CMEDE

CENTER FOR
MATERIALS IN EXTREME
DYNAMIC ENVIRONMENTS

2019 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.


IMPACT SPORT

TABLE OF CONTENTS

From the Director 4
About Us 6
Organization 8
Structure 10
Research Strategy 14
Supporting U.S. Army Multi-Domain Operations 2028 16
Research Activities 18
Ceramics 21
Composites 31
Metals 41
Integrative and Collaborative Tools 51
Additional Collaborative Activities 56
Significant Meetings 60
Related Academic Programs 64
CMEDE Strategic Partnerships 67
CMEDE Leadership and Staff Members 68
Abbreviations and Acronyms 69
Contact Us 70

CONSORTIUM MANAGEMENT COMMITTEE

FROM THE CMEDE DIRECTOR:

As the Materials in Extreme Dynamic Environments Collaborative Research Alliance (MEDE CRA) completes its 8th year, we are excited to present our highlights for 2019. The research conducted within our three materials groups (ceramics, composites, and metals) have achieved significant scientific advances, resulting in the designing of new materials and transitioning of new computational design codes and tools to the CCDC Army Research Laboratory (ARL). These research groups have also allowed us to continue our dedication to educating and building the materials-by-design workforce. As of this writing, the MEDE consortium has graduated 55 doctoral students and 30 post-doctoral researchers into DoD/National laboratories, academia and industry.

This year, we welcomed Dr. Sikhanda Satapathy as the new Collaborative Alliance Manager and look forward to his leadership. Additionally, we provided a program update to the new Army Futures Command as well as underwent a successful midcycle review of the MEDE program with the ARL chief scientist. In 2019, we again experienced significant Congressional interest in the MEDE program. The consortium hosted several visits by Congressional delegations and legislative staff, and I am pleased to report they have been impressed by what the MEDE CRA has accomplished.

Our academic programs continue to lead the way for U.S. Army STEM programs. We supported the highest number Army Educational Outreach Program undergraduate internships this past summer. The Extreme Science Internship program with Morgan State University continued to excel in the depth and breadth of research experiences for minority students. Finally, we established a joint research fellowship with the Defence Science Technology Laboratory of the United Kingdom which will promote an exchange of students between our two countries.

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

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Director, CMEDE

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of Science and Engineering

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and Planetary Sciences, Materials
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Collaborative Alliance Manager
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RICHARD HABER

Professor, Materials Science
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Rutgers University

ABOUT US

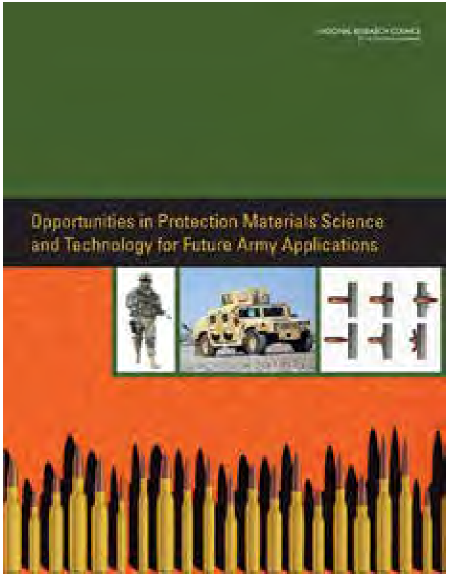
In 2010, two National Research Council boards established a committee to examine opportunities in protection materials science and technology for future Army applications. This committee recommended that the Department of Defense establish an initiative for protection materials by design. This initiative 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 U.S. Army Combat Capabilities Development Command Army Research Laboratory (CCDC 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.

> **Called the Enterprise for Multiscale Research of Materials (EMRM), the focus of the program is to develop a materials-by-design capability for the US Army using validated multiscale and multidisciplinary modeling capabilities to predict material structure, properties, and performance.**

The EMRM enables CCDC 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, CCDC 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



National Research Council report

within the consortium of university and research partners, to establish the Center for Materials in Extreme Dynamic 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.

> **"The MEDE program has developed advanced materials...these materials all reduce the size and weight of vehicle armor while enhancing protection...in my opinion, we need to keep the research and development moving ahead in this area."**
>
> **- CONGRESSMAN DUTCH C.A. RUPPERSBERGER (D-MD)**
> *House Appropriations Committee, Subcommittee on Defense hearing on U.S. Army budget request for FY2020*

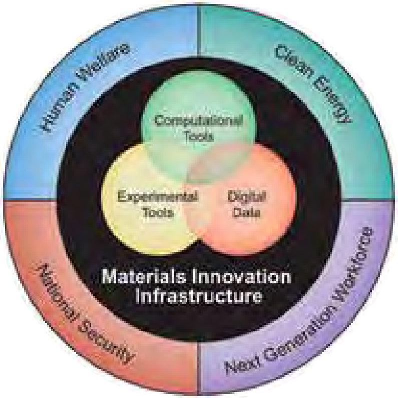


Figure 1: *Materials Genome Initiative: MEDE focuses on developing the experimental and computational tools needed to develop protection materials for national security.*

ORGANIZATION

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

- **Johns Hopkins University (Lead)**
- **California Institute of Technology**
- **University of Delaware**
- **Rutgers University**
- **Defence Science and Technology Laboratory (United Kingdom)**
- **Drexel University**
- **Ernst Mach Institut (Germany)**
- **ETH Zürich (Switzerland)**
- **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**

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

JOHNS HOPKINS
UNIVERSITY

Caltech

UNIVERSITY OF DELAWARE

LEHIGH
UNIVERSITY

RUTGERS

Drexel
UNIVERSITY

MORGAN
STATE UNIVERSITY

DEVCOM

NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH • UNIVERSITY

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PURDUE
UNIVERSITY

SwRI

TEXAS A&M
UNIVERSITY

UNIVERSITY of
HOUSTON

UNC CHARLOTTE

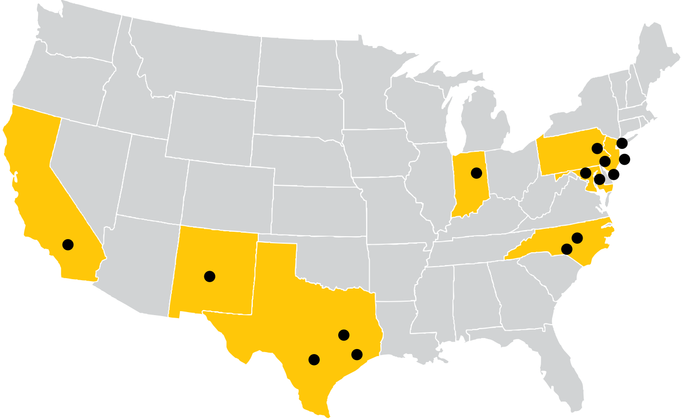


Figure 2: *MEDE Collaborative Research Alliance*

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 CCDC 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 CCDC ARL Collaborative Alliance 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 a CCDC 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 a CCDC ARL researcher co-leading each major effort.

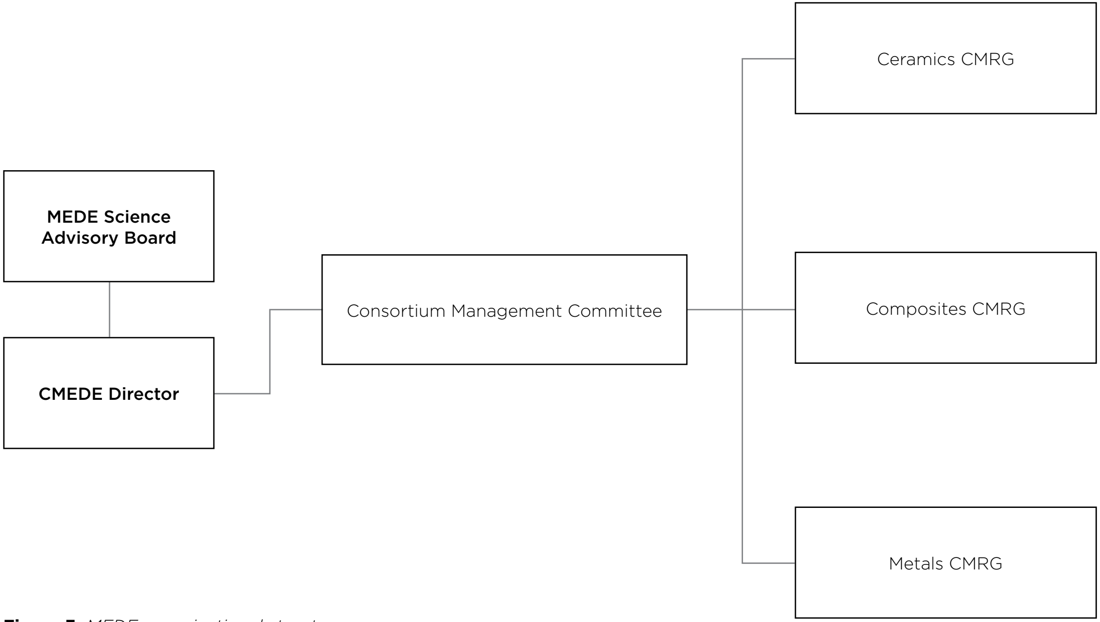
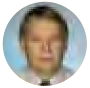
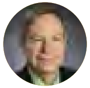


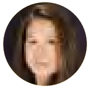
Figure 3: *MEDE organizational structure*

Members of the MEDE Science Advisory Board with Dr. Sikhanda Satapathy, CCDC ARL (far left) and Prof. KT Ramesh (far right): Prof. David McDowell, Dr. Douglas Templeton, Prof. Thomas Russell, Prof. Marc Meyers, Prof. Steven McKnight.

MEDE SCIENCE ADVISORY BOARD MEMBERS


Dr. Douglas Templeton
DWT Consulting (Acting Chair)


Dr. Charles E. Anderson, Jr.
CEA Consulting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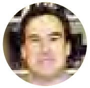
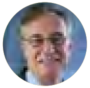
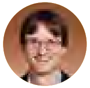
University of California, Santa Barbara

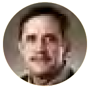

Professor Horacio Espinosa
Northwestern University

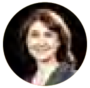

Professor David McDowell
Georgia Institute of Technology

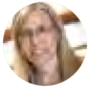

Professor Steve McKnight
Virginia Polytechnic Institute


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

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 4. 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.

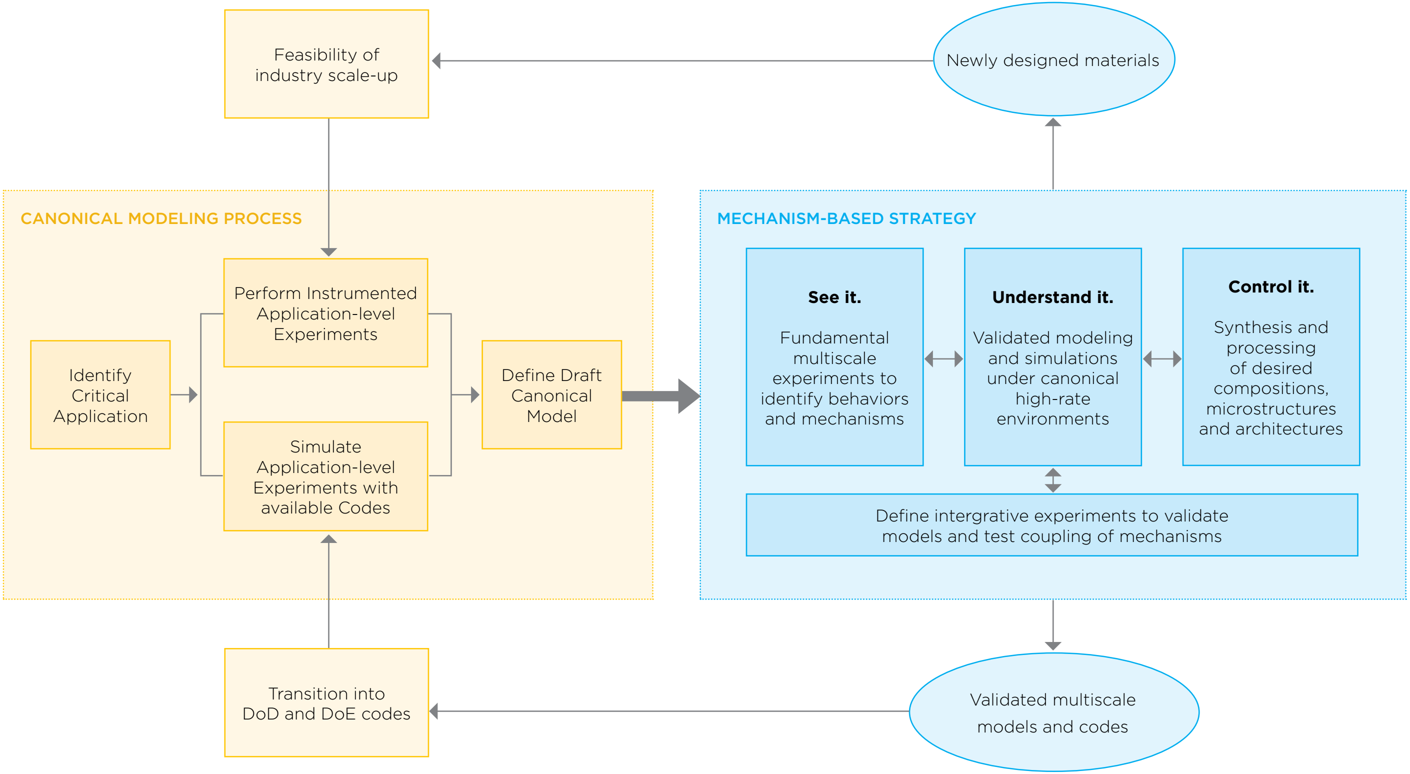


Figure 4: *Overall design strategy for protection materials. Left hand boxes are driven by CCDC ARL, while right hand boxes are driven by the MEDE Consortium.*

SUPPORTING U.S. ARMY MULTI-DOMAIN OPERATIONS 2028

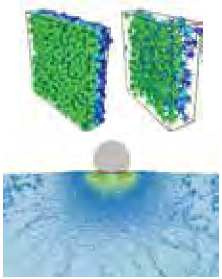
MATERIALS-BY-DESIGN STRATEGY

Advanced Experiments

Simulating ballistic events through high strain rate experiments

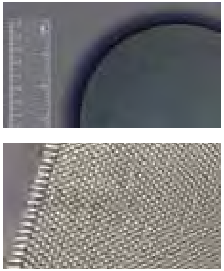
Computational Modeling

Modeling from the atomistic to the continuum scales



Synthesis & Processing

Creating new materials to validate experimental and modeling data



MATERIALS-BY-DESIGN RESULTS

- **New lightweight materials**
- **Computational codes for armor material design**
- **Knowledge products**
- **Scientific discovery**
- **Use-inspired research**


U.S. ARMY MULTI-DOMAIN OPERATIONS 2028

> “**Tactical overmatch** is the product of adaptable, aggressive leaders and soldiers organized in cohesive, well-trained formations; and **aircraft, fighting vehicles, small units, and individuals with superior mobility, protection, and lethality.**”

Army Material Modernization Priorities

Developing material solutions to support new protection concepts:

- **Soldier Lethality**
- **Next Generation Combat Vehicle**
- **Future Vertical Lift**

CCDC ARL Core Competencies & Essential Research Programs

- **Terminal ballistics and materials research**
- **Physics of soldier protection to defeat evolving threats**
- **Convergence of lethality, protection and autonomy to dominate ground combat**

MEDE Provides Foundational Research

- **Advanced Experiments**
- **Computational Modeling**
- **Synthesis & Processing**

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.

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.

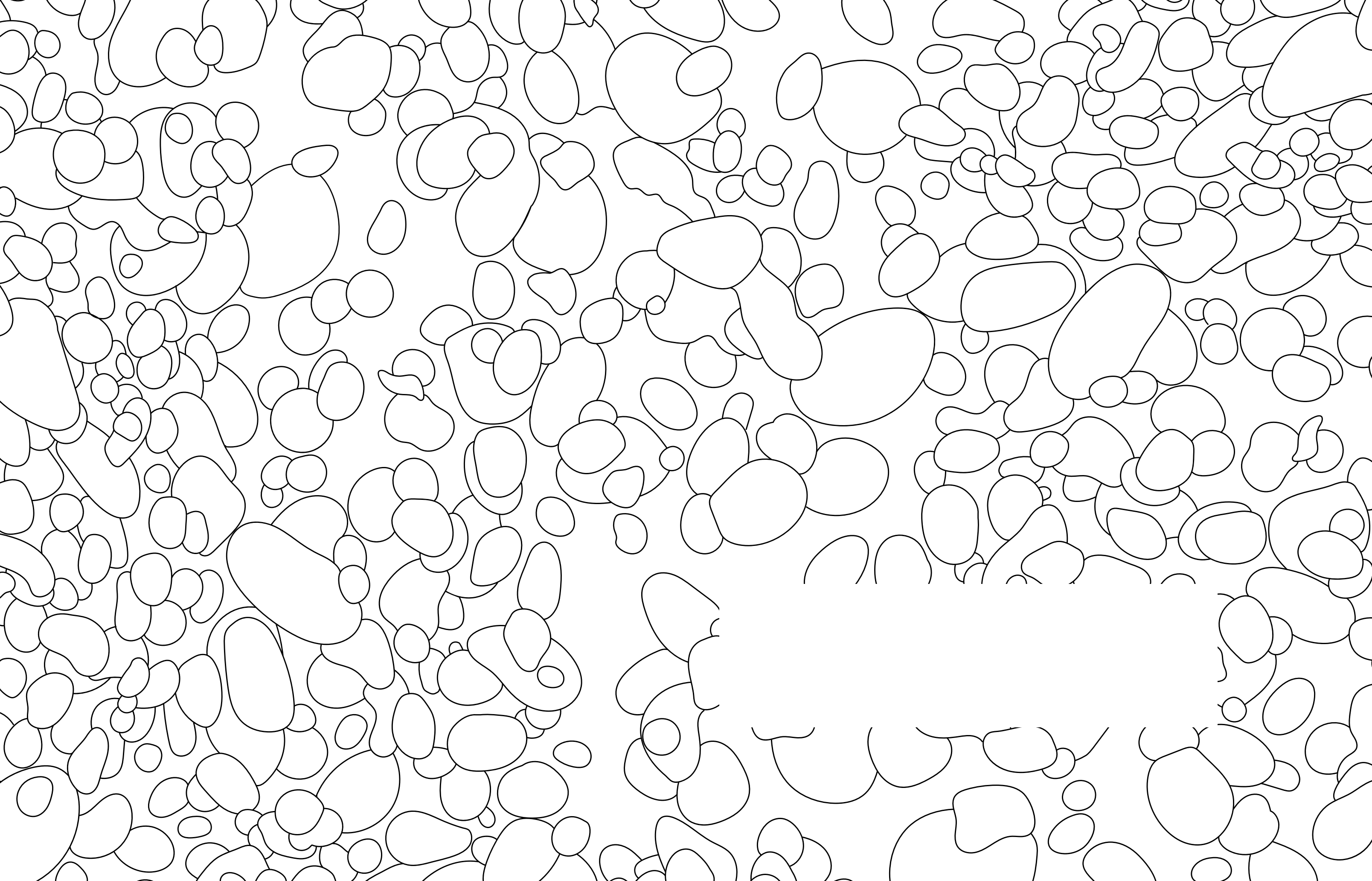
- **Synthesis and Processing:** incorporate research discoveries to enable the synthesis of novel materials and the processing of final products with critical material characteristics and resulting properties.

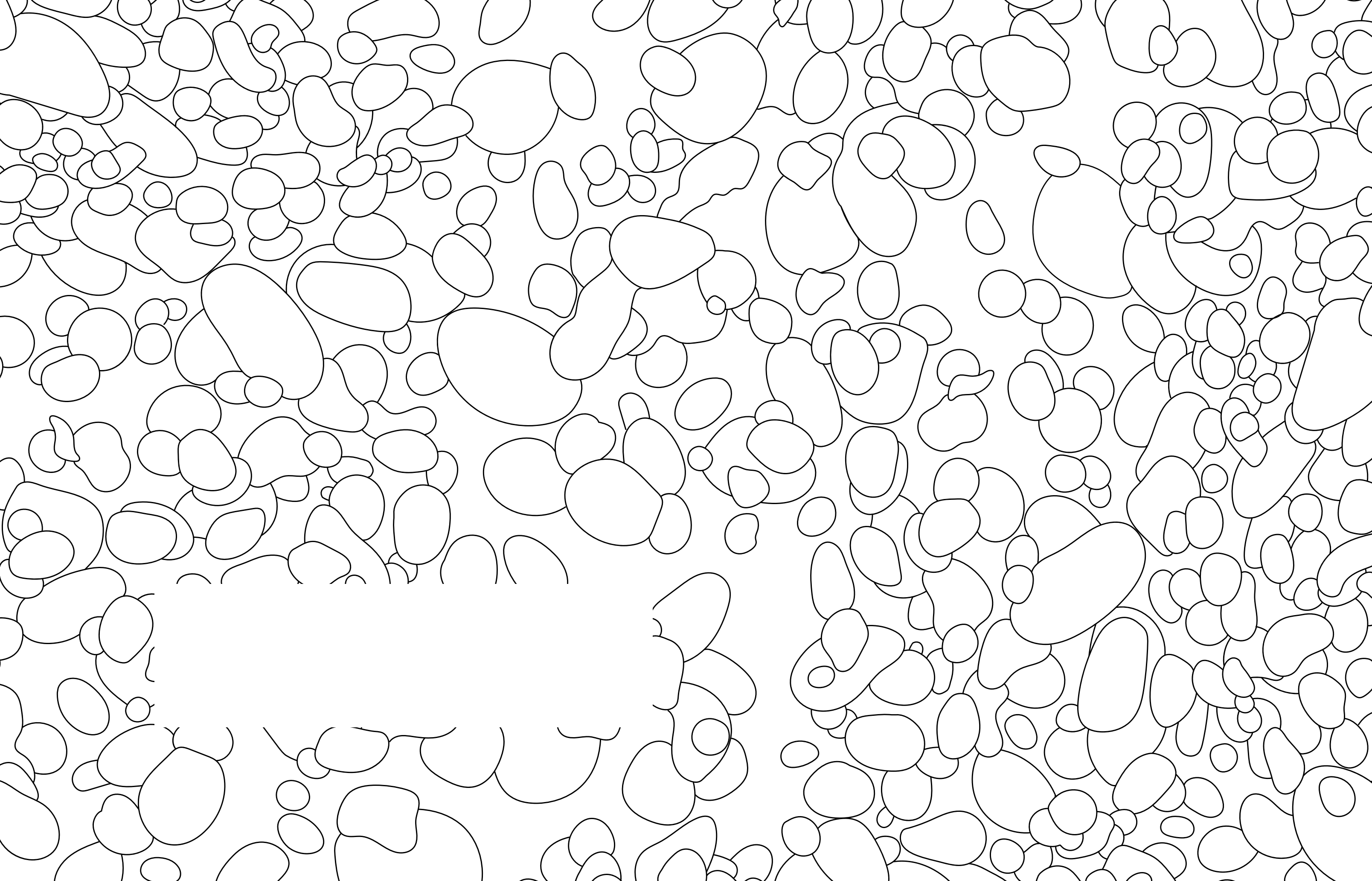
Michael Straker (MSU)

Jason Parker (JHU)

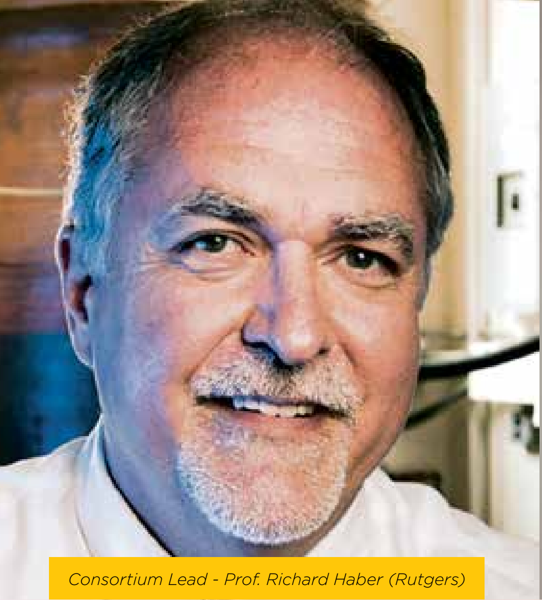
Jenna Krynicki (JHU)

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





CERAMICS


Consortium Lead - Prof. Richard Haber (Rutgers)


CCDC ARL Lead - Dr. Jerry LaSalvia


Ceramics CMRG

CONSORTIUM INVESTIGATORS

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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

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Prof. Mark Robbins, JHU

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Dr. Taylor Shoulders

Dr. Jeffrey Swab

Dr. Jennifer Synowczynski-Dunn

Dr. Andrew Tonge

Dr. Lionel Vargas-Gonzalez

Dr. Scott Walck

N. Scott Weingarten

Dr. Cyril Williams

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, Rutgers; Ramesh and Hemker, JHU)
- Synthesis and Processing (Haber, Rutgers; Harmer and Marvel, Lehigh; Spencer, Morgan State; Chandrashekhar, South Carolina)

Grain Boundary Structures and Compositions of Si Graded Boron Carbide

Dr. Christopher Marvel
Lehigh University

Professor Martin Harmer
Lehigh University

Dr. Anthony Etzold
Rutgers University

Dr. Vlad Domnich
Rutgers University

Professor Richard Haber
Rutgers University

Dr. Kristopher Behler
CCDC Army Research Laboratory

Dr. Jerry LaSalvia
CCDC Army Research Laboratory

Si-doping has the potential to improve the fracture resistance of boron carbide. For example, it has been shown that Si substitution into the 3-atom chains limits icosahedra disintegration and therefore reduces stress-induced amorphization. While mechanical benefits of Si-doping into the bulk lattice are proven, it is relatively unclear how Si is realistically distributed throughout boron carbide microstructures (i.e. bulk lattice, grain boundaries, and second phases) with given doping concentrations. Considering grain boundaries, another strategy to improve fracture resistance is to engineer Si-rich nanolayer films and promote intergranular fracture, similar to toughening silicon nitride via Si-rich intergranular films (IGFs). The current work aims to explore bulk and grain boundary thermodynamics of Si-doped boron carbide with the ultimate goal to incorporate nanolayer films and maximize fracture toughness of boron carbide.

A diffusion couple of boron carbide (B_4C) and silicon hexaboride (SiB_6) was hot-pressed using 50 MPa applied pressure at 1600 °C for 24 hours. Fabricating a diffusion couple (i.e. Si graded boron carbide) ensured that varying Si bulk solubilities in boron carbide were achieved and the resulting effect on grain boundary structure and composition could be studied. The hypothesis is that the maximum amount of Si solubility will maximize the probability of the formation of nanolayer films. Finally, aberration-corrected scanning transmission electron microscopy (ac-STEM) was conducted at Lehigh University.

Figure 5a shows the diffusion zone between the B_4C and SiB_6 polycrystals. The bright bands across the diffusion zone designate where thin specimens were extracted using focused ion beam methods. Typical grain boundary structures are shown in Figures 5b-d where the increased intensities in each image indicate an enhancement of Si. However, while Si clearly segregates to grain boundaries, there is no evidence of the formation of disordered Si-rich nanolayer films. The bulk Si solubility (at.%) and average excess grain boundary coverage (atoms/nm^2) from each region were determined using ζ-factor microanalysis. The average excess coverage was determined from at least five grain boundaries and the results are shown in Figure 6. Here it is demonstrated that increasing Si concentration in boron carbide increases the extent of Si segregation. The current observations of this work show that despite the high Si solubility in the boron carbide lattice, Si-rich nanolayer films, which could potentially improve fracture resistance, are likely not stable in boron carbide if Si is the sole additive. Future work may include doping boron carbide with other additives in addition to Si that could promote the formation of disordered nanolayer films and thus improve fracture toughness.

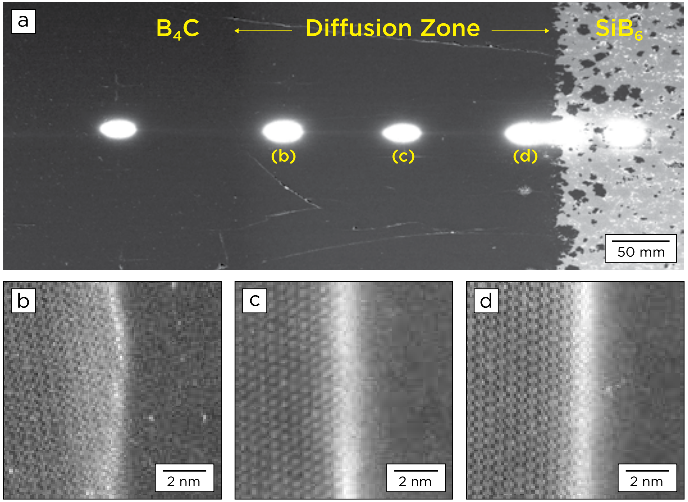

Figure 5: *Bulk and grain boundary imaging of a* SiB_6*:*B_4C *diffusion couple annealed at 1600 °C for 4 hours. The backscatter electron micrograph shown in (a) is the bulk microstructure. The bright bands indicate the locations where thin specimens are extracted for atomic-resolution characterization. Several high-angle annular dark field images in (b-d) are examples of grain boundary structures in different regions of the diffusion zone with increasing Si bulk concentrations.*

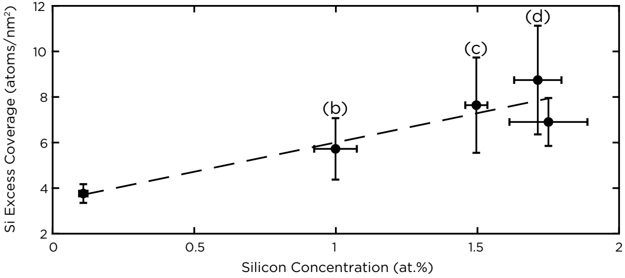

Figure 6: *Average Si excess coverage measurements from different regions of the diffusion zone. The points labeled (b-d) correspond to Figures 5b-d.*

Modeling the Transition to Granular Phase and Subsequent Granular Flow in Highly Comminuted Ceramics

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Dr. Andrew Tonge
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Dr. Joel Clemmer
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Professor KT Ramesh
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Under impact loading, highly comminuted ceramics transition to a granular phase and undergo granular flow. Characterising the post peak strength transition to rapid fragmentation and subsequent granular flow is difficult to capture experimentally. Our current work attempts to address the competitive crack coalescence leading to fragmentation and uses a continuum breakage mechanics model for the subsequent mobility of fragments and tracking the evolving fragment size distribution.

Crack size statistics obtained at each instant from flaw size statistics using a wing crack growth-based damage model has been used to model three dimensional elliptical cracks. Using different nearest crack models, crack coalescence has been addressed, enabling prediction of fragment size/shape distributions using a connected region-based algorithm. This model also provides insights regarding the criterion for transition from damaged solid to granular medium. The predicted fragment statistics serve as an input to a breakage mechanics-based continuum granular flow model. A micro-mechanics based damage model, the granular transition model, and breakage mechanics model all form the framework of the Ceramics CMRG's integrative model (built on the Tonge-Ramesh constitutive code), which helps understand the dynamic response of brittle ceramics including evolving fragmentation and post peak softening response.

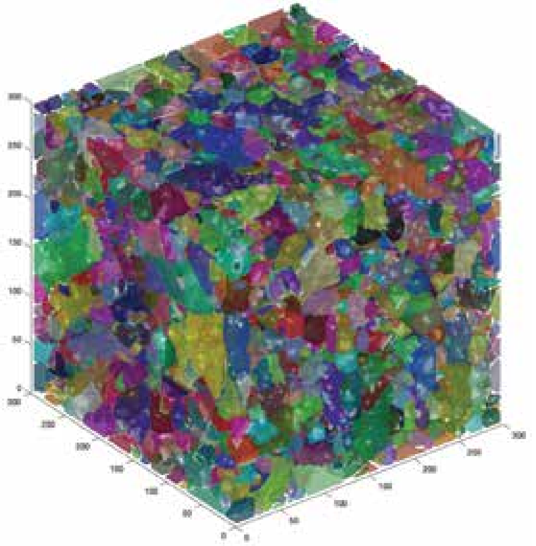


Figure 7: *Representative fragmentation of ceramics at the onset of granular flow.*

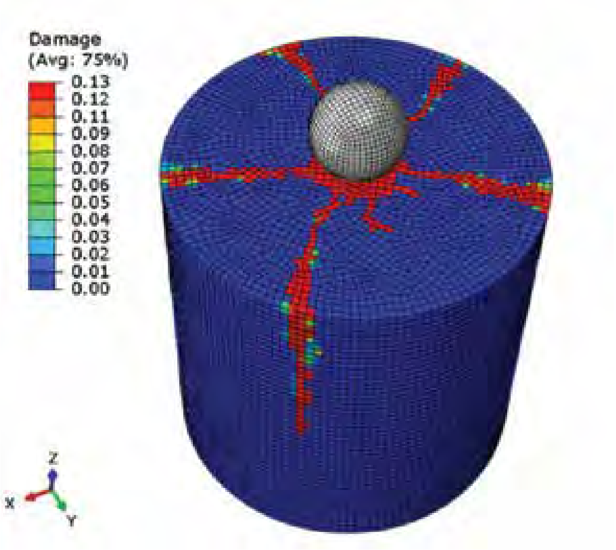


Figure 8: *Predicted damage in a boron carbide cylinder from a spherical tungsten carbide impactor at a velocity of 100 m/s, using the Ceramics CMRG's constitutive model in ABAQUS..*

PROF. MARTIN P. HARMER

Alcoa Foundation Professor of Materials Science and Engineering, Lehigh University

MEDE Area of Research:
Atomic-Resolution Characterization of Boron Icosahedra Ceramics

> "The MEDE program has allowed me to forge new interactions with top-notch scientists from other institutions, giving me a broader perspective and a deeper understanding of this highly interdisciplinary field. I have especially enjoyed interacting with the future generation of graduate students and junior research scientists, who impressed me with their knowledge, enthusiasm and creativity. I look forward to many more fruitful interactions with the MEDE team."

DR. CHRISTOPHER J. MARVEL

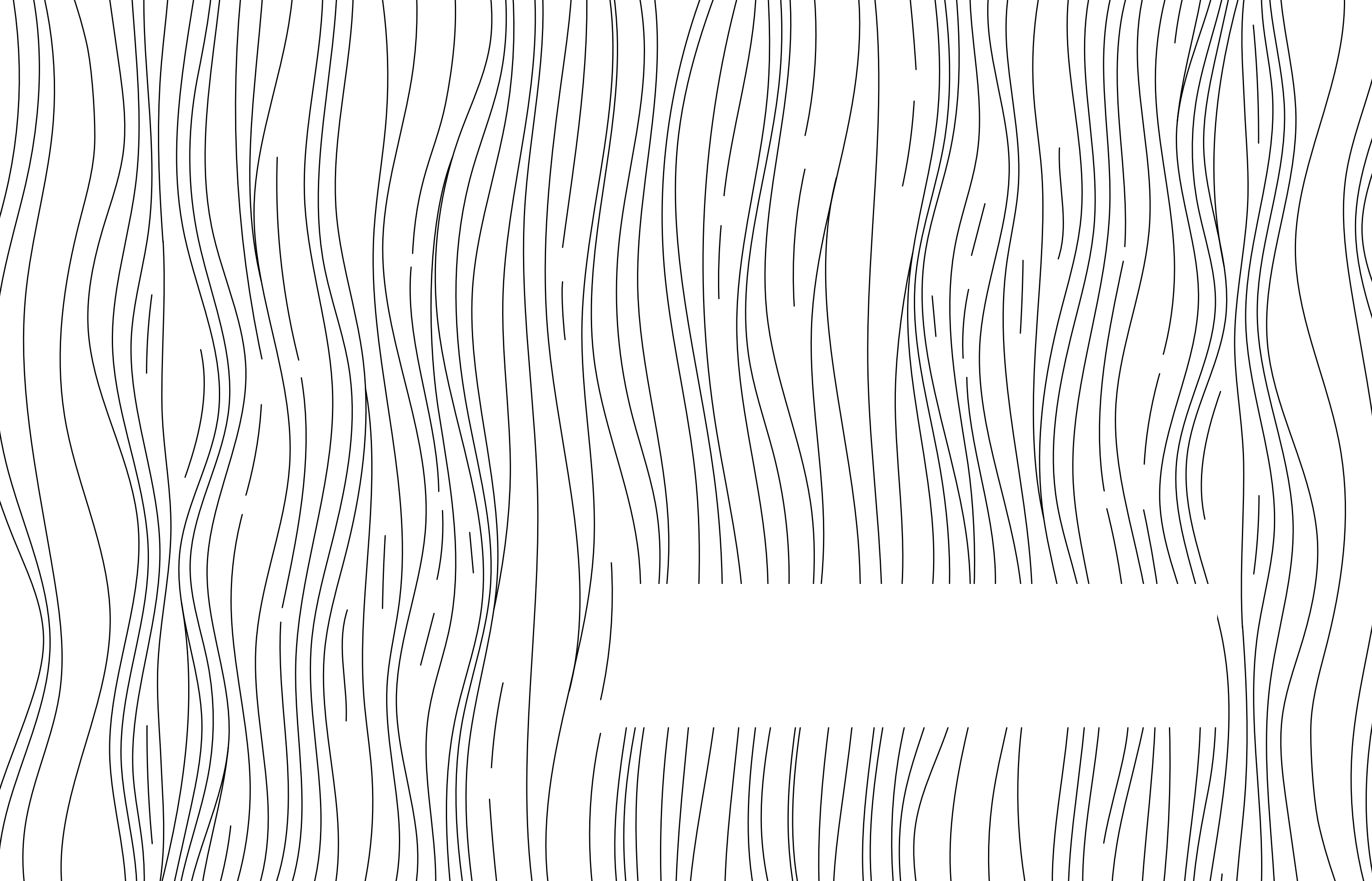
Research Scientist, Lehigh University

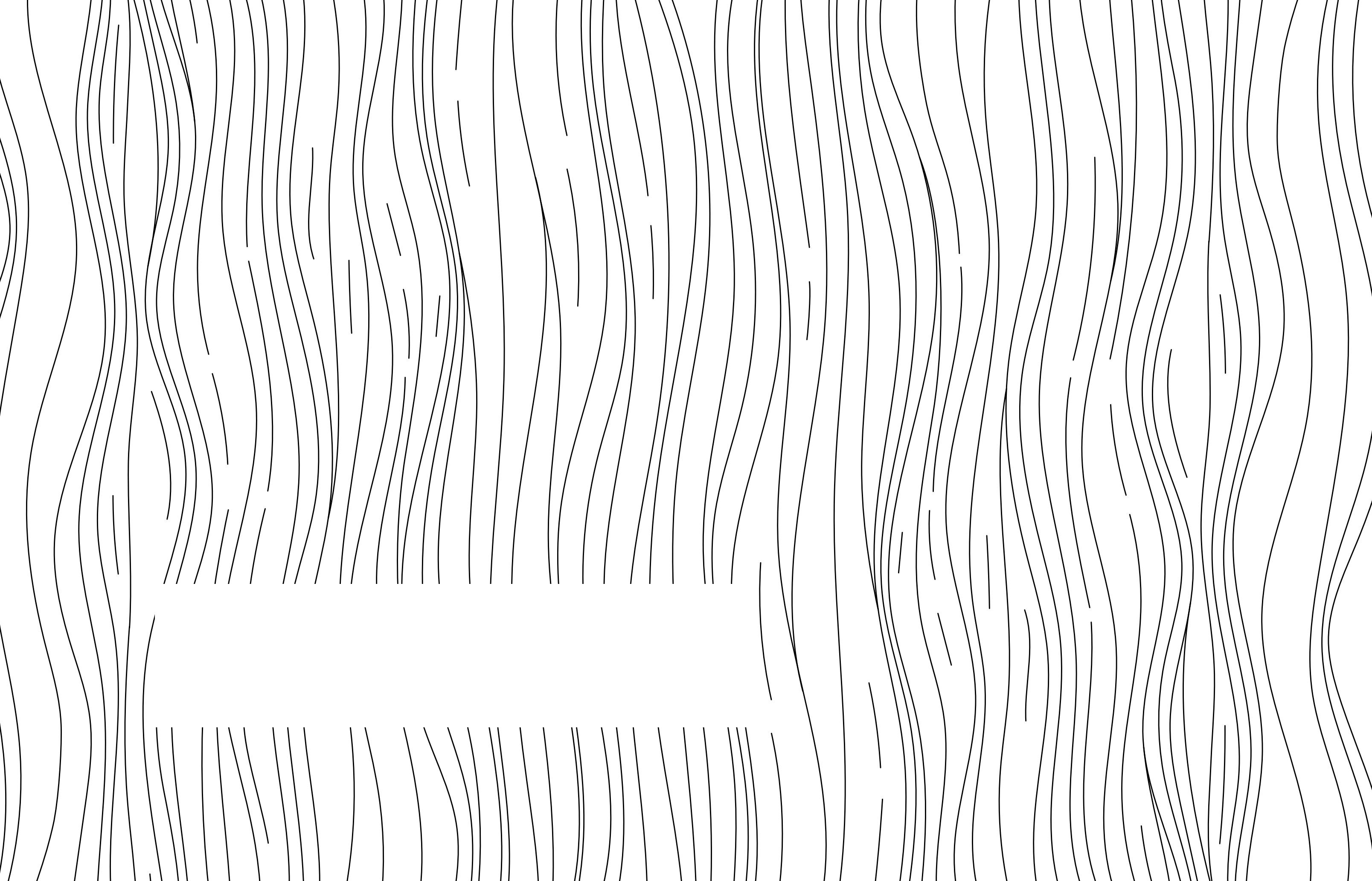
MEDE Area of Research:

Atomic-Resolution Characterization of Boron Icosahedra Ceramics

"The MEDE program has been a rewarding opportunity to work with world-class researchers on both fundamental and applied scientific problems. Contributing towards a large research consortium has also been a great learning experience at the start of my academic career. Finally, I am fortunate to have been given the opportunity to develop and apply advanced characterization methods to study complex materials and discover atomic mechanisms of material behavior in extreme environments."

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





COMPOSITES

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

CCDC ARL Lead - Dr. Daniel J. O'Brien

Composites CMRG

CONSORTIUM INVESTIGATORS

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Prof. Kadir Aslan, Morgan State

Prof. Wayne Chen, Purdue

Dr. Sanjib Chowdhury, Delaware

Prof. Somnath Ghosh, JHU

Prof. John W. Gillespie, Jr., Delaware

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Prof. Bazle Haque, Delaware

Prof. Giuseppe Palmese, Drexel

Prof. Michael Shields, JHU

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Dr. Kevin Masser

Mr. Chris Meyer

Dr. Daniel J. O'Brien

Dr. Brendan Patterson

Dr. James Sands

Dr. Timothy Sirk

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)

Micro-Mechanical Finite Element Modeling of Progressive Punch-Shear Behavior of Unidirectional Composite

Dr. Bazle Z. (Gama) Haque
University of Delaware

Professor John W. Gillespie, Jr.
University of Delaware

Dr. Chian-Fong Yen
CCDC Army Research Laboratory

Dr. Daniel J. O'Brien
CCDC Army Research Laboratory

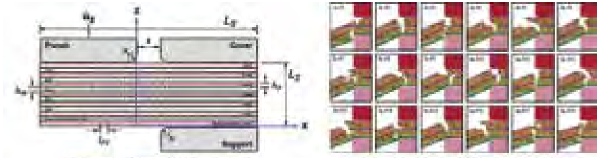
Punch shear is a unique damage mechanism observed around a projectile while penetrating or perforating a composite target under high velocity impact which involves micromechanical mixed-mode transverse shear dominated fiber-fracture, fiber-matrix debonding, large deformation and cracking of matrix resin. A micromechanical finite element model of punch shear can allow the stochastic prediction of punch shear strength and associated non-linear progressive damage with the model input for stochastic fiber tensile and shear strength distribution, rate dependent mixed mode fiber-matrix interface traction laws, and rate dependent non-linear large deformation matrix behavior.

Micro punch shear experiments on unidirectional (UD) S-2 glass/DER353 composite ribbons with 6 to 7 through-thickness fibers have been conducted to determine the statistical distribution of punch shear strength, to quantify the relative fiber-fracture heights and fiber-matrix debonding lengths for model validation. An equivalent 2D FE model of the punch shear experiments of unidirectional composite has been developed and validated with experiments. The validated model is then used to run stochastic simulations in predicting the statistical distribution of punch shear strengths which matches well with the experiments. By the use of rate dependent matrix and fiber-matrix interface properties, computational simulations have also been conducted at different loading rates in determining the rate dependent punch shear strength of UD S-2 glass/DER353 composites, which shows logarithmic rate dependency.

In order to capture the 3D effects, a 3D FE model of unidirectional composites with 28 fibers in a hexagonal array has been developed. In this 3D model, each fibers are modeled as an assembly of 2 micron segments connected by zero-thickness mixed-mode traction law to mimic all probable locations of surface micro cracks on the fiber. Experimentally measured bi-modal (with 16mm & 365 micron gage length) Weibull parameters for glass fiber have been extrapolated for 4 micron gage length and randomly assigned between each fiber segments. This segmented fiber model is verified by simulating axial tension yielding the correct modulus of the unsegmented glass fiber. Furthermore, the mixed mode fiber fracture is verified by conducting a transverse impact on the fiber. The surrounding matrix is modeled as one large part with holes for the fiber array with coincident nodes for zero-thickness cohesive definition of the fiber-matrix interface between each fiber and the matrix. Punch shear of a single fiber with surrounding matrix has been simulated to verify the fiber-matrix debonding model.

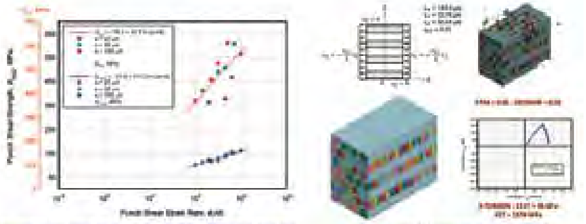
The 3D FE model of the unidirectional composite is then subjected to axial tension and compression in all three material directions in predicting the non-linear progressive stress-strain for continuum model applications such as MAT162 in LS-DYNA®. In addition, inplane shear, interlaminar shear, and punch shear loading have been applied for micromechanical prediction of the shear behavior of unidirectional composites.

We are in the process of developing a 3D FE model of punch shear and axial tension in a way such that stochastic parametric computations can be performed varying the input properties. This new modeling framework will allow materials-by-design capabilities where material properties and attributes predicted in the molecular length scale will be used as input to this micromechanical model in predicting the energy dissipating damage modes and help optimize materials energy absorption both under punch shear and tensile loading.



Schematic Diagram of 2D Punch Shear

Stochastic Prediction of 2D Punch Shear Fracture



Prediction of Rate Dependent Punch Shear Strength & Modulus

3D Model of UD Composite: Axial Tension

Figure 9: *Micromechanical modeling of punch shear and axial tension of unidirectional composites*

References:

1. *(Gama) Haque, B. Z., Ali, M. A., Ganesh, R. H., Tamrakar, S., Yen, C-F., O'Brien D. J., and Gillespie Jr., J. W. Stochastic micromechanical modeling of transverse punch shear damage behavior of unidirectional composites. Journal of Composite Materials. 2019, Volume 53(9), pp. 1197-1213.*

2. *John W. Gillespie Jr., Molla A. Ali, Chian F. Yen, Daniel O'Brien, and Bazle Z. (Gama) Haque. Micro Punch Shear Testing of Unidirectional Composites: A New Test Method. ASC 33rd Annual Technical Conference, 18th US-Japan Conference on Composite Materials, ASTM D30. September 24-26, 2018. Seattle, WA, USA.*

3. *Bazle Z. (Gama) Haque, Molla A. Ali, Raja H. Ganesh, Sandeep Tamrakar, Chian F. Yen, Daniel O'Brien, and John W. Gillespie Jr. Micromechanical Finite Element Modeling of Micro Punch Shear Experiments on Unidirectional Composites. ASC 33rd Annual Technical Conference. September 24-26, 2018. Seattle, WA, USA.*

4. *Bazle Z. (Gama) Haque, Molla A. Ali, Daniel O'Brien, and John W. Gillespie Jr. Micromechanical Modeling of High Rate Punch Shear Behavior of Unidirectional Composites. ASC 34rd Annual Technical Conference. September 23-25, 2019. Atlanta, GA, USA.*

Molecular Modeling of Glass Fiber

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University of Delaware

Mr. Ethan M. Wise
University of Delaware (URAP Intern)

Mr. Raja Ganesh
University of Delaware

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University of Delaware

Dr. Timothy W. Sirk
CCDC Army Research Laboratory

Our model composite consists of three primary constituents: S-Glass fiber, epoxy matrix and the interphase that governs load transfer between fiber and matrix and the mechanical properties of the composite. A systematic Materials by Design approach has been developed to study failure mechanisms and bridge length scales from the atomic to the continuum length scale of a single layer of a woven composite. At the lowest length scale, classical molecular dynamics (MD) simulations have been conducted to understand high strain rate failure mechanisms of the individual constituents as well as their interactions [1-4]. MD simulations of glass fiber has identified the strain rate dependent and progressive damage mechanisms within the fiber, the sensitivity of tensile strength to surface defects and the prediction of fiber surface reactivity needed to design optimal interphase properties [2-4].

During fiber spinning, sizing and composite processing, nanometer size surface cracks develop during these handling operations that reduce tensile strength significantly below theoretical limits. In unidirectional composites, fiber fails at these defect sites resulting in a dynamic release of stored strain energy that subjects the interphase and matrix to very high strain rates and high levels of inelastic deformation that propagate at high speed along the broken fiber. Nearest neighbor fibers are also subjected to a tensile wave with a dynamic stress concentration that can trigger additional fiber breaks at locations with critical defects. This process continues resulting in a localization of damage that is sufficient to cause catastrophic failure of the composite [5]. Our Materials by Design approach focuses on optimizing the rate dependent interphase and resin properties as a function of the defect size and spatial distribution of defects within the glass fiber to improve composite properties. Therefore, to design high performance composites, it is imperative to have a fundamental understanding of the fracture mechanisms of the fiber at the smaller length scale and how the fiber defects effect composite failure mechanisms. In this summary, we have highlighted some of our key studies on glass fiber.

Recently, we have carried out reactive MD simulations using state-of-the-art reactive force field ReaxFF to study the strain rate dependent progressive failure of the fibers as well as the effects of surface crack on the mechanical properties of glass fiber [2]. We have developed an atomistic J-integral method to determine the fracture energy release rate (Figure 10). The J-integral method captures all sources of energy dissipation and agrees well with the Griffith fracture mechanics for crack length larger than 1 nm. As part of this study, MD was used to partition energy absorption mechanisms from both the creation of new crack surface area and progressive damage of bonds that develop within a very narrow cohesive zone adjacent to the crack surface. Nanometer size surface crack significantly affects the fiber strength without influencing the fiber modulus. Strength decreases with increase in the crack length and MD predicts a 35 nm surface crack is sufficient to reduce fiber tensile strength to experimental levels measured in commercial glass fiber (average strengths of 3.5 GPa). The developed MD framework will enable us to study crack healing mechanism of glass fibers to improve strength and the prediction of surface reactivity for interphase design.

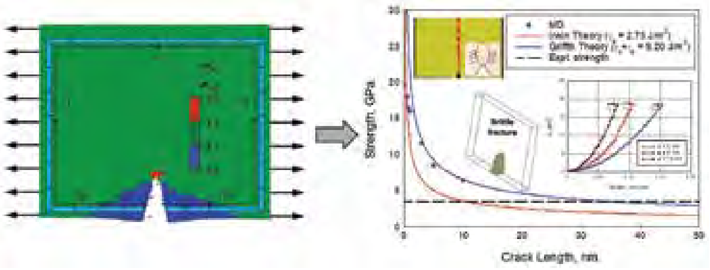

Figure 10: *Surface crack effects and atomistic J-integral approach to predict fracture energy release rate.*

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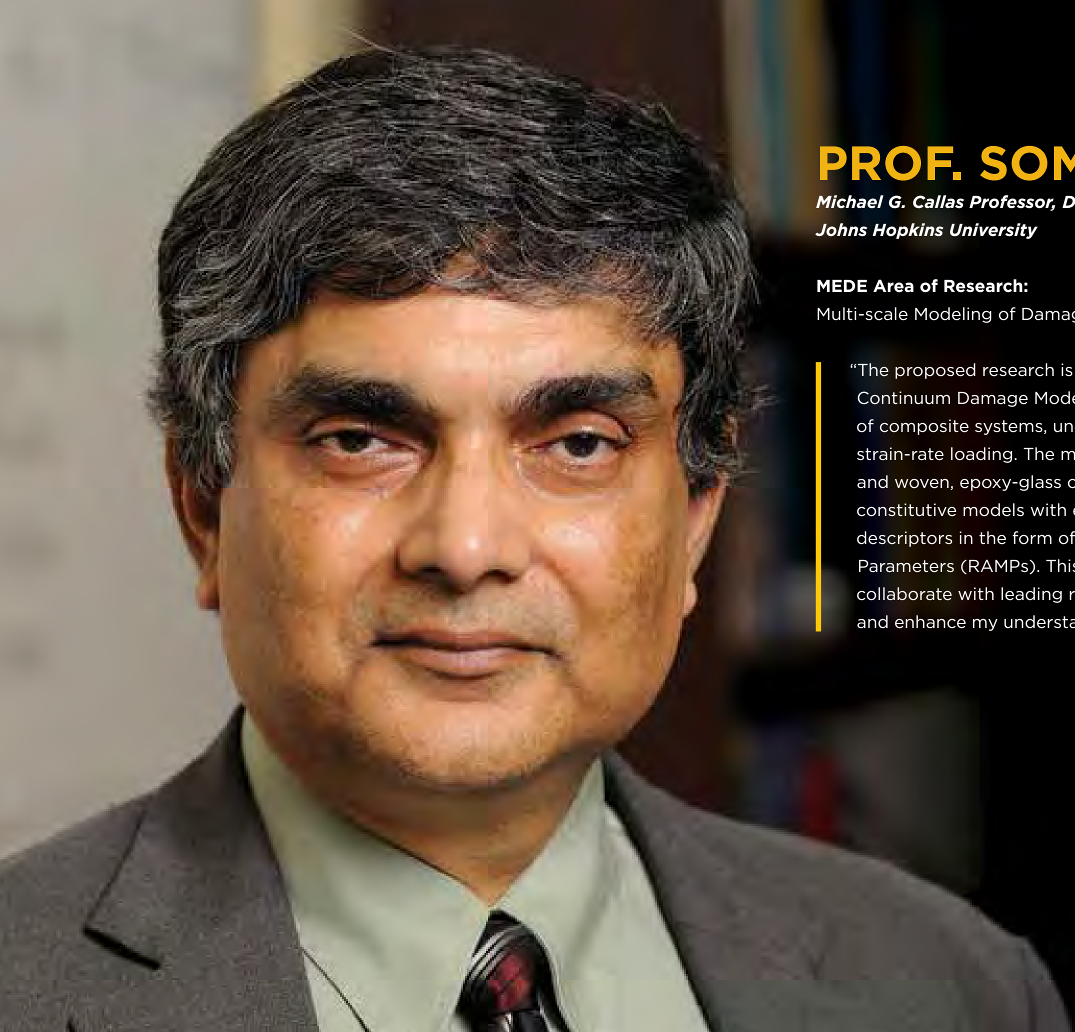
2. Chowdhury S. C., Wise E. A., Ganesh R., and Gillespie Jr. J. W., Effects of surface crack on the mechanical properties of silica: A molecular dynamics simulation study, Engineering Fracture Mechanics, 2019, 207:99-108.

3. Chowdhury S. C., and Gillespie. Jr. J. W., Silica - silane coupling agent interphase properties using molecular dynamics simulations, Journal of Materials Science, 2017, 52:12981-12998.

4. Chowdhury S. C., Haque B. Z., and Gillespie. Jr. J. W., Molecular dynamics simulations of the structure and mechanical properties of silica glass using ReaxFF, Journal of Materials Science, 2016, 51(22):10139-10159.

5. Ganesh R., Sockalingam S., Gillespie Jr. J. W., Dynamic effects of a single fiber break in unidirectional glass fiber-reinforced polymer composites: Effects of matrix plasticity. Journal of Composite Materials 2018; 52(14):1873–1886.



PROF. SOMNATH GHOSH

Michael G. Callas Professor, Department of Civil and Systems Engineering, Johns Hopkins University

MEDE Area of Research:
Multi-scale Modeling of Damage and Failure in Composites

> "The proposed research is developing a Parametrically Homogenized Continuum Damage Model (PHCDM) for structural-scale simulations of composite systems, undergoing damage and failure under high strain-rate loading. The material classes considered are unidirectional and woven, epoxy-glass composite systems. PHCDMs are macro-scale constitutive models with explicit representation of microstructural descriptors in the form of Representative Aggregate Microstructural Parameters (RAMPs). This MEDE task has given me the opportunity to collaborate with leading researchers in the field of composite modeling and enhance my understanding of a challenging problem."

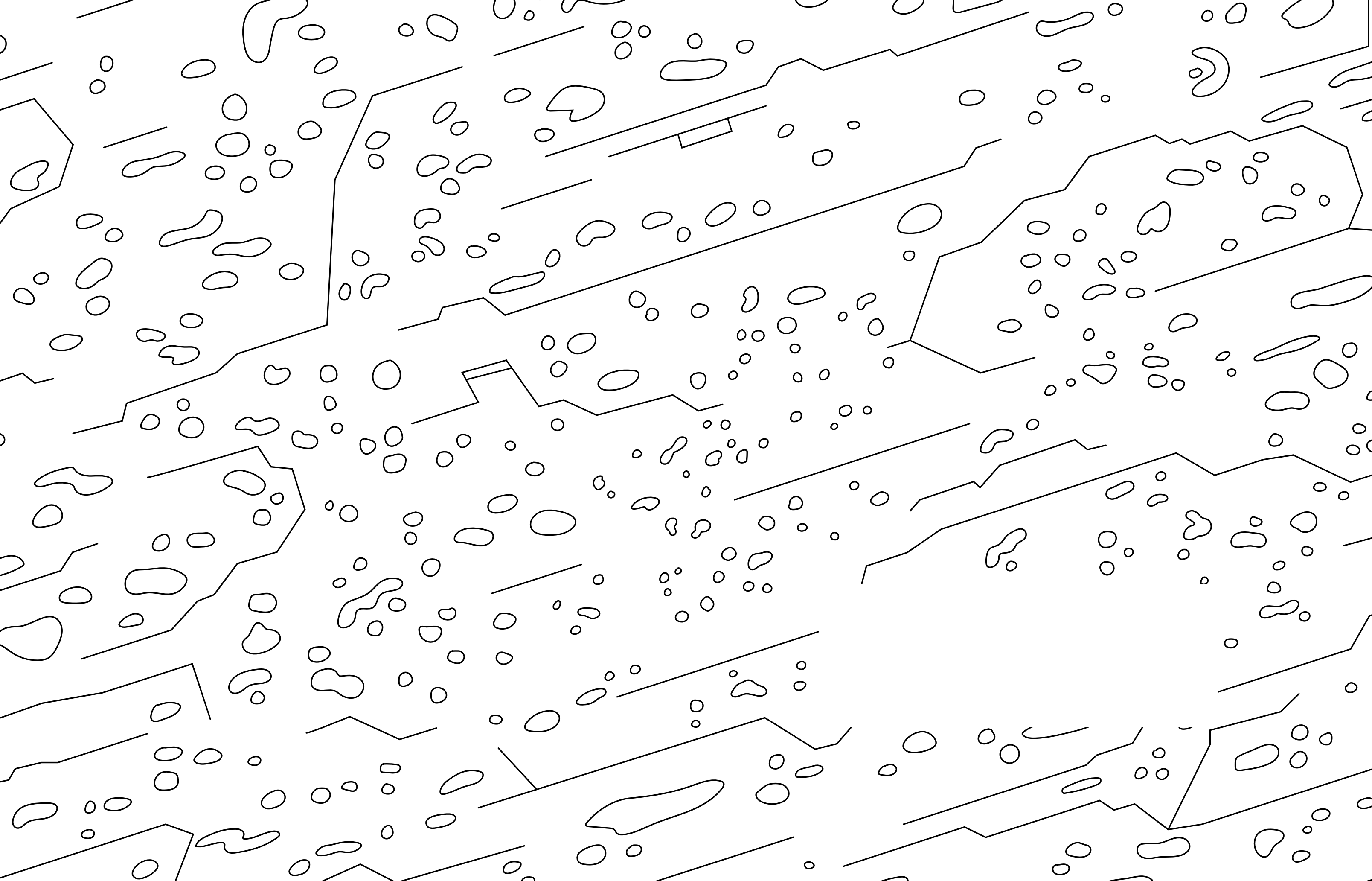
MR. XIAOFAN ZHANG

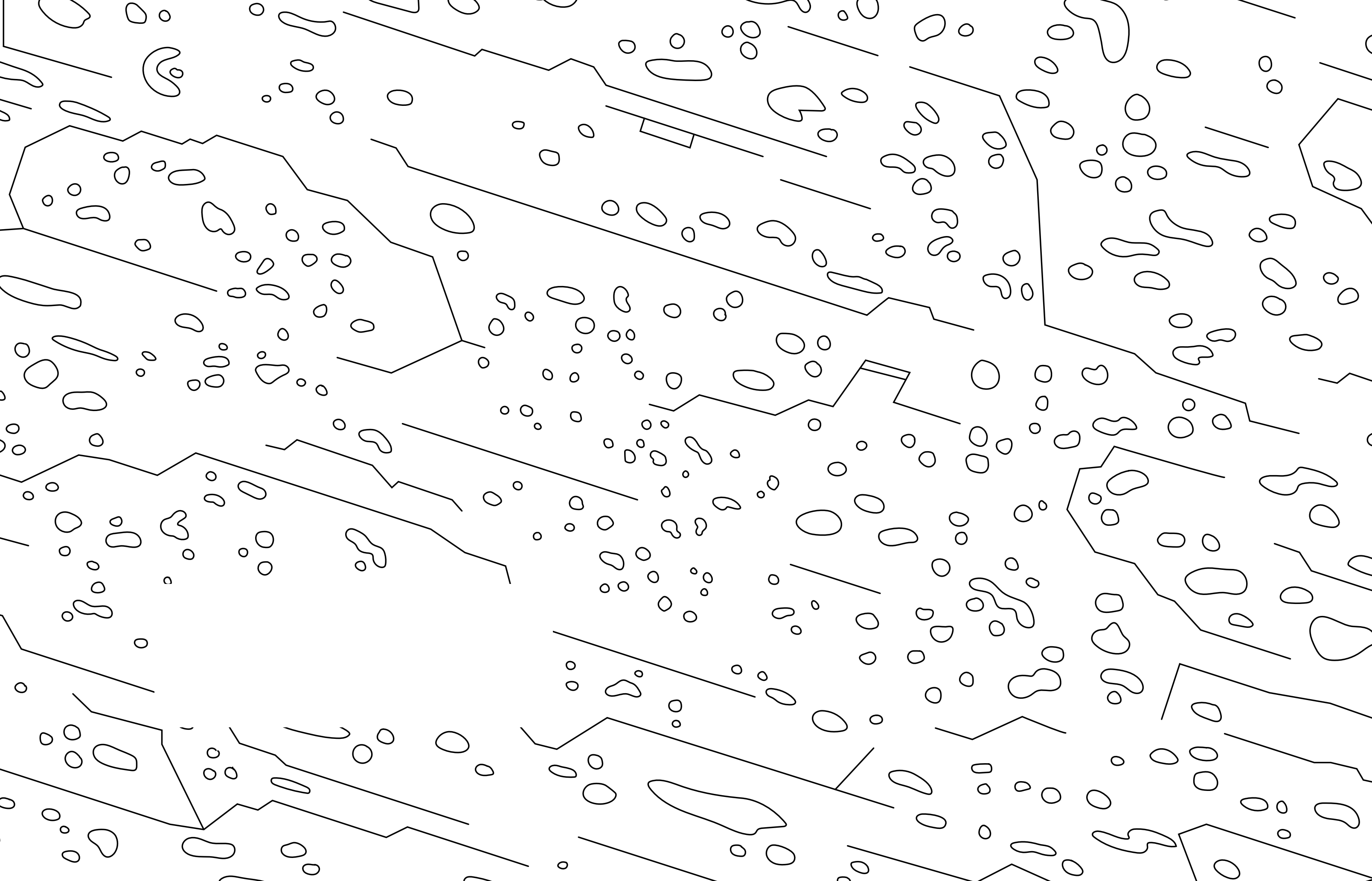
Graduate Research Assistant, Johns Hopkins University

MEDE Area of Research:
Multi-scale Modeling of Damage and Failure in Composites

"In the MEDE program, we are developing multi-scale damage models for composite materials under different loading conditions. This Parametrically Homogenized Continuum Damage Mechanics (PHCDM) model can be used in structural-scale simulations of composite systems and provide detailed failure behaviors across various material length-scales. Being part of the Composites Collaborative Materials Research Group, I am able to collaborate and exchange ideas with outstanding people from different universities and research institutions. I really appreciate the opportunity the MEDE program provides me to conduct these cutting-edge research problems in the composites field."

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





METALS

Consortium Lead - Prof. Todd Hufnagel (JHU)

CCDC ARL Lead - Dr. Jeffrey Lloyd

Metals CMRG

CONSORTIUM INVESTIGATORS

Prof. Kaushik Bhattacharya, Caltech

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

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Prof. Guruswami Ravichandran, Caltech

Prof. Jagannathan Sankar, NC A&T

Prof. Andrew Stuart, Caltech

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

CONSORTIUM RESEARCH GROUPS

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

CCDC ARL COLLABORATORS

Dr. Richard Becker

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Dr. John Clayton

Dr. Micah Gallagher

Dr. Vince Hammond

Dr. Philip Jannotti

Mr. Tyrone Jones

Dr. Jarek Knap

Dr. Jeffrey Lloyd

Dr. Bryan Love

Dr. Christopher Meredith

Dr. Brian Schuster

Dr. Cyril Williams

Development of a Laser-driven Shock Compression Facility

Dr. Debjoy D. Mallick
Johns Hopkins University

Mr. Jason Parker
Johns Hopkins University

Mr. Suhas Eswarappa-Prameela
Johns Hopkins University

Mr. Hao Sheng
Johns Hopkins University

Dr. Vignesh Kannan
Johns Hopkins University

Dr. Meng Zhao
Johns Hopkins University

Dr. Bryan Bosworth
Johns Hopkins University

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Professor Mark Foster
Johns Hopkins University

Professor KT Ramesh
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Professor Justin Wilkerson
Texas A&M University

Dr. Jeffrey Lloyd
CCDC Army Research Laboratory

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The low density but high strength of magnesium offers advancements in transportation and protection technologies, where weight-savings are paramount. Unfortunately, pure and alloyed Mg have a relatively low resistance to failure, hindering their incorporation into vehicles and armors. This low resistance is often attributed to the unusual material properties of Mg: anisotropy in irrecoverable deformation, profuse deformation twinning, and texture or precipitate morphology introduced during material processing.

Engineering Mg to withstand extreme environments requires fundamental knowledge of the failure process. To better understand the failure of Mg, we have developed a laser-driven shock compression facility to perform spall experiments on Mg alloys.

Spall experiments interrogate the dynamic ultimate tensile strength of the target material and can highlight the microstructure features where failure nucleates first. However, these experiments are traditionally difficult and expensive to perform. The laser-shock facility at the Hopkins Extreme Materials Institute allows spall strength measurements on the lab-bench without the costs and complexities of conventional methods at ultra-high rates of deformation, permitting high throughput data collection. We employ a pulsed laser to accelerate a projectile just millimeters in diameter and microns in thickness for spall generating impacts on magnesium targets with similar dimensions. Laser-based in-situ velocimetry is the general technique for data collection in spall experiments, but the small scales of our experiments has necessitated several innovations to analyze the micron scale experiment over nanoseconds of duration. We have demonstrated the facility while studying the spall strength of AZ31B and Mg-9%Al alloys at rates up to 107 s-1. After coupling our experimental results to analytical cavitation models and massively parallel finite element simulations, our preliminary investigation suggests that introducing precipitates during material processing can negatively impact the dynamic tensile strength of the material, even when these second phase particles may improve static yield strength.

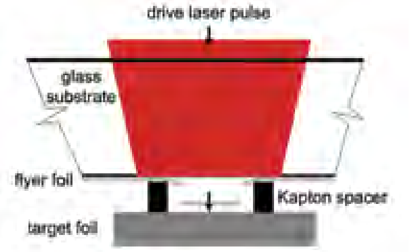

Figure 11: *A schematic of the side view of flyer launch with the incoming driving laser pulse from top to bottom shown in red.*

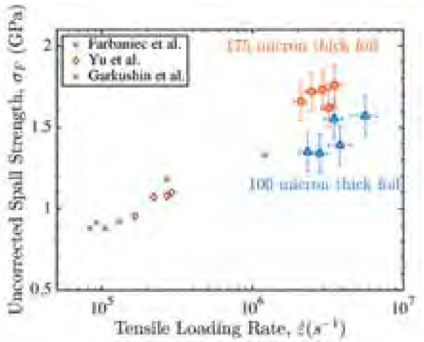

Figure 12: *Spall strength measurements of AZ31B magnesium thin foils from analyzed in-situ velocimetry data of various thicknesses shown in red and blue with lower rate spall strength experiments from the literature also shown for comparison.*

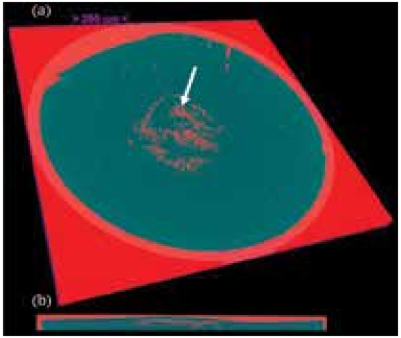

Figure 13: *Micro-computed tomography images of a single magnesium specimen post-mortem. The red color within the gray disks represents low density, or air, regions where dynamic cavitation has occurred.*

Predicting Particle-initiated Failure during Dynamic Loading in Magnesium

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CCDC Army Research Laboratory

Dr. Richard Becker
CCDC Army Research Laboratory

Dr. Timothy Walter
CCDC Army Research Laboratory

Professor Jamie Kimberley
New Mexico Tech

Mr. Andrew Matejunas
New Mexico Tech

Professor Justin Wilkerson
Texas A&M University

Ms. Angela Olinger
Texas A&M University

Strengthening in metals is accomplished either by introducing defects in the material through deformation or by the introduction of alloying elements. Alloying magnesium is essential for increasing its strength so that it can resist deformation during high rate loading events such as penetration. However, clusters of these alloying elements, called precipitates, act as nucleation sites for damage that leads to failure. In order to predict how a high strength magnesium alloy fails we need to be able to account for failure that initiates at these precipitates. In this collaborative work between researchers at ARL and Texas A&M, we develop a model that takes in 3d images of second phase particles in magnesium alloys and simulates how these particles cause the material to fail under dynamic tension. Model predictions are compared with dynamic tension experiments performed at New Mexico Tech to ensure that the predictions give physically meaningful results.

In most metals the alloying elements tend to precipitate preferentially on certain material planes. In magnesium this effect is amplified due to the material's strong texture. Therefore, not only does the material's strength differ along different directions, but the clusters of precipitates are also strongly directional. Computer simulations showed that when the directionality of precipitates was not included in the failure predictions, the predicted failure behavior was opposite from what was experimentally observed. Only when the experimentally measured precipitate shapes were included did predictions of the failure behavior match the experiments.

Computer simulations at this scale require a level of detail that is not suitable for engineering-scale simulations of large structures. Therefore, researchers are currently determining how we can extract the essential features of these simulations and map them onto a model that efficiently correlates the underlying precipitate morphology to the macroscale failure behavior.

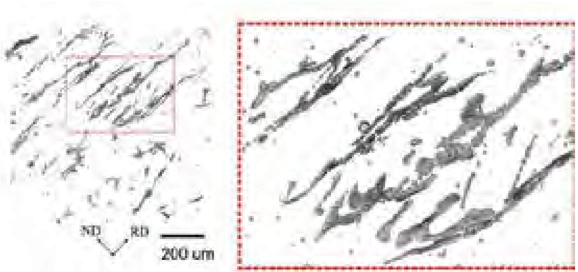


Figure 14: *X-Ray Computed Tomograpy (CT) image of second phase particles in a rolled magnesium sample, where (RD) indicates the rolling direction and (ND) indicates the plate normal direction.*

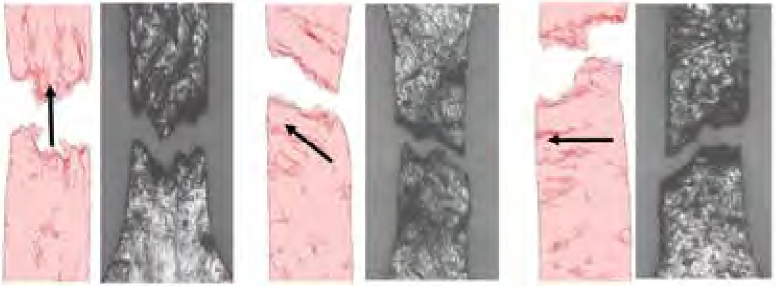


Figure 15: *Polycrystal plasticity predictions of dynamic failure in rolled magnesium that incorporate experimentally measured second phase particles compared with experiments. Black arrow denotes the normal to the rolling direction. Simulated specimens were approximately half the size of experimental specimens but are blown up for comparison.*

MS. JENNA KRYNICKI

PhD Candidate, Department of Materials Science and Engineering, Johns Hopkins University

MEDE Area of Research:
Microstructural evolution and mechanical behavior of Mg alloys after Equal Channel Angular Extrusion (ECAE)

> “The MEDE program has provided me with various opportunities to collaborate with unique individuals and has shown me how we can enhance the relationship between the experimentalists and modelers, such that our experimental work can inform models, and vice versa. Working with researchers within our consortium has enriched my understanding of the processing and properties of Mg alloys, and has demonstrated how my research can be translatable to the Army Research Laboratory.”

PROF. JAGANNATHAN SANKAR

Distinguished University Professor, Director ERC, North Carolina A&T State University

MEDE Area of Research: *Fabrication of novel Mg alloys and their deformation processing via confined and differential speed rolling to support dynamic strength improvement and spall modeling for the ARL-MEDE vision.*

"Over the years, NC A&T State University has developed a well-recognized broad-based materials engineering and processing facility, spanning various materials systems.

The MEDE program specifically provided us with an exciting opportunity to work collaboratively towards the development of Mg alloy systems with combined novel thermo-mechanical treatments to lead forward and meet the ARL-MEDE's mission requirements, while enhancing the depth and breathe of NC A&T's research capacity and infrastructure."

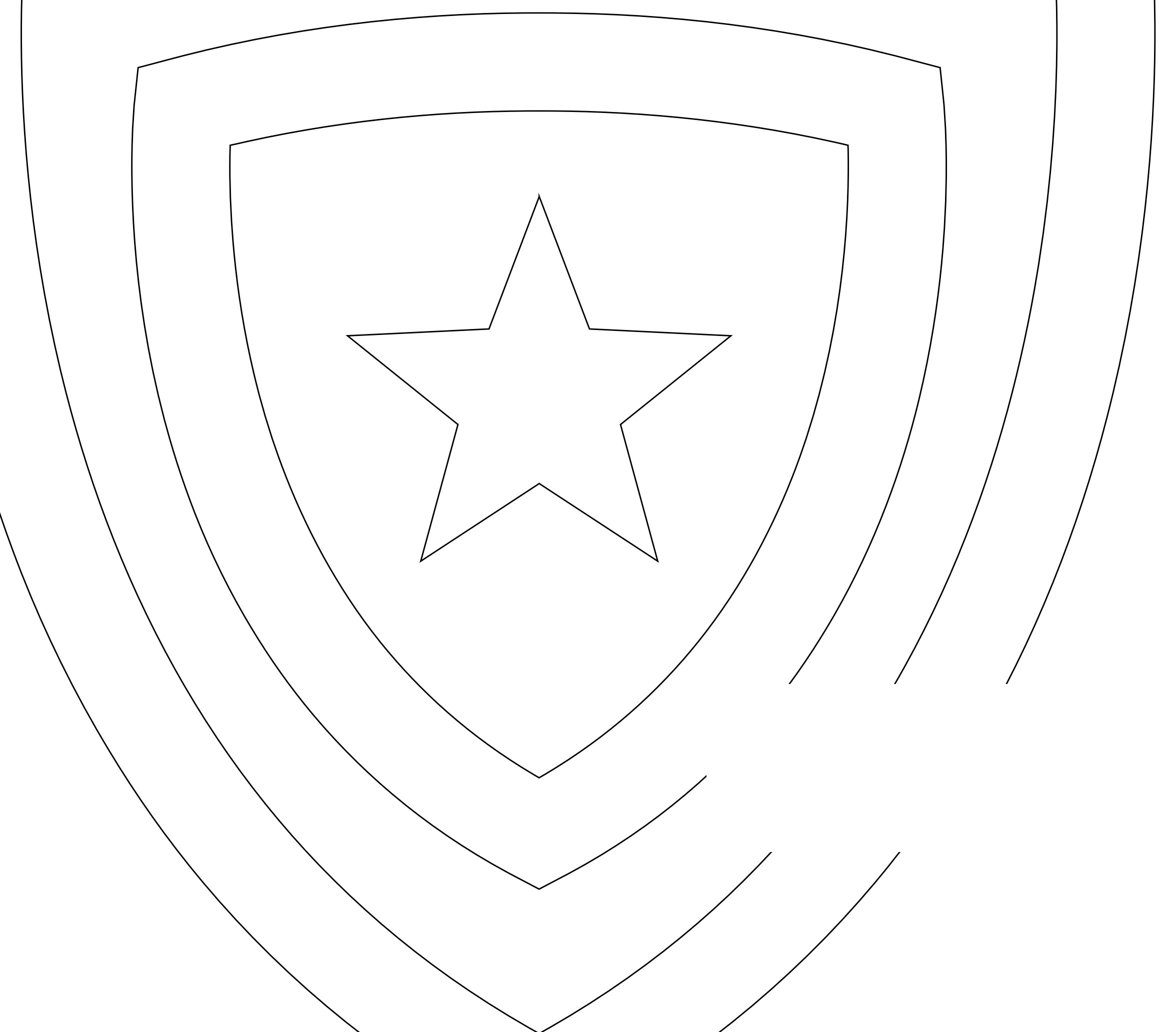
DR. DEBJOY D. MALLICK

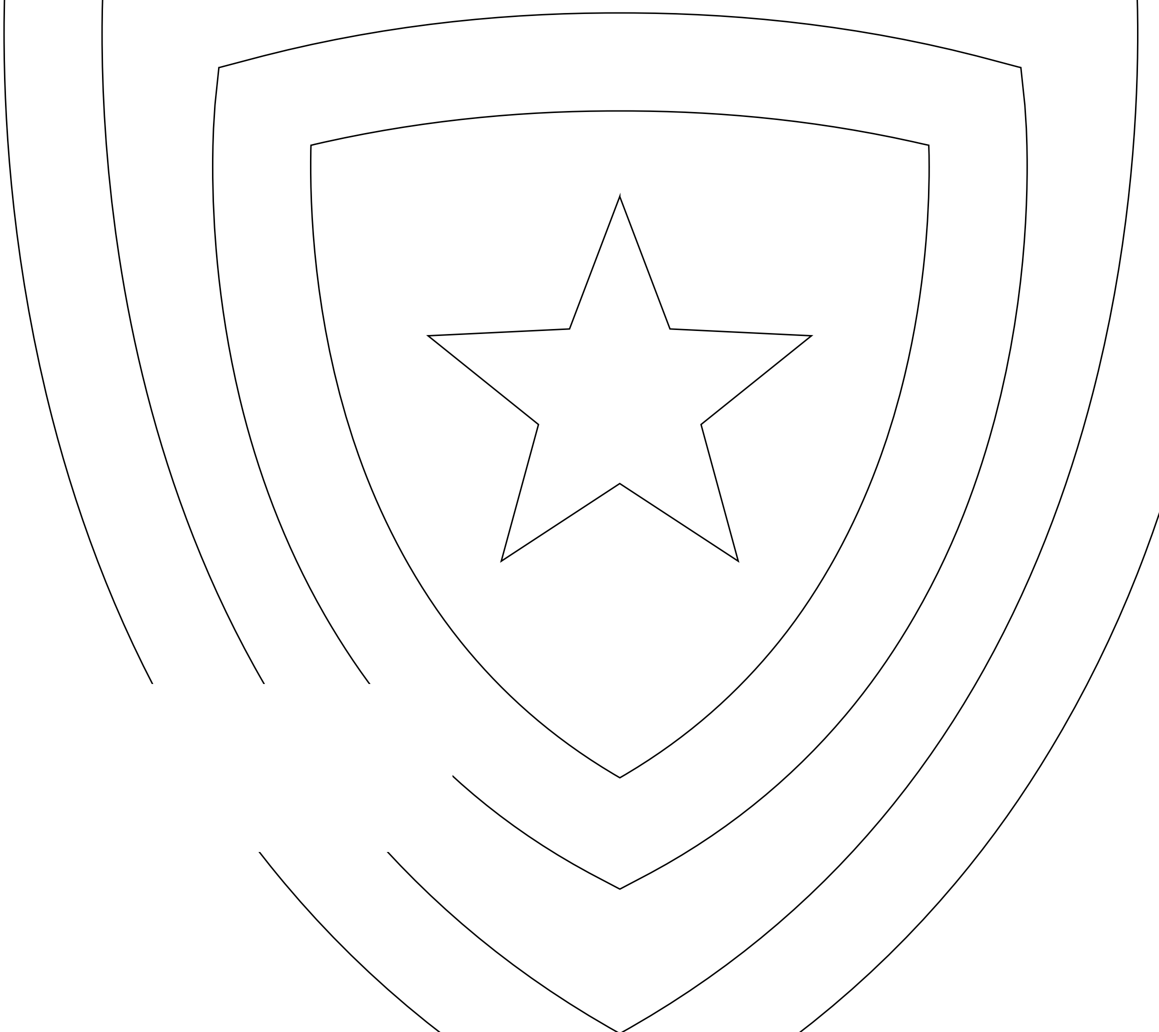
U.S. Army CCDC Army Research Laboratory

MEDE Area of Research: *Dynamic failure of metals and ceramics using laser shock*

"My research on laser-driven techniques for high throughput impact experiments would not be possible without the fruitful collaborations with the world-class researchers and scientists spanning government and academia in the MEDE consortium."

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





INTEGRATIVE AND COLLABORATIVE TOOLS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Prof. Lori Graham-Brady


Mr. David Elbert


Dr. Adam Sierakowski


Prof. Tamás Budavári


Dr. Betsy Rice


Mr. Eric Walker


Dr. Richard Becker

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Mr. David Elbert, JHU

Prof. Lori Graham-Brady, JHU

Prof. K.T. Ramesh, JHU

Dr. Adam Sierakowski, JHU

SELECT CCDC ARL COLLABORATORS

Dr. Richard Becker

Dr. William Mattson

Dr. Betsy Rice

Mr. Wayne Ziegler

INTEGRATIVE RESEARCH ACTIVITIES

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

MEDE Data Science Cloud (MEDE-DSC): Deep Learning Analysis of Time Resolved Ballistics Data

The MEDE Data Science Cloud's materials-specific infrastructure provides data curation, visualization, analysis, and a platform to develop machine learning solutions for diverse, materials-domain problems. The MEDE-DSC is built on SciServer with data-centric computing infrastructure and collaborative integration for 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.

MEDE-DSC provides novel approaches to data-intensive problems such as the analysis of HIDRA (High-voltage, In-situ, Diagnostic Radiographic Apparatus, Fig. 16) results from the WMRD ballistics range at ARL. In collaboration with Drs. Brian Schuster and Andrew Tonge, we've developed new methodologies that vastly accelerate data reduction for time-resolved imaging of failure and fracture in boron-carbide ceramics. Computer vision automates image registration and feature correlation across HIDRA's eight flash X-ray images allowing high-throughput. A valuable, although originally unexpected, outcome of this automation has been refinement and simplification of experimental design. In other words, better data reduction tools lead to better experimental design that creates options to expand coverage of the parameter space while reducing manpower costs.

The MEDE-DSC also provides prototyping for machine learning methods. For HIDRA range data, we leverage accurate image segmentation from deep learning to capture penetrator parameters including dwell time, velocity, rod consumption, and penetration depth (Fig. 17). Convolutional neural networks (CNN) provide efficient methods to locate and classify image regions. For HIDRA data, pixel-level detection is extracted using a region-based CNN augmented to maintain spatial information within the convolutional layers and the addition of a parallel feature extractor for masking[1]. Models were pretrained using both the publicly available Common Objects in Context (COCO) dataset and simulated radiographs generated with the Tonge-Ramesh model. Final training utilized labeled HIDRA radiographs of penetrators spanning the full range of deformation states.

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 analyze the large, diverse data commonplace in materials today. Direct collaboration with MEDE investigators creates new ways to maximize the impact of their data.

1. He, K., Gkioxari, G., Dollár, P., & Girshick, R. (2017). Mask R-CNN. In Proceedings of the IEEE international conference on computer vision (pp. 2961-2969).

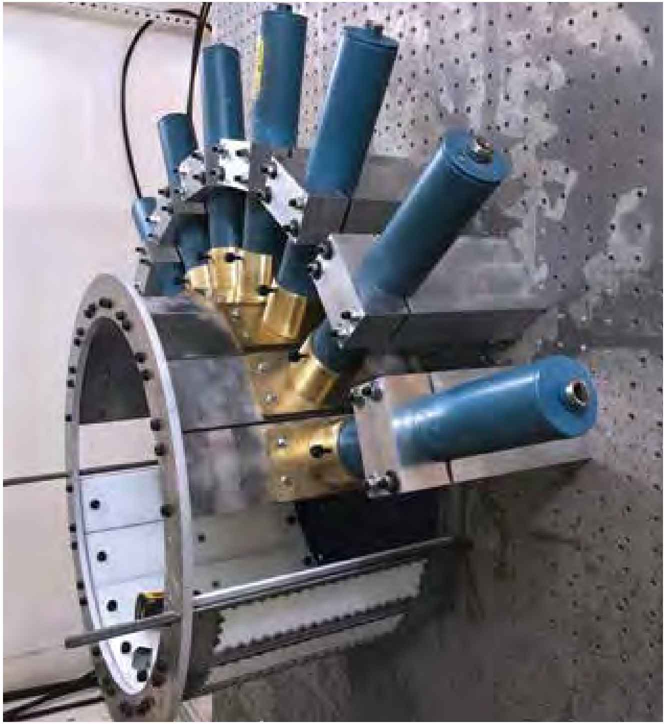


Figure 16: *ARL's High-Voltage, In-Situ, Diagnostic Radiography Apparatus (HIDRA) uses flash X-ray sources (blue) to capture time-resolved ballistic diagnostics of protection materials.*

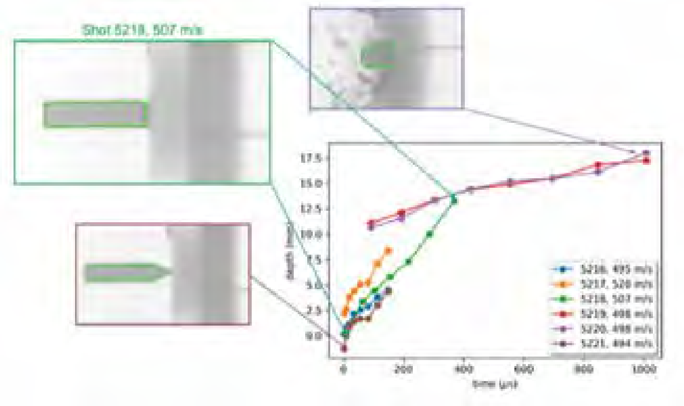


Figure 17: *MEDE-DSC deployed deep-learning analysis of HIDRA radiographs reveal projectile dynamics.*

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.

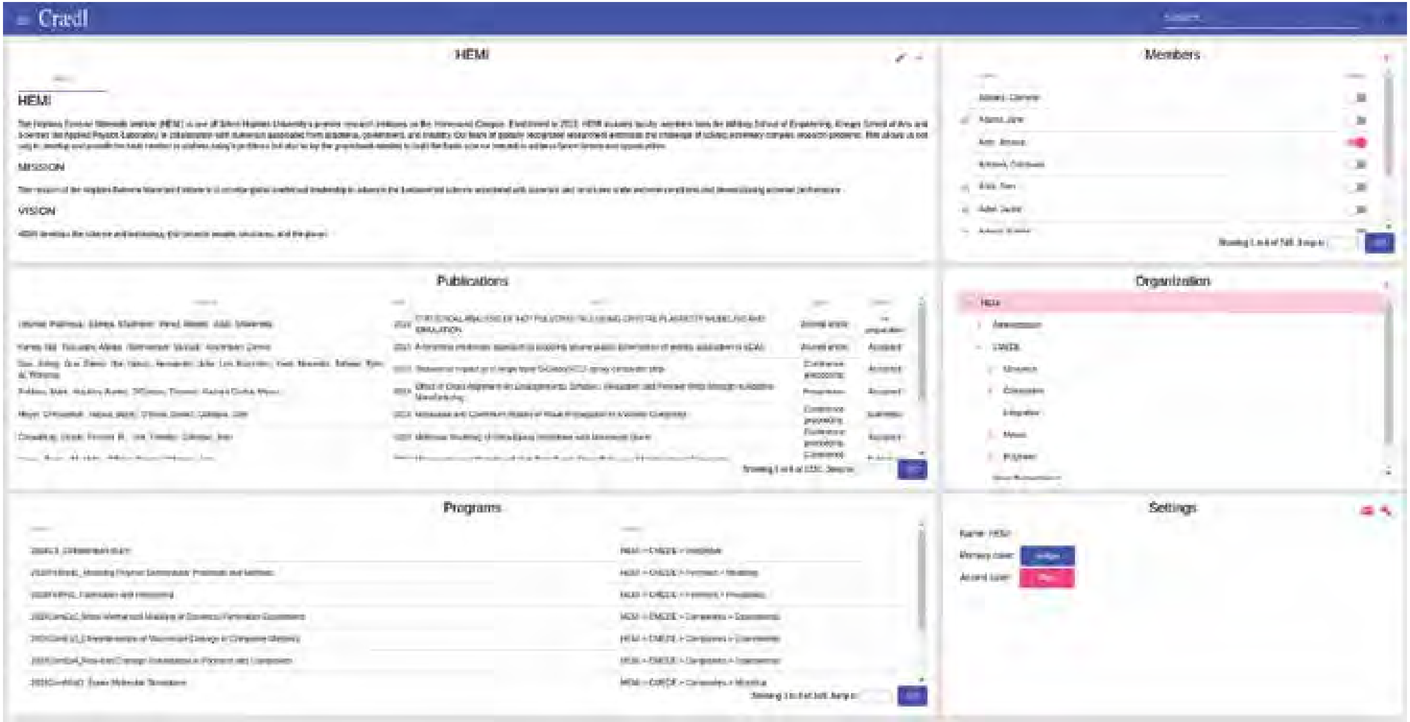
Craedl, the Collaborative Research Administration Environment and Data Library, is a tool being developed to overcome these challenges. Accessible at https://craedl.org/hemi, Craedl provides a secure environment for CMEDE affiliates to store their data, share it with collaborators, and search the data 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 data sets large and small (up to tens of terabytes) and is currently underpinned by a 284TB file storage system.

Crædl

Collaborative Research
Administration Environment
and Data Library



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

CCDC ARL Open Campus

The MEDE CRA embraces the CCDC ARL Open Campus Initiative. The highly collaborative nature of the MEDE program intrinsically supports consortium members working side by side with CCDC ARL scientists and engineers. In addition to taking advantage of CCDC 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 CCDC 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.

Collaboration with the MEDE Programme

Contributed by: Chris Hawkins MPhys MIMMM – UK Lead for MSA/MEDE interaction

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 third year and continues to have a strong focus on materials for physical protection for the dismounted soldier and land vehicles.

A strong cohort of PhD students is now established looking at topics including laser sintering of ceramics, novel routes for ceramic manufacture and understanding ballistic interfaces. Imperial College London, in collaboration with John Hopkins, are using microstructural models developed for armour ceramics, and now implemented in commercial finite element code, to simulate the large deformation of Dyneema® at multiple scales.

In spring of 2020 the MSA team look forward to welcoming the first recipient of the MEDE/MSA research fellowship to the UK where they will undertake modelling activity to understand the role of precipitate strengthening and precipitate-twin interactions in collaboration with Manchester University.

The UK MSA Programme anticipate a highly productive ongoing relationship with MEDE, both in terms of Dstl staff meeting and conference participation, the alignment of our respective research activities, and the continuation of MEDE / MSA research scholarships.

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 2019, the event was attended by 120 individuals including special guests from the United Kingdom's Defence Science and Technology Laboratory; US Army Engineer Research and Development Command, U.S. Army CCDC Soldier Center, and the Office of Naval Research. Professor K.T. Ramesh (JHU) and Dr. Sikhanda Satapathy (CCDC 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

UD Day in DC

This year, MEDE researchers participated in 'UD Day in DC,' an event that showcases the research completed by groups from the University of Delaware from who receive support from federal agencies. Senators from Delaware were presented with a commemorative item containing samples of each of the three materials that have been created through the materials-by-design process of the MEDE program.

Congressional Staffer Visit

Legislative staffers from the Office of U.S. Senator Ben Cardin visited MEDE facilities at Johns Hopkins University on April 25, 2019. The visit included a tour of the new Hypervelocity Facility for Impact Research Experiments (HyFIRE) and Focused Ion Dual Beam Laboratory spaces.

Hopkins on the Hill

Hopkins on the Hill is a biennial showcase of the range, value, and impact of federally funded research and programming at Johns Hopkins University. MEDE was one of the 21 major projects selected throughout JHU for the event held on June 12, 2019 in the Rayburn House Office Building. The event was attended by the Maryland Congressional delegation, JHU alumni, and university leadership.

Visit to Army Futures Command

On July 30, 2019, the MEDE leadership provided a program update to the Director of Strategic Initiatives at the Army Futures Command (AFC) located in Austin, Texas. The update included technical accomplishments, discussions on future research directions, assisting with an upcoming Congressional visit to AFC.

MEDE research conducted at the University of Delaware is showcased at UD Day in DC.

From left: U.S. Senator Tom Carper (D-DE) receives his MEDE commemorative item from Composites CMRG Co-lead Prof. John Gillespie, Jr.

Legislative staffers from the office of U.S. Senator Ben Cardin get a close-up look at the laser shock facility at JHU.

(Far right) CMEDE Director KT Ramesh and HEMI Associate Director Lori Graham-Brady visit U.S. Army Futures Command in Austin, TX.

MEDE research conducted at Johns Hopkins is showcased at Hopkins on the Hill.

Dr. Victor Nakano, MEDE Executive Program Director, describes MEDE research to U.S. Representative David Trone (D-MD).

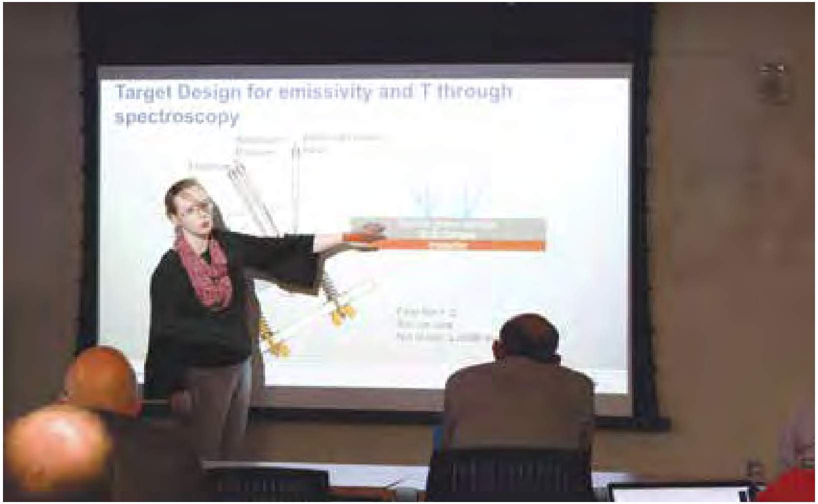
RELATED ACADEMIC PROGRAMS

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.



Dr. Minta Akin from Lawrence Livermore National Laboratory gives a seminar.

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 Sohan Mugi performs research at NC A&T.

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.

2019 AEOP Research in Engineering Apprenticeship students pose with special guests from the U.S. Army after giving their final presentation.

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)

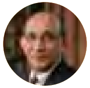
Ceramics, Composite and Optical Materials Center (CCOMC)

U.S. Naval Research Laboratory

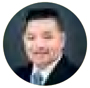
National Institutes of Standards and Technology

CMEDE LEADERSHIP AND STAFF MEMBERS AT JOHNS HOPKINS UNIVERSITY

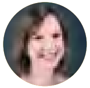
CMEDE Leadership


Prof. K.T. Ramesh
Director

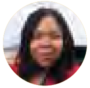

Prof. Lori Graham-Brady
Associate Director


Dr. Victor Nakano
Executive Program Director

CMEDE Staff

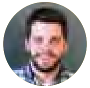

Jessica Ader
Communication Specialist

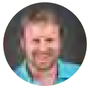

Bess Bieluczyk
Senior Administrative Coordinator

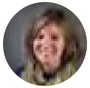

Denise R. Brown
Budget Specialist


Lisa Eklund
Grants and Contracts Manager


Scott McGhee
Senior Administrative Manager


Andrew Proulx
Grants and Contracts Analyst


Matthew Shaeffer
Staff Engineer


Katie Vaught
Senior Administrative Coordinator

ABBREVIATIONS AND ACRONYMS

AEOP	Army Educational Outreach Program
CCDC ARL	U.S. Army Combat Capabilities Development Command Army Research Laboratory
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
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
RUTGERS	Rutgers University
STEM	Science, Technology, Engineering and Math
UNCC	University of North Carolina at Charlotte
URAP	Undergraduate Research and Apprenticeship Program

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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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