, sliding will occur along bands, which will introduce additional damage to the material.

With this proposed model, we have investigated the deformation mechanisms in plate impact experiments and calibrated material parameters based on the experiments performed by Vogler et al. The simulated particle velocity histories are in good agreement with the experimental results. We have also performed preliminary simulations of sphere-cylinder impact experiments and observed the competition between microcracking and amorphization during the failure process. Further parametric study based on experiments is in progress.

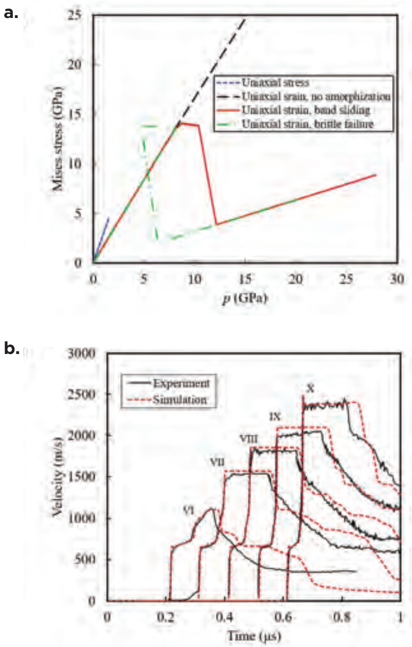


Figure 6: *(a) Stress paths in a representative volume element (RVE) under uniaxial stress and uniaxial strain loading conditions. (b) The comparison of simulation results with the experiments by Vogler et al.*

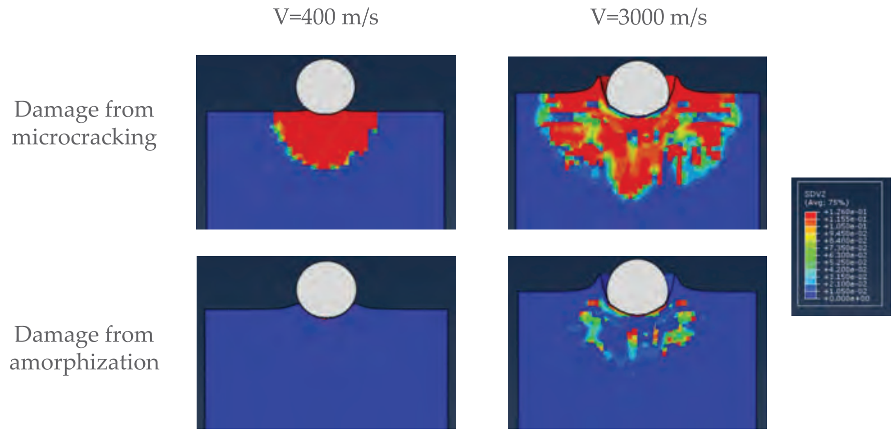


Figure 7: *The damage induced by microcracking and amorphization in sphere-cylinder impact with different impact velocities.*

DR. KRIS BEHLER

Senior Material Scientist (SURVICE Engineering), U.S Army Research Laboratory

MEDE Area of Research:
Ceramic Processing and Grain Boundary Engineering for Improved Soldier Protection

> “The MEDE program has allowed me to delve into the interactions of matter at the atomic scale through the study of grain boundaries and interfaces in advanced armor ceramics. I have been fortunate to meet and work with many bright and creative researchers. Collaborations within ARL and academic partners have helped foster different approaches to solve many challenging questions and improve future protection technologies for the Soldier. I have enjoyed and benefitted from being able to work with graduate students and help mentor them through their studies.”

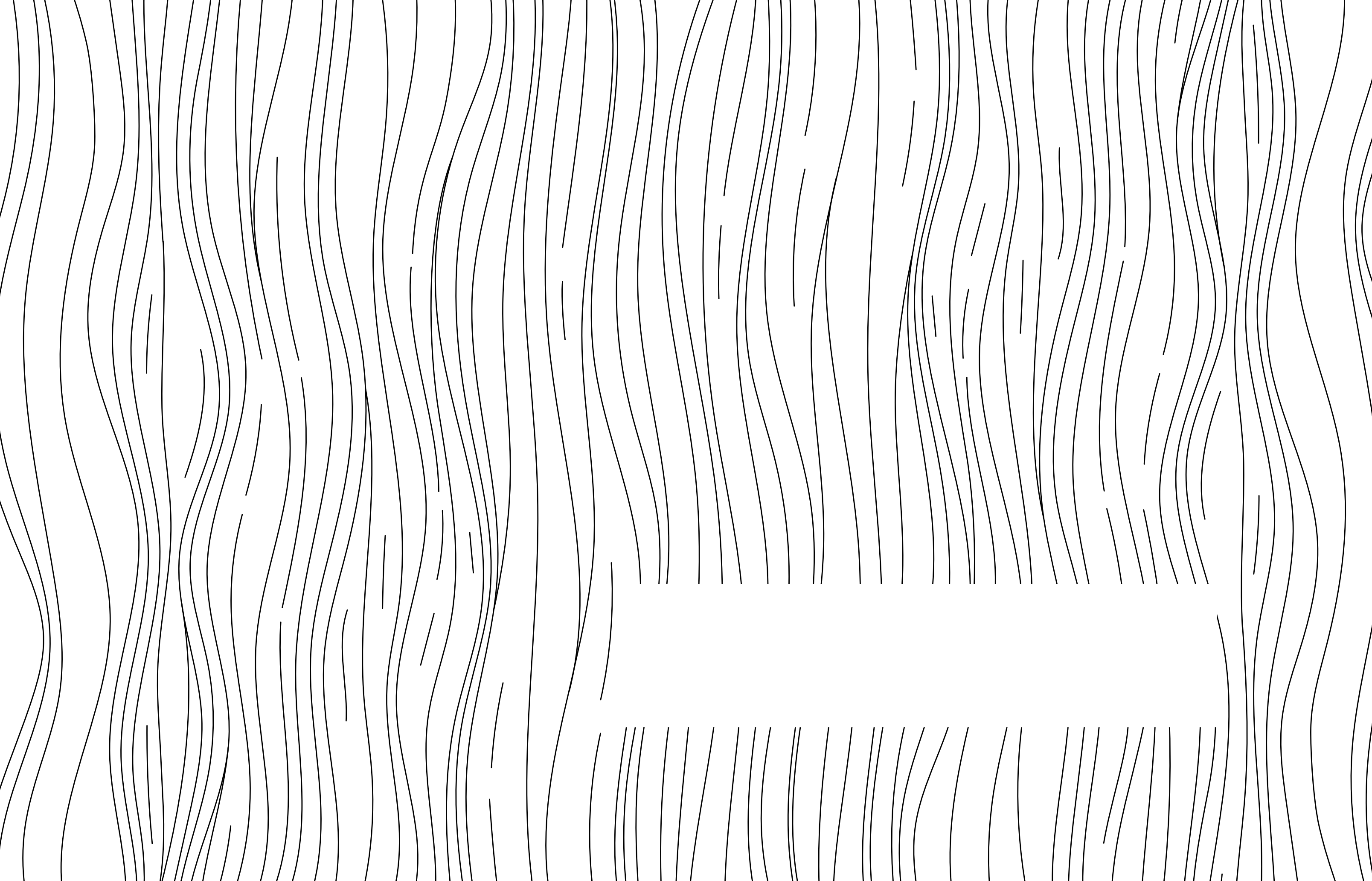
DR. ATTA ULLAH KHAN

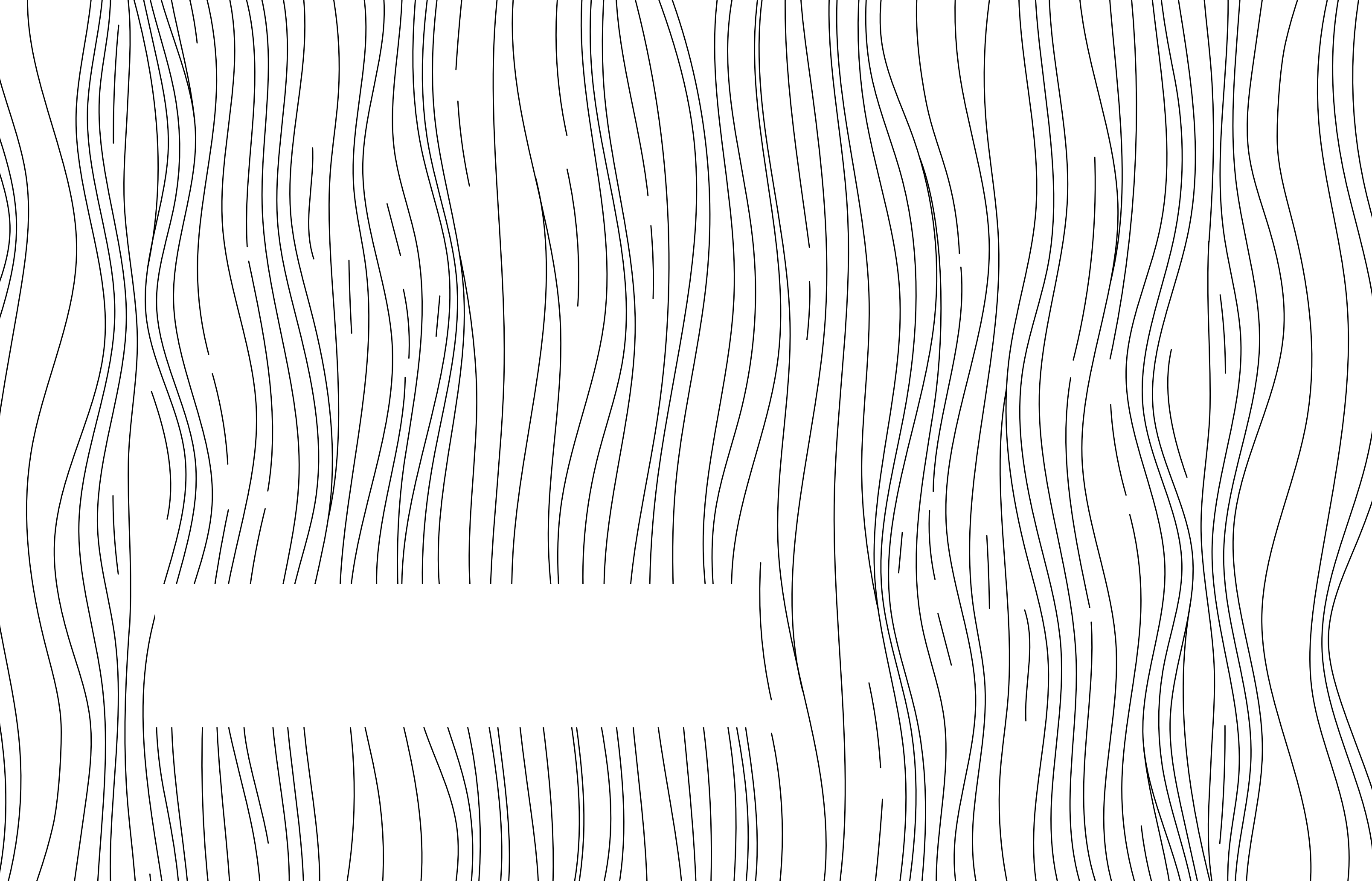
Postdoctoral Researcher, Rutgers University

MEDE Area of Research:
Synthesis and Processing

“MEDE has provided me a platform to conduct high quality research work and to collaborate with top researchers from leading universities and Army Research lab. These collaborations and data sharing has helped me to expand my knowledge of ceramics.”

Artistic rendering of a cross-section of the S-2 Glass/Epoxy composite material.





COMPOSITES

Consortium Lead - Prof. John W. Gillespie, Jr. (Delaware)

ARL Lead - Dr. Daniel J. O'Brien

Composites CMRG

CONSORTIUM INVESTIGATORS

Prof. Cameron Abrams, Drexel

Prof. Kadir Aslan, Morgan State

Prof. Wayne Chen, Purdue

Dr. Sanjib Chowdhury, Delaware

Prof. Somnath Ghosh, JHU

Prof. John W. Gillespie, Jr., Delaware

Prof. Lori Graham-Brady, JHU

Prof. Bazle Haque, Delaware

Prof. Giuseppe Palmese, Drexel

Prof. Michael Shields, JHU

ARL COLLABORATORS

Dr. Jan Andzelm

Dr. Travis Bogetti

Dr. Robert Elder

Dr. Joe Lenhart

Dr. Kevin Masser

Mr. Chris Meyer

Dr. Daniel J. O'Brien

Dr. James Sands

Dr. Timothy Sirk

Dr. Tusit Weerasooriya

Dr. Chian Fong Yen

CONSORTIUM RESEARCH TASKS

- Characterization of Macroscale Damage in Composite Materials (Aslan, Morgan State)
- Epoxy Molecular Simulations (Abrams and Palmese, Drexel)
- Meso-Mechanical Modeling of Canonical Perforation Experiments (Haque and Gillespie, Delaware)
- Micro-Mechanical Modeling of Progressive Punch-shear and Punch Crush Behavior of Unidirecional Composites (Gillespie and Haque, Delaware)
- Micromechanical FE Modeling of Tensile Failure of Unidirectional Composites (Gillespie, Delaware)
- Multi-scale Modeling of Damage and Failure in Composites (Ghosh, JHU)
- Multi-scale Modeling of Fiber-Matrix Interphase (Chowdhury and Gillespie, Delaware)
- Probabilistic Modeling and UQ for Computational Models of Composites (Graham-Brady and Shields, JHU)
- Real-time Damage Visualization in Polymers and Composites (Chen, Purdue)
- Synthesis of Epoxy Networks and Interphases with Controlled Topology (Palmese and Abrams, Drexel)

Determination of Rate Dependent Mode II Traction Separation Laws for Composite Interphases

Professor John W. Gillespie, Jr.	**Dr. Daniel J. O'Brien**	**Dr. Sandeep Tamrakar**
University of Delaware	*U.S. Army Research Laboratory*	*Ford Motor Company*

Lightweight composite materials offer superior specific stiffness, strength and energy dissipation during impact events. Under dynamic loading, energy is dissipated through various strain rate dependent micromechanical mechanisms such as fiber breakage, interfacial debonding and frictional sliding and localized matrix plasticity and cracking. The interaction between fiber and matrix at the interface determines the overall energy absorption capability of the composite material. Our Materials by Design strategy requires accurate characterization of rate dependent properties of the fiber, matrix and composite interphases to validate our lower length scale molecular dynamic models as well as serve as input into our higher length scale computational models to predict continuum properties. In this study, our focus is on the methodology to characterize rate dependent Mode II Traction laws for composite interphases.

Our experimental studies use a model composite material comprised of a single S-2 glass fiber (10 micron) coated with 3-glycidoxypropyl) trimethoxy silane coupling agent and epoxy film former sizing. The matrix is a DER 353 epoxy with a PACM-20 curing agent. During processing the interphase between the fiber and matrix forms through diffusion and reaction with a thickness in the range of 10-100nm.

The study involved development of novel experimental methods. A micromechanical test method uses a microdroplet test specimen. A typical epoxy droplet size is 100 microns. The average interfacial shear strength (IFSS) can be measured at loading rates spanning six decades of magnitude. At higher loading rates, a tensile Hopkinson bar has been designed that can load the interface in the range of 1-10 m/s. Crack initiation at the interface was studied by modifying the fiber surface through the deposition of an electrically percolating carbon nanotube network using electrophoretic deposition method. Experimental results and post-failure inspection of the fiber matrix interface showed that the test method is effective in measuring high rate interface properties of composites.

A methodology using Finite Element (FE) modeling of the experiments is established to uniquely determine rate dependent Mode II cohesive traction laws of the composite interfaces. To accurately model the microdroplet experiments, rate dependent resin properties were measured over a wide range of strain rates (0.001/s to 12,000/s) and strain range up to 70%. For DER 353 epoxy resin, yield stress increased significantly with applied strain rate and exhibited a bi-linear dependency. Thermal softening was observed under high strain rates at large strains due to adiabatic heating. A constitutive model was developed and used in the modeling of experiments. The simulation allows partitioning of energy absorbing mechanisms (interface and resin plasticity) and prediction of cohesive zone sizes for all loading rates. Incorporating strain rate dependent resin plasticity ensures energy absorption during interface softening is accurate. A minimum of three droplet sizes ranging from 75 to 125 micron are tested at each loading rate and used to validate the rate dependant traction law parameters.

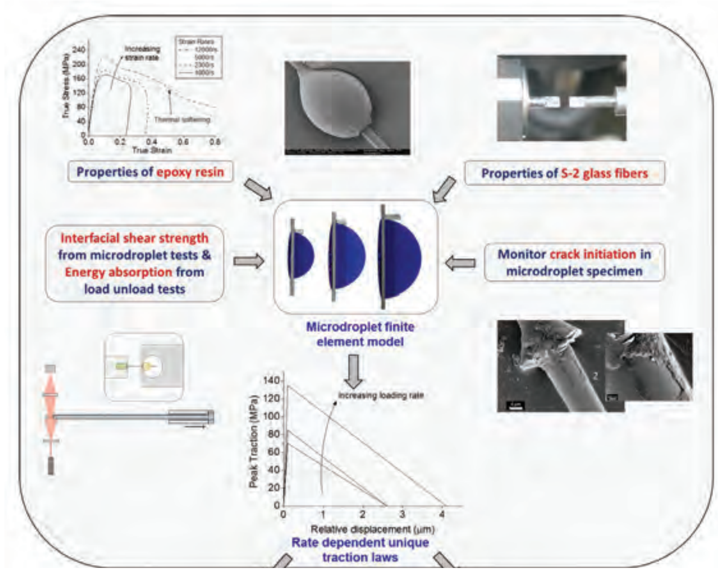


Figure 8: *Methodology for Determination of Unique Rate Dependent Traction Laws*

References:

1. *Tamrakar, S., R. Ganesh, S. Sockalingam, J. W. Gillespie, Jr., "Determination of Mode II Traction Separation Law for S-2 Glass/Epoxy Interface Under Different Loading Rates Using a Microdroplet Test Method," Proceedings of the Automotive Composites Conference & Exhibition, Society of Plastic Engineers, Detroit, MI, Sept. 5-7, 2018.*

2. *Tamrakar, S., R. Ganesh, S. Sockalingam, B. Z. (Gama) Haque, and J. W. Gillespie, Jr., "Experimental Investigation of Strain Rate and Temperature Dependent Response of an Epoxy Resin Undergoing Large Deformation," Journal of Dynamic Behavior of Materials, 4 (1), 114-128, 2018.*

3. *An, Q., S. Tamrakar, J. W. Gillespie, Jr., A. N. Rider, and E. T. Thostenson, "Tailored Glass Fiber Interphases via Electrophoretic Deposition of Carbon Nanotubes: Fiber and Interphase Characterization," Composites Science and Technology, https://doi.org/10.1016/j.compscitech.2018.01.003, 166 pp, 131–139 September 29, 2018.*

Probabilistic Modeling and Uncertainty Quantification for Computational Models of Composites

Professor Lori Graham-Brady	Professor Michael Shields	Professor Michael Kirby	Professor Yanyan He
Johns Hopkins University	*Johns Hopkins University*	*University of Utah*	*New Mexico Institute of Mining and Technology*

Goal: The long-term goal of this project is to develop an efficient sampling-based framework for performing uncertainty quantification (UQ) and/or probabilistic modeling of composite materials in armor applications.

Research strategy: This joint team from the MEDE and MSME CRAs addresses probabilistic modeling and UQ for continuum plain-weave composite models under projectile impact. The efficient sampling framework is being applied to better understand the sensitivities of the model parameters with respect to the residual velocity of the projectile and other outputs of interest.

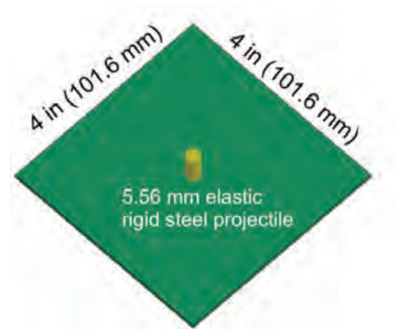


Figure 9: *Isometric view of a plain weave single layer composite model under impact*

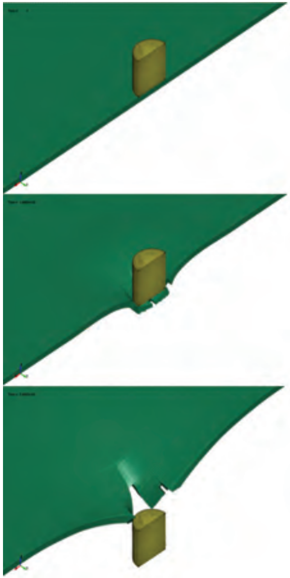


Figure 10: *LS-DYNA prediction of projectile penetration*

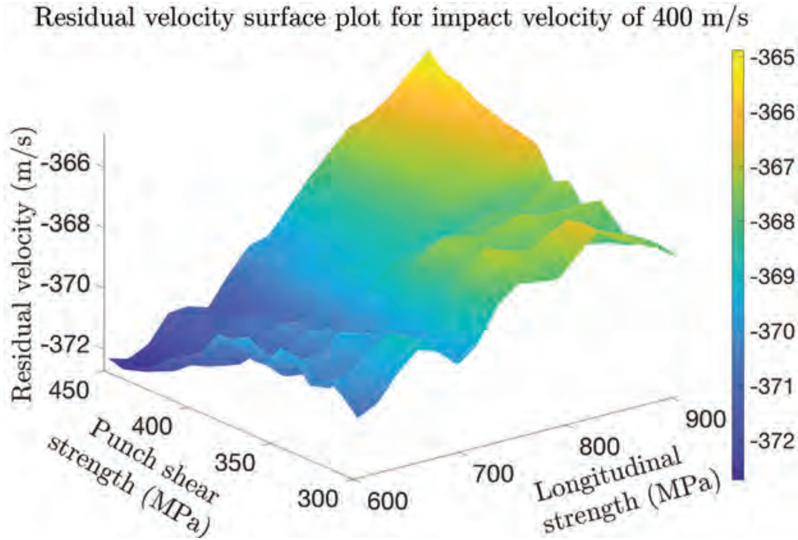


Figure 11: *Residual velocity of projectile as a function of longitudinal and punch shear strength for an impact velocity of 400 m/s*

DR. SANJIB CHOWDHURY

Associate Scientist, Center for Composite Materials, University of Delaware

MEDE Area of Research:
Multi-Scale Modeling of Fiber-Matrix Interphase

> "Through the MEDE program, we are developing a molecular dynamics-based, materials-by-design framework to identify the mechanisms of interphase formation and tailoring properties for strength and energy absorption. It's a great pleasure for me to being part of the Composites Collaborative Materials Research Group. This program has provided me the opportunity to collaborate with researchers on the forefront of composites fields while also enriching both my mentoring and collaboration skills and my computational capability."

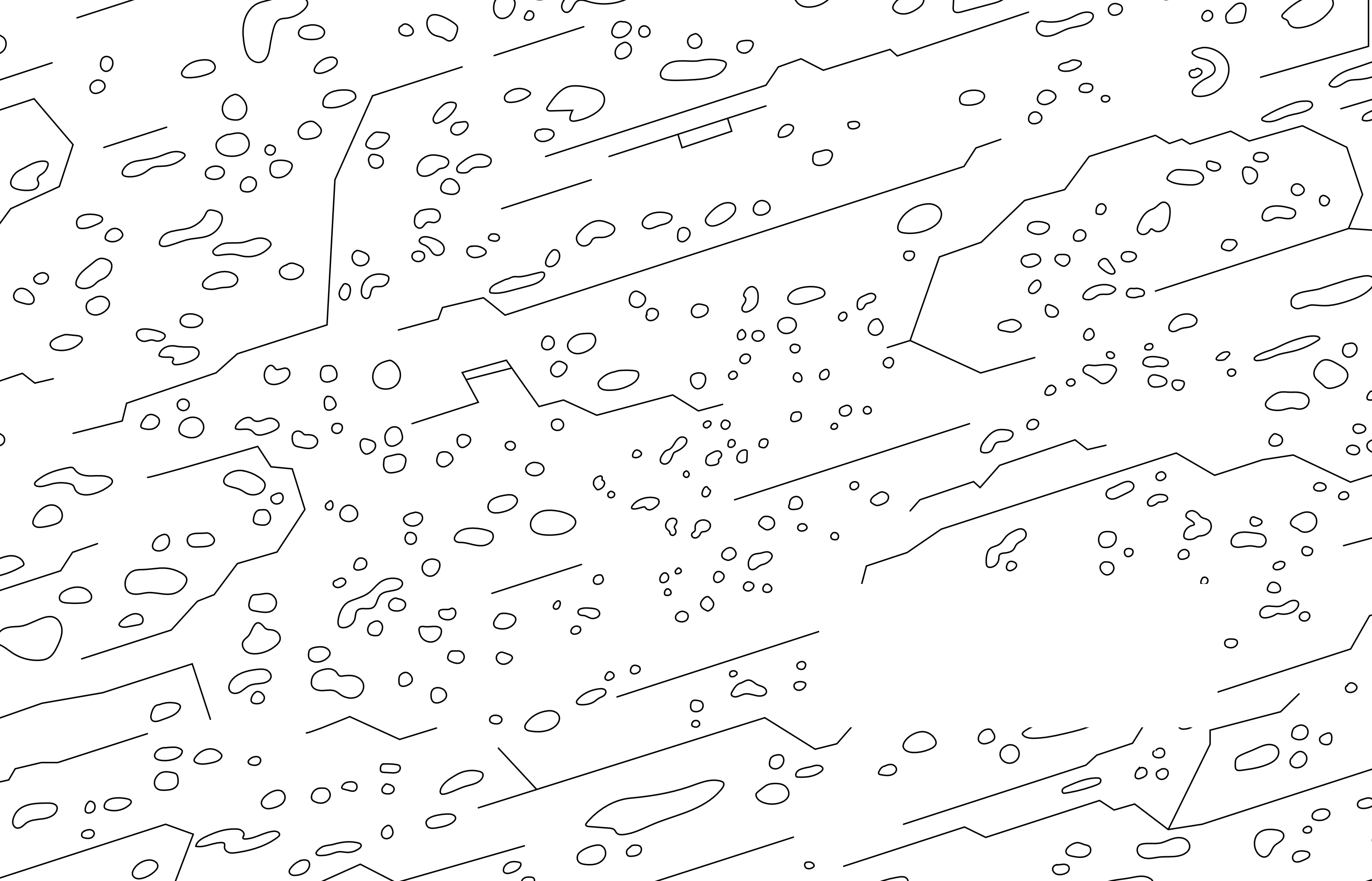
MR. ETHAN WISE

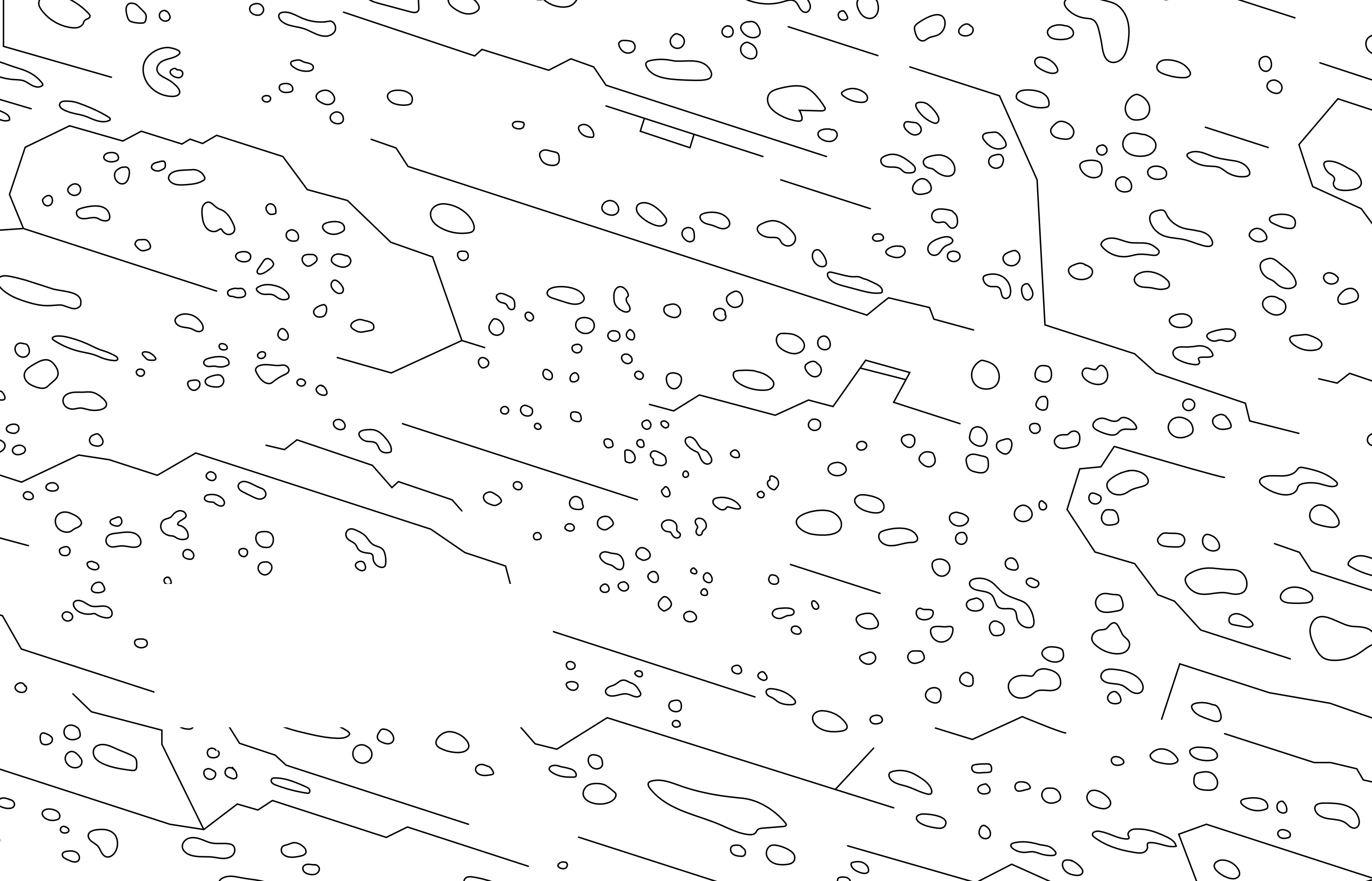
Undergraduate Researcher, University of Delaware

MEDE Area of Research:
Multi-scale Modeling of Fiber-Matrix Interphase

"Through MEDE, I have participated in pertinent and rewarding materials science research. I am grateful for the opportunities to learn from and work alongside experts in my field. It is rewarding to see the impact of my research beyond the university and to contribute to the protection of our armed forces."

Artistic rendering of magnesium as seen through a transmission electron microscope.





METALS

Consortium Lead - Prof. Todd Hufnagel (JHU)

ARL Lead - Dr. Jeffrey Lloyd

Metals CMRG

CONSORTIUM INVESTIGATORS

Prof. Kaushik Bhattacharya, Caltech

Prof. Jaafar El-Awady, JHU

Prof. Michael Falk, JHU

Prof. Todd Hufnagel, JHU

Prof. Shailendra Joshi, Univ. of Houston

Dr. Laszlo Kecskes, JHU

Prof. Jamie Kimberley, NMT

Prof. Dennis Kochmann, ETH Zürich

Prof. Michael Ortiz, Caltech

Prof. K.T. Ramesh, JHU

Prof. Jagannathan Sankar, NC A&T

Prof. Qiuming Wei, UNCC

Prof. Tim Weihs, JHU

Prof. Justin Wilkerson, Texas A&M

Dr. Zhigang Xu, NC A&T

Dr. Sergey Yarmolenko, NC A&T

ARL COLLABORATORS

Dr. Richard Becker

Dr. Todd Bjerke

Mr. Brady Butler

Dr. Daniel Casem

Dr. John Clayton

Dr. Robert Elder

Dr. Vince Hammond

Mr. Micah Gallagher

Dr. Efrain Hernandez

Dr. Philip Jannotti

Mr. Tyrone Jones

Dr. Jarek Knap

Dr. Jonathan Ligda

Dr. Krista Limmer

Dr. Jeffrey Lloyd

Dr. Christopher Meredith

Dr. Tomoko Sano

Dr. Scott Schoenfeld

Dr. Brian Schuster

Dr. N. Scott Weingarten

Dr. Cyril Williams

CONSORTIUM RESEARCH GROUPS

- Dynamic Deformation and Strength (El-Awady and Ramesh, JHU; Ortiz, Caltech; Kimberley, NMT; Joshi, Univ. of Houston)
- Thermal Mechanical Processing (Weihs, Falk, and Kecskes, JHU; Bhattacharya and Kochmann, ETH Zürich; Sankar, Xu, Yarmolenko, NC A&T; Wei, UNCC)
- Void Dominated Failure and Spall (Hufnagel and Weihs, JHU; Wilkerson, Texas A&M)

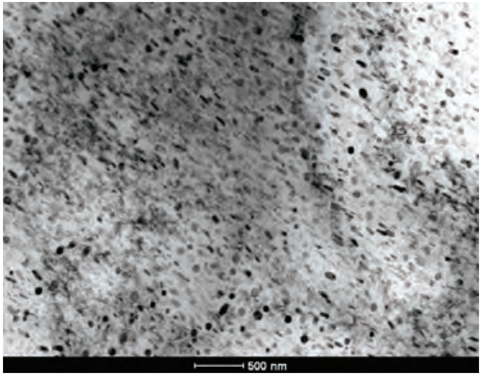
Deformation Driven Dynamic Precipitation in Magnesium Alloys

Mr. Suhas Eswarappa Prameela *Johns Hopkins University*	**Dr. Xiaolong Ma** *Johns Hopkins University*	**Dr. Peng Yi** *Johns Hopkins University*	**Mr. Vance Liu** *Johns Hopkins University*
Dr. Laszlo Kecskes *Johns Hopkins University*	**Dr. Tomoko Sano** *U.S. Army Research Laboratory*	**Professor Michael L. Falk** *Johns Hopkins University*	**Professor Timothy P. Weihs** *Johns Hopkins University*

Conventional heat treatment of Magnesium alloys causes long, thin intermetallic particles to precipitate throughout the alloy. These particles are often spaced far apart and offer little resistance to moving dislocations, leading to poor strengthening. By designing efficient thermomechanical processing routes, we are able to control microstructural features such as grain size, texture, solute decomposition, and precipitate size and spacing. Changing these features can alter the material's strength, ductility, anisotropy, and corrosion resistance. As part of our effort we are focused on understanding factors and mechanisms that influence nucleation and growth of precipitates in a Mg-9Al (wt%) alloy.

Equal Channel Angular Extrusion (ECAE) was carried out on this alloy at low temperatures and slow extrusion rates. This process leads to a bimodal microstructure that includes 1) the original matrix grains containing a high density of finely spaced, $Mg_{17}Al_{12}$ precipitates with a more compact shape and 2) sub-micron sized, recrystallized matrix grains with similarly sized $Mg_{17}Al_{12}$ precipitates along the initial grain boundaries.

We theorize that deformation enhances continuous precipitation through dislocation-assisted nucleation. In this case, Cottrell atmospheres of Al solute atoms are drawn around the dislocations and effectively reduce the nucleation barrier to zero. We used the analytical Larché-Cahn model and DFT and experimental data to calculate the massive reduction in the nucleation barrier due to these atmospheres of Al atoms around the Mg dislocations. In addition, we also used Monte Carlo and molecular dynamics simulation methods to validate the theoretical prediction and examine the fundamental assumptions of the theory.



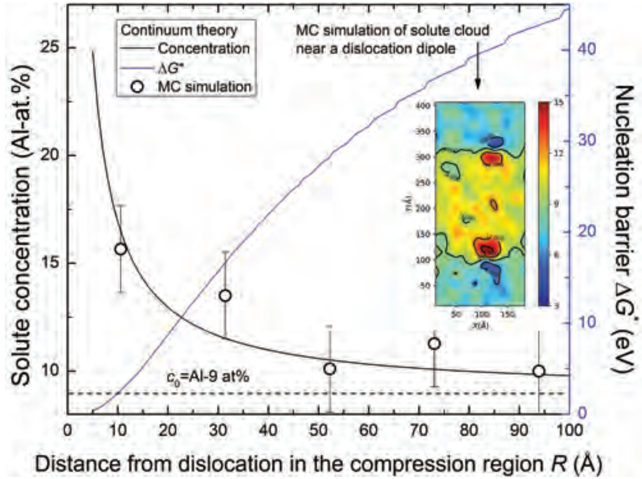


Figure 12: *Transmission electron micrograph showing a dense distribution of* ***fine*** *$Mg_{17}Al_{12}$ precipitates in a Mg-9Al (wt%) alloy processed at a low temperature using Equal Channel Angular Extrusion (ECAE) along Bc route.*

Figure 13: *Larché-Cahn theory prediction of the Al solute concentration profile in a Mg-9Al at.% alloy along the vertical line above a positive basal <a> edge dislocation, and the effect on $Mg_{17}Al_{12}$ precipitate nucleation barrier.*

(inset) Monte Carlo simulation of the solute segregation near a basal <a> edge dislocation dipole in a Mg-9Al at.% alloy.

Mapping Anisotropy and Triaxiality Effects on Strength and Deformation Stability of Magnesium Alloys

Professor Shailendra P. Joshi *University of Houston*	**Mr. Ali Nabaa** *University of Houston*	**Mr. Padmeya Indurkar** *University of Houston*
Dr. Jeffrey Lloyd *U.S. Army Research Laboratory*	**Dr. Richard Becker** *U.S. Army Research Laboratory*	**Professor Timothy P. Weihs** *Johns Hopkins University*

While a fair understanding of the microstructure-load interaction on the strength, deformation stability and damage has been achieved for common engineering alloys, the same is not true for Mg alloys. The remarkable crystallographic plastic anisotropy, tension-compression asymmetry and strong texture effects are often referred to as origins of deformation instabilities and damage intolerance in Mg. A fundamental understanding of how the net plastic anisotropy arising from crystallographic and textural effects influences the macroscopic load-deformation characteristics and deformation stability under multiaxial loading states is critical for the development of high-performance Mg alloys. This calls for a two-pronged computational approach that – (a) provides a deeper understanding of the deformation micromechanics of Mg alloys, and (b) enables efficient predictive capabilities of macroscopic deformation and flow responses under multiaxial loading.

For a systematic analysis and quantification of the emergent effects due to plastic anisotropy, loading and the microstructure, we have implemented a computational strategy that integrates and automates – (i) polycrystal generation, (ii) texture incorporation, (iii) 3D crystal plasticity (CP) finite element simulations under prescribed multi-axial stress ratios, and (iv) data mining. Separately, we have also implemented a reduced order model (ROM) based on homogenized anisotropic plasticity with tension-compression asymmetry. Our preliminary investigation suggests that despite sophisticated theory, ROM may not capture some of the most discriminating effects of the crystallographic anisotropy and textural variations on macroscopic yield responses. Our continuing effort aims at quantifying the deficiencies of the ROM and incorporating physically sound modifications to improve their predictive ability while retaining their computational efficacy.

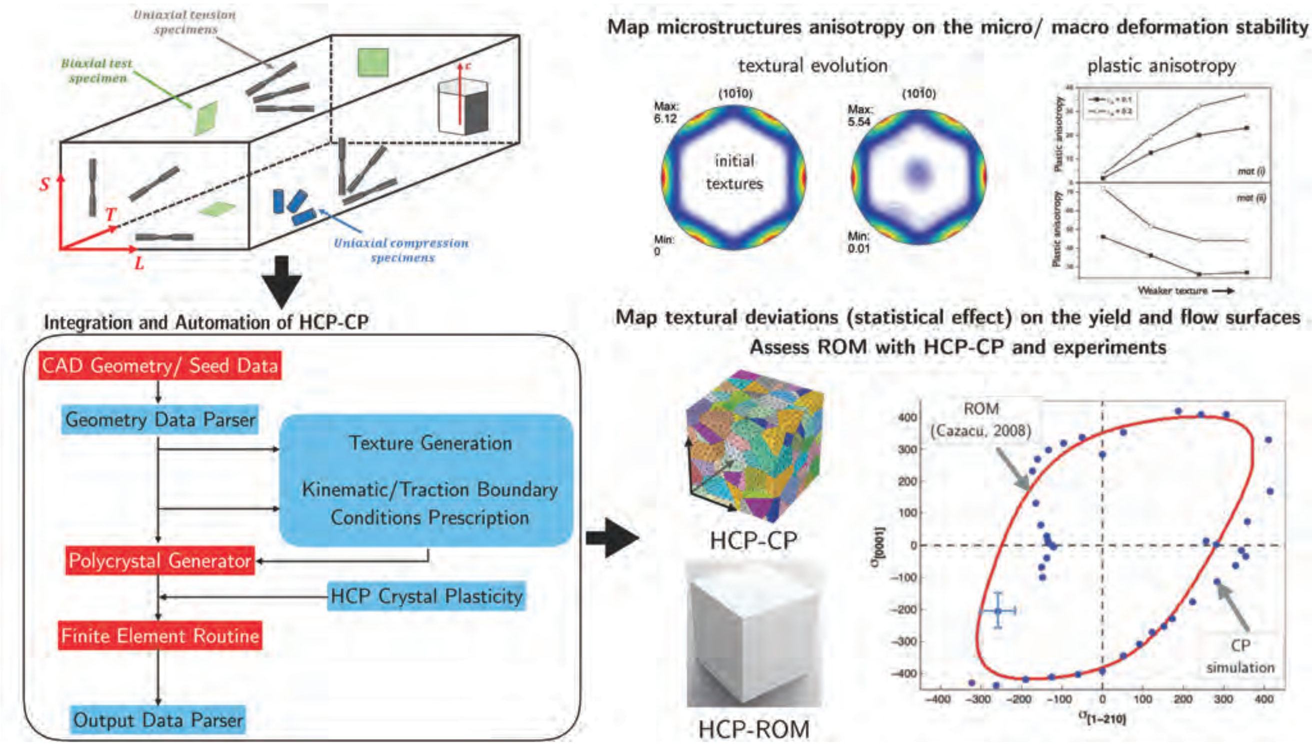


Figure 14: *Schematic of the integrated and automated computational protocol to map anisotropy-texture-loading state interaction on microscopic and macroscopic responses of polycrystalline Mg alloys.*

SUHAS ESWARAPPA PRAMEELA

Graduate student, Johns Hopkins University

MEDE Area of Research:
Deformation Driven Dynamic Precipitation in Magnesium Alloys

> "The MEDE program has set-up an excellent framework where a wide variety of researchers come together to work on interesting and challenging problems in the area of protection materials. The dynamic nature of collaboration within the program has been extremely beneficial to a young researcher like me to learn things at an accelerated pace."

PROF. SHAILENDRA P. JOSHI

Bill D. Cook Assistant Professor, Department of Mechanical Engineering, University of Houston

MEDE Areas of Research:

Plasticity Across Multiple Grains; Predicting Anisotropy-texture-triaxiality Linkages; Damage Evolution

"A fundamental understanding of how the net plastic anisotropy influences the material strength, stability, damage and failure is critical for the development of high-performance Mg alloys under dynamic conditions. Our collaboration with MEDE provides excellent opportunities to unravel heretofore elusive connections between anisotropic plasticity and damage by formulating advanced mechanics models that are informed by state-of-the-art materials science.

To paraphrase Shakespeare: To yield, or not to yield, that's the question. But we go deeper - when to let yield, how much and in what modes?"

DR. CYRIL WILLIAMS, P.E.

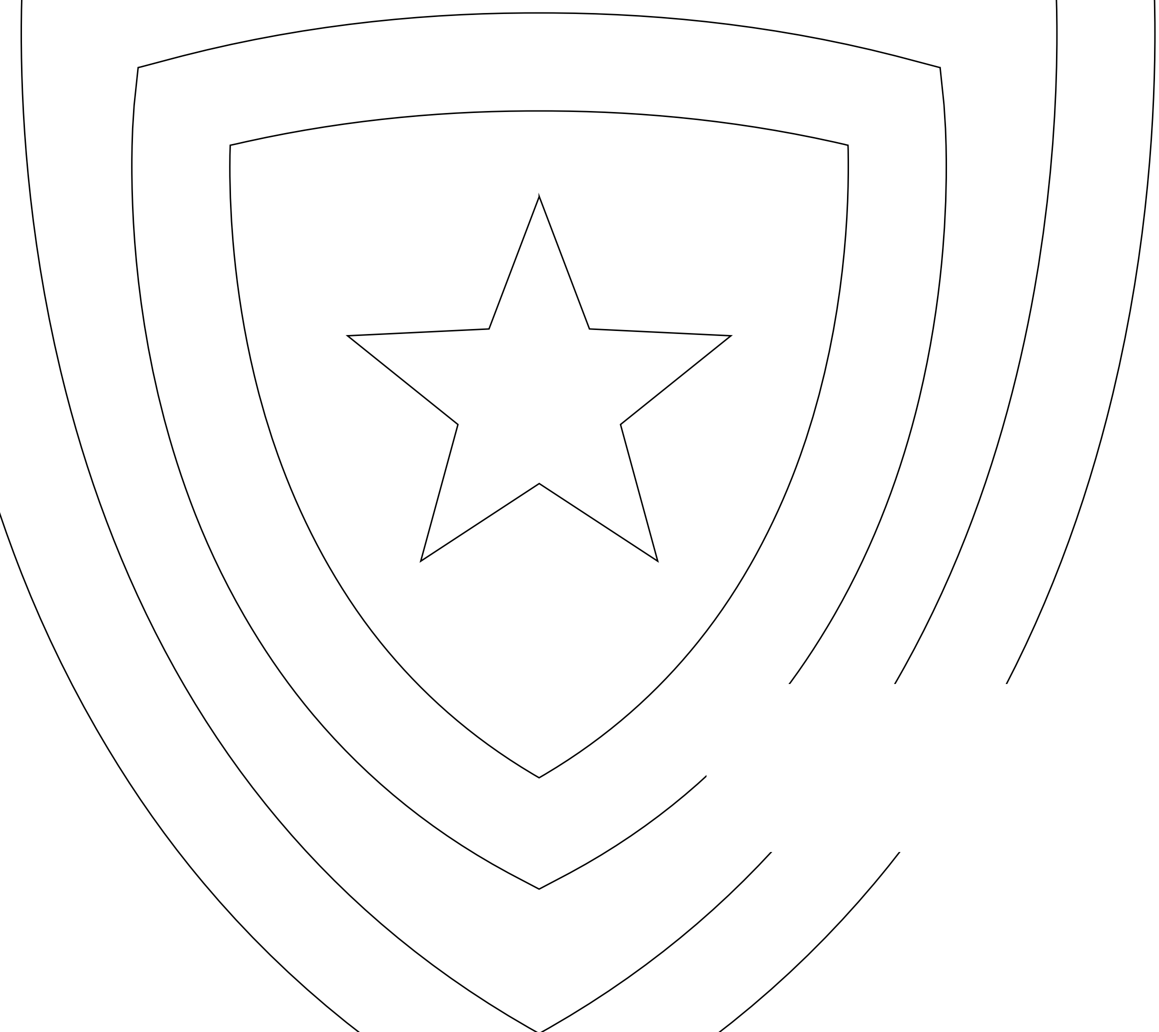
Research Engineer, U.S. Army Research Laboratory

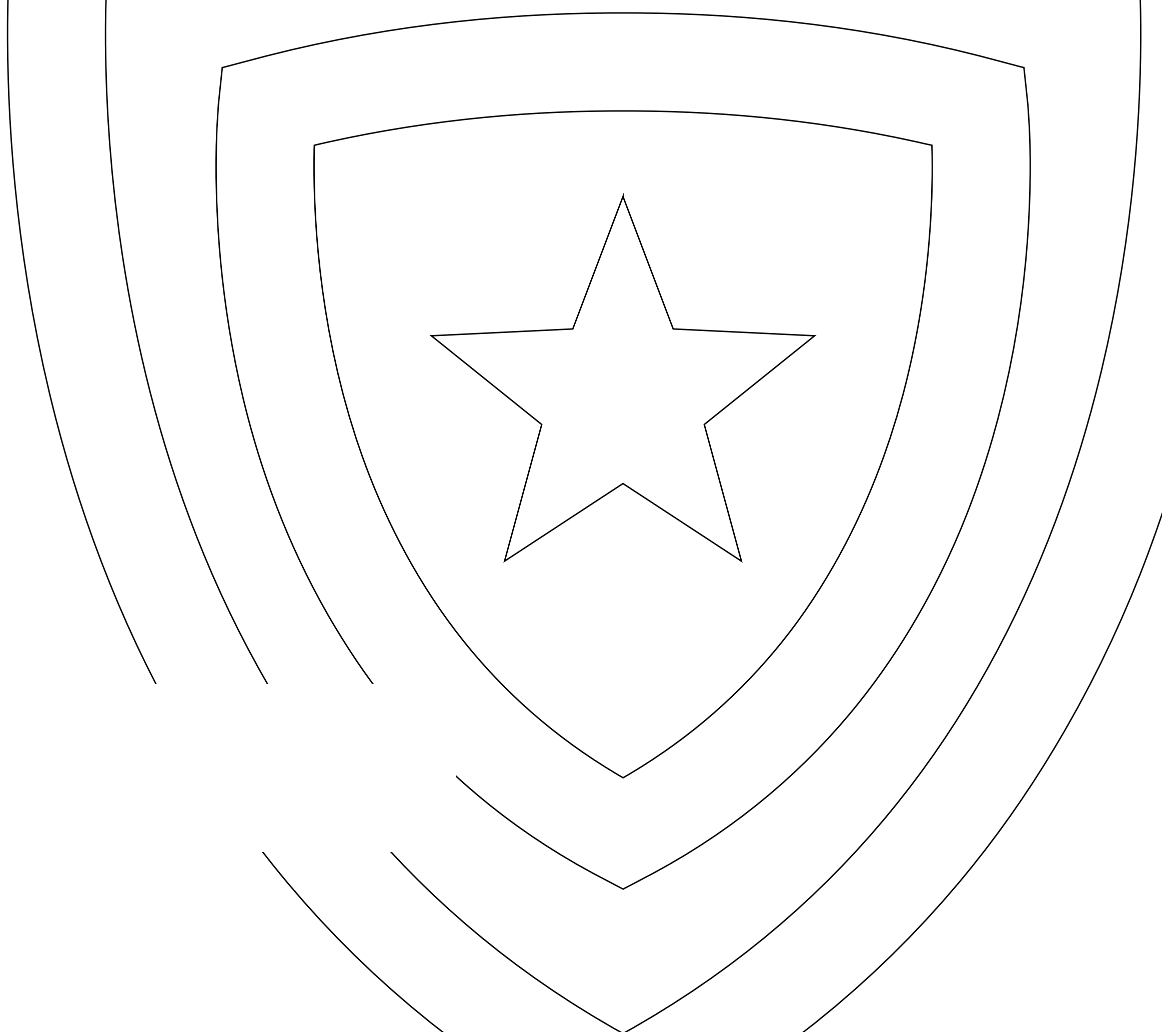
MEDE Area of Research:

Void Dominated Failure

"The MEDE program dovetails perfectly with my research pertaining to the Structure-Property Relationships in condensed matter under extreme dynamic environments. This consortium has provided me with the opportunity to collaborate with world renown researchers in their respective fields: solid mechanics, materials science and engineering, metallurgy, shock compression science, etc. Working with such diverse group of researchers has allowed me to better probe the Structure-Property Relationships in shock compressed solids at multiple length-scales. Developing a better understanding of shock compressed solids at multiple length-scales is crucial in manipulating the physics of failure such that, better materials can be developed for protection and lethality systems for the Army."

The CMEDE shield symbolizes the protection and the strong collaboration found within the MEDE program.





INTEGRATIVE AND COLLABORATIVE TOOLS


Prof. K.T. Ramesh


Prof. Lori Graham-Brady


Mr. David Elbert


Dr. Adam Sierakowski


Prof. Tamás Budavári


Dr. Betsy Rice


Prof. Erica Schoenberger


Dr. Richard Becker

SELECT CONSORTIUM PRINCIPAL INVESTIGATORS

Prof. Tamás Budavári, JHU

Mr. David Elbert, JHU

Prof. Lori Graham-Brady, JHU

Prof. K.T. Ramesh, JHU

Prof. Erica Schoenberger, JHU

Dr. Adam Sierakowski, JHU

SELECT ARL COLLABORATORS

Dr. Richard Becker

Dr. Travis Bogetti

Mr. Brian Leavy

Dr. William Mattson

Dr. Daniel J. O'Brien

Dr. Betsy Rice

Dr. Brian Schuster

Mr. Wayne Ziegler

INTEGRATIVE RESEARCH ACTIVITIES

- Collaboration Study (Schoenberger, JHU)
- Collaborative Research Administrative Environment and Data Library (Sierakowski, JHU)
- Data Science: Integration (Budavari, JHU)
- MEDE Data Science Cloud (Elbert, JHU)

MEDE-Data Science Cloud (MEDE-DSC)

The MEDE Data Science Cloud's materials-specific infrastructure provides data curation, visualization, and analysis for diverse, materials-domain problems. The MEDE-DSC is built on SciServer with data-centric computing infrastructure and collaborative integration into the materials design loop. Shared data are accessible from local, containerized, computational tools using a web based, Jupyter frontend. Version-controlled containers and notebooks bring power, consistency and transparency while moving towards reproducible, narrated computation. RESTful APIs provide integration to other MGI resources.

This year the MEDE-DSC has provided support for analysis of HIDRA (High-voltage, In-situ, Diagnostic Radiographic Apparatus) data from the WMRD ballistics range at ARL. In collaboration with Dr. Brian Schuster, we're working on accelerated analysis for time-resolved imaging of failure and fracture in boron-carbide ceramics. The analysis automates image registration and feature correlation across HIDRA's eight flash X-ray images allowing capture of penetrator parameters including dwell time, velocity, rod consumption, and penetration depth. Automating repetitive data extraction expands the options for experimental design and scaling.

The MEDE-DSC continues to work with Dr. Shawn Coleman on data curation for atomistic simulations of grain-boundaries in canonical materials. For this project, we've prototyped hosting grain-boundary data in the NIST Materials Data Curation System (MDCS) and utilized the RESTful API access for data access. Data federation is done with OAI-PMH data harvester and provider functionality.

A central role for the MEDE-DSC is helping MEDE researchers meet Big Data challenges from advances in instrumentation and computational modeling. Towards this end, we continue to develop more effective ways to capture and import the large, diverse data commonplace in materials today. In collaboration with the PARADIM Materials Innovation Project at Johns Hopkins, our work includes developing automated data streaming from instruments and user facilities.

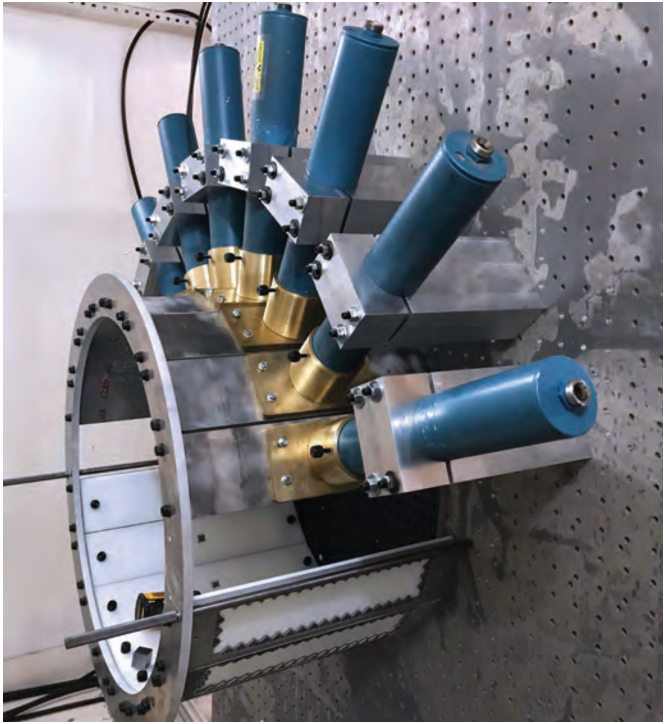


Figure 15: *ARL's High-Voltage, In-Situ, Diagnostic Radiography Apparatus (HIDRA) uses flash X-ray sources (blue) to capture time-resolved ballistic diagnostics of protection materials.*

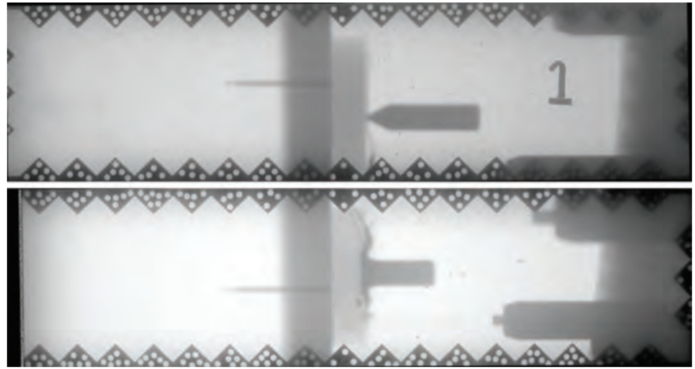


Figure 16: *HIDRA radiographs reveal projectile and target dynamics.*

ADDITIONAL COLLABORATIVE ACTIVITIES

Collaborative Research Administration Environment and Data Library (Craedl)

Contributed by: Dr. Adam Sierakowski

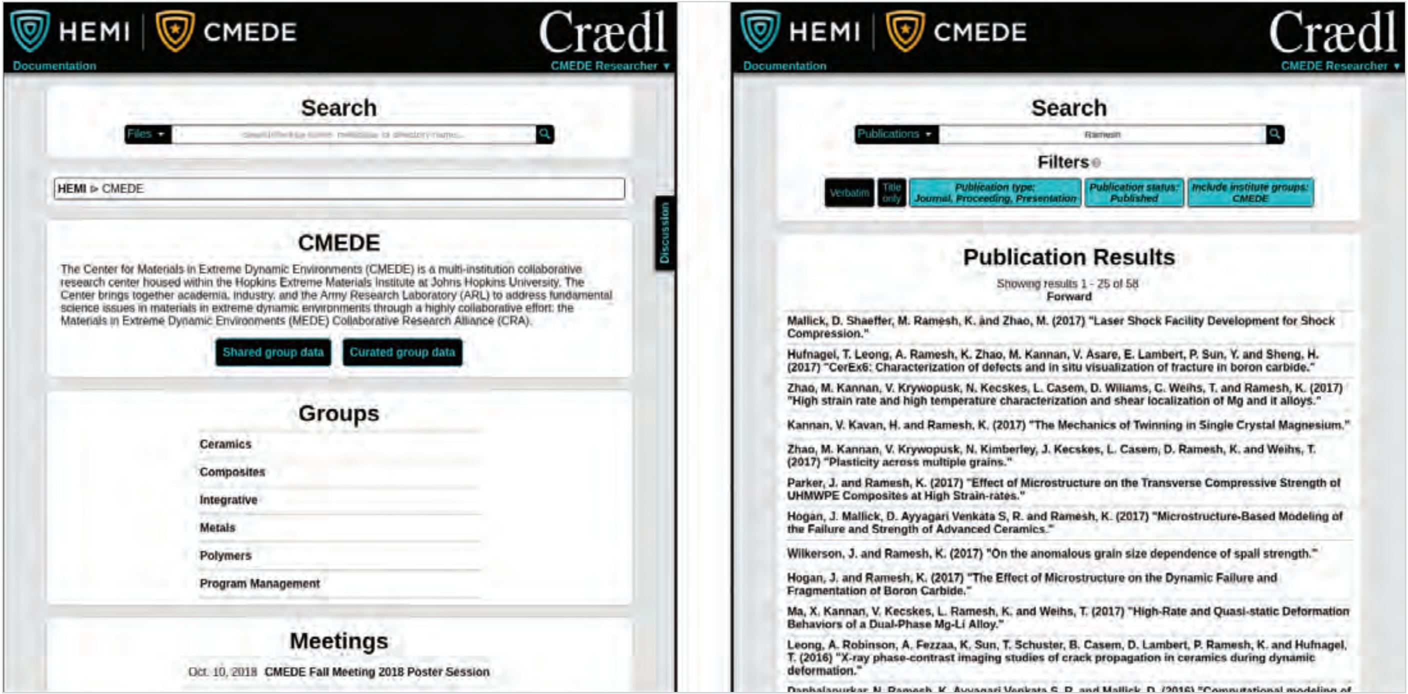
Beyond its primary scientific mission, the CMEDE consortium faces three key challenges:

1. Managing the research efforts of hundreds of researchers distributed across the country;
2. Sharing large data sets across institutional boundaries; and
3. Igniting collaborative efforts through data discovery.

Craedl, the Collaborative Research Administration Environment and Data Library, is a tool being developed to overcome these challenges. Accessible at https://craedl.org/hemi, Craedl provides a secure environment for CMEDE affiliates to store their data, share it with collaborators, and search the data shared by other affiliates.

Craedl balances structure and flexibility, enabling researchers to incorporate it directly into their workflow. By doing so, researchers can take advantage of Craedl's automatic metadata population capabilities to document their work in small increments over the life of a project. This metadata---the data that describes the data---is crucially important because it facilitates searching, which prevents data from getting lost and helps colleagues discover otherwise hidden data. Importantly, the researcher maintains complete control over his or her data: All of a researcher's data remains private unless explicitly shared with a collaborator, at which time the data becomes visible to the collaborator's searches. Further, Craedl enhances the short- and long-term operations of research groups by providing discussion boards and other group management tools that assist in the documentation of the work.

Researchers log in to Craedl using the credentials of their home institution or using their email address. Craedl organizes the network of CMEDE researchers by tracking their grants, projects, data, publications, and presentations to assist in the management of CMEDE's distributed research groups. Craedl facilitates the sharing of large data sets (up to tens of terabytes) using the Globus file transfer service and is currently underpinned by a 350 TB file storage system.



In addition to supporting the sharing, archival, and discovery of research data, Craedl helps manage CMEDE's collaborative efforts.

ARL Open Campus

The MEDE CRA embraces the ARL Open Campus Initiative. The highly collaborative nature of the MEDE program intrinsically supports consortium members working side by side with ARL scientists and engineers. In addition to taking advantage of ARL's laboratories at Aberdeen Proving Ground in Maryland, CRA members frequently utilize facilities at other MEDE consortium locations. Johns Hopkins University, Rutgers University, and the University of Delaware each have dedicated space for ARL researchers. This promotes the building of a science and technology ecosystem that encourages groundbreaking advances in basic and applied research areas of relevance to the Army.

UK Collaboration with the MEDE Programme

Contributed by: Peter Brown PhD CSci CEng FIMMM

The Dstl Materials for Strategic Advantage (MSA) Programme is funded by the UK Ministry of Defence and undertakes innovative materials research that will enable Front Line Commands to deliver future defence platforms and capabilities. MSA is now in its second year and continues to have a strong focus on materials for physical protection for the dismounted soldier and land vehicles. Recent highlights include the development of a dynamic microstructural model for armour ceramics, due to be integrated into a widely used commercial finite element simulation software, foundation of a new permanent Magnesium Fellowship at Oxford University, development of alternative boron carbide powder synthesis and processing routes, carbon nanotube toughening of polymer composites and dynamic, large deformation modelling.

Many of these have been achieved in collaboration with the US which continues to be seen as a vital UK partner for accelerating and exploiting innovative defence materials research. A good example of this is the application of micro-bullet testing, developed by MIT, Rice University, ARL and AFRL, to the high strain rate testing of micro-cantilever beams ion machined at Oxford University from alumina and boron carbide. Similarly, PhD student exchange visits between UK and US academics working on corrosion prevention, organised in collaboration with the DoD Corrosion and Policy Oversight Office, has served to significantly strengthen materials links in this area of significant mutual benefit.

The UK MSA Programme therefore looks forward to a highly productive, ongoing relationship with MEDE, both into terms of Dstl staff meeting and conference participation and the alignment of our respective research activities, including several PhD studentships MSA has recently approved for funding up to a total of around £1M a year until 2022.

MEDE Fall Meeting

The MEDE Fall Meeting is an annual, closed event that brings the entire MEDE CRA together for program overviews, collaborative activities and discussion. In 2018, the event was attended by 130 individuals including special guests from the United Kingdom's Defence Science and Technology Laboratory; US Army Engineer and Development Center and members of the MEDE Science Advisory Board. Professor K.T. Ramesh (JHU) and Dr. John Beatty (ARL) led the meeting, which focused on technical collaboration across the MEDE CRA and program planning for the upcoming year.

Mach Conference

The Mach Conference is an annual, open event that showcases the state of the art of multiscale research in materials, with an emphasis on advancing the fundamental science and engineering of materials and structures in extreme environments. MEDE CRA members are significant participants in this event, which shares research discoveries to the broader community.

SIGNIFICANT MEETINGS

EMRM RMB

On January 26, 2018, the Research Management Board (RMB) convened at Johns Hopkins University to review the Enterprise for Multiscale Research of Materials (EMRM). The RMB was co-chaired by the director of the Army Research Laboratory and the director of Basic Research from the Office of the Assistant Secretary of the Army (Acquisition, Logistics and Technology). The review focused on technical and programmatic accomplishments of the MEDE and MSME CRAs.

MEDE Science Advisory Board

The MEDE Science Advisory Board is convened annually to review the scientific and collaborative activities within the program. The Board's recommendations in coordination with those from ARL's Technical Advisory Board are used to help prioritize research activities and shape the overall program.

ASA(ALT) Visit

On April 3, 2018, Dr. Kimberly Sablon, director of Basic Research, Office of the Assistant Secretary of the Army (Acquisition, Logistics and Technology) made a visit to the Hopkins Extreme Materials Institute at Johns Hopkins University. During the visit, she received updates on the MEDE program, toured the laboratories, and met with students. She was accompanied by Ms. Cindy Bedell, director of ARL's Computational and Information Sciences Directorate.

Congressional Staffer Visits

Legislative staffers from the offices of U.S. Senator Ben Cardin, U.S. Senator Chris Van Hollen, U.S. Congressman C.A. Dutch Ruppersberger (Maryland, Second District), U.S. Congressman John Sarbanes (Maryland, Third District), and U.S. Congressman Steny Hoyer (Maryland, Fifth District) visited MEDE facilities at Johns Hopkins University on July 30, 2018. Additionally, in October, legislative staffers from the office of U.S. Senator Christopher Coons visited the MEDE facilities at the University of Delaware.

Legislative staffers during their visit to the CMEDE laboratories at Johns Hopkins University.

Pictured left to right: D.K. Morris (Defense Fellow, Sen. Cardin), Peter Gelman (Legislative Assistant, Rep. Sarbanes), Kristen Reek (JHU), Rachel Snyder (Senior Policy Advisor, Rep. Hoyer), K.T. Ramesh (JHU), Alyssa Penna (Health Policy Advisor, Sen. Van Hollen), Chuck Conner (Deputy State Director, Sen. Van Hollen), Kevin Miller (Defense Fellow, Rep. Ruppersberger), Lori Graham-Brady (JHU).

Members of the University of Delaware CCM pose with legislative staffers during their visit to campus.

From left: Sanjib Chowdhury (UDel), Christopher Meyer (UDel), Jejoon Yeon (UDel), Raja Ganesh (UDel), John W. Gillespie, Jr. (UDel), Drew Story (Legislative Fellow, Sen. Coons), Franz Wuerfmannsdoble (Deputy Chief of Staff, Sen. Coons), Allie Davis (Legislative Aide, Sen. Coons), Andrew Dinsmore (Projects Manager, Sen. Coons), and Tyler Rivera (Constituent Advocate, Sen. Coons).

Research Management Board members pose with Dean T.E. 'Ed' Schlesinger of the JHU Whiting School of Engineering.

RELATED ACADEMIC PROGRAMS

In addition to its research activities, CMEDE runs several academic programs that broaden the scientific impact of the MEDE program.

Traditional

- Short Courses – Intensive, two-day courses taught by a master in his/her field that are co-sponsored by the Hopkins Extreme Materials Institute. Attendees include professionals, researchers, and graduate students from industry, government, national laboratories and academia.

- Lectures and Seminars – CMEDE supports the Enterprise for Multiscale Research of Materials lecture series that helps to educate and promote collaboration across the entire enterprise. Additionally, CMEDE hosts seminars from distinguished experts from scientific fields related to MEDE research.

Prof. Jean-Francois Molinari gives a short course on Numerical Methods for Modeling Dynamic Fracture of Materials.

Internships and Apprenticeships

- Extreme Science Internships (ESI) – The ESI program is a year-round, paid internship program with Morgan State University. ESI provides internal internships at Morgan State to allow students to develop their research skills before participating in an external internship at a MEDE CRA location. ESI has been a highly successful program and serves as a model collaboration for student development.

- Undergraduate Research and Apprenticeship Program (URAP). URAP provides undergraduate students with an authentic science and engineering research experience alongside university researchers at one of the MEDE university locations. Through this program, students develop skills in Army critical science and engineering research areas to prepare them for the next steps of their educational and professional career. URAP is sponsored by the Army Research Office and is a part of the Army Educational Outreach Program.

- Research and Engineering Apprenticeship Program (REAP). The Hopkins Extreme Materials Institute (HEMI), parent to CMEDE at Johns Hopkins University, was selected as a host site for REAP. REAP is a summer STEM program that places talented high school students, from groups historically under-represented and underserved, in STEM in research apprenticeships. REAP apprentices work under the direct supervision of a mentor on a hands-on research project. REAP is a part of the Army Educational Outreach Program.

URAP intern Kaitlin Wang investigates the effect of molten salt on boron nitride synthesis during her internship at Rutgers University.

Other Activities

- HEMI/MICA Extreme Arts Program – The HEMI/MICA Extreme Arts Program is an initiative that brings faculty and students from Johns Hopkins University and the Maryland Institute College of Art (MICA) together to explore unique perspectives on extreme events. The program aims to encourage collaboration among artists and researchers to examine data, interpret outcomes, and translate results from extreme events in new ways. It is our hope that this dialogue will create a stronger community through a shared sense of curiosity and exploration. CMEDE is a significant participant in this program.

2018 AEOP Research in Engineering Apprenticeship students

CMEDE STRATEGIC PARTNERSHIPS

MEDE has established strategic partnerships with several key organizations. These partnerships enable CMEDE to collaborate, leverage resources and broaden its impact to the scientific community.

Subcommittee of the Materials Genome Initiative (SMGI) of the National Science and Technology Council	**Center for Composites Materials (CCM)**	**Army Educational Outreach Program**	**US Advanced Ceramics Association (USACA)**

The Insitute for Data Intensive Engineering and Science	**Air Force Research Laboratory**	**Maryland Advanced Research Computing Center (MARCC)**

Lightweight Innovations for Tomorrow (LIFT)	**Ceramics, Composite and Optical Materials Center (CCOMC)**	**U.S. Naval Research Laboratory**	**National Institutes of Standards and Technology**

CMEDE LEADERSHIP AND STAFF MEMBERS AT JOHNS HOPKINS UNIVERSITY

CMEDE Leadership

Prof. K.T. Ramesh
Director

Prof. Lori Graham-Brady
Associate Director

Dr. Victor Nakano
Executive Program Director

CMEDE Staff

Jessica Ader
Communication Specialist

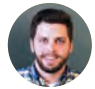
Bess Bieluczyk
Senior Administrative Coordinator

Ryan Bradley
Software Engineer

Tia Brownlee
Budget Analyst

Lisa Eklund
Grants and Contracts Manager

Scott McGhee
Senior Administrative Manager



Andrew Proulx
Grants and Contracts Analyst

Phyllis Sevik
Research Service Manager

Matthew Shaeffer
Staff Engineer

Katie Vaught
Senior Administrative Coordinator

ABBREVIATIONS AND ACRONYMS

AEOP	Army Educational Outreach Program
ARL	Army Research Laboratory
ASA(ALT)	Assistant Secretary of the Army (Acquisition, Logistics, and Technology)
CALTECH	California Institute of Technology
CCM	Center for Composite Materials
CCOMC	Ceramic, Composite and Optical Materials Center
CMC	Consortium Management Committee
CMEDE	Center for Materials in Extreme Dynamic Environments
CMRG	Collaborative Materials Research Group
CTRG	Collaborative Technical Research Group
CRA	Collaborative Research Alliance
CRAEDL	Collaborative Research Administration Environment and Data Library
DELAWARE	University of Delaware
DOD	Department of Defense
DREXEL	Drexel University
DSTL	Defence Science and Technology Laboratory
EMRM	Enterprise for Multiscale Research of Materials
ESI	Extreme Science Internship
HEMI	Hopkins Extreme Materials Institute
JHU	Johns Hopkins University
MEDE	Materials in Extreme Dynamic Environments
MEDE CRA	MEDE Collaborative Research Alliance
MGI	Materials Genome Intitative
MICA	Maryland Institute College of Art
MSU	Morgan State University
NC A&T	North Carolina Agricultural & Technical State University
NIST	National Institute of Standards and Technology
NMT	New Mexico Institute of Mining and Technology
PURDUE	Purdue University
REAP	Research in Engineering Apprenticeship Program
RMB	Research Management Board
RUTGERS	Rutgers University
STEM	Science, Technology, Engineering and Math
UNCC	University of North Carolina at Charlotte
URAP	Undergraduate Research and Apprenticeship Program

IN MEMORIAM: DR. BRAD E. FORCH

Dr. Forch was born in Chicago, Illinois in 1955. He earned a Bachelor of Science degree in chemistry and a Master of Science degree in physical chemistry from Illinois State University (ISU) in 1978 and 1979, respectively. He received a Ph.D. in physical chemistry/chemical physics from Wayne State University (WSU) in 1984.

He was a National Research Council Postdoctoral Fellow at the Ballistic Research Laboratory in 1985, where he performed research in laser spectroscopy in the areas of ignition and combustion research. He was subsequently hired as a civilian employee in 1986. His research contributions led to the discovery of a new laser-based resonant ignition mechanism that rapidly transitioned to practical applications for many Army weapons systems. From 1986 to 1994, this work was the subject of intense research that fed parallel developmental efforts for large caliber weapons systems within the Army. The work led to extensive new research programs, international collaborations, 40 Small Business Innovation Research (SBIR) programs, and the creation of a new industrial capability within the U.S. During this period, he published 30 journal articles, 28 technical reports, and over 100 technical publications. In 1994, Dr. Forch was asked to be branch chief and served 15 years up through January 2009 as Chief of the Propulsion Science Branch, composed of approximately 60 scientists and engineers.

Dr. Forch served as a member of the Research Management Board and provided key advice to help guide the MEDE CRA.

Throughout his Army career, Dr. Forch has been a strong proponent of the idea that the need for discovery from basic research does not end once a specific use is identified, but continues through numerous supporting connections to development and application activities. High-risk basic research can provide risk mitigation to extremely complex and challenging applications research programs, which lead to new capabilities for the Army. He will be greatly missed by members of the MEDE CRA.

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For more information on CMEDE, visit us at: hemi.jhu.edu/cmede,
call us at 410-516-7257 or email us at mede@jhu.edu.

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