



Air Force Research Laboratory



Integrity ★ Service ★ Excellence

Dynamic Materials and Interactions Portfolio

**Spring Review
March 2016**

**Jennifer L. Jordan, Ph.D
AFOSR/RTA Team 1**

Air Force Research Laboratory



Outline



- Portfolio Motivation and Investment Strategy
- Research Thrusts
 - Energetic Materials Science
 - Dynamics of Heterogeneous Materials
 - Reactive Materials
- Summary and Issues



Enabling 6th Motivation Generation Aircraft



**F-35 and Beyond –
Demands munition innovation**

Internal Carriage



High energy density; Multifunctional materials;
Insensitive

Survivable Systems



Mechanics of heterogeneous materials;
Survivable energetics; Combined thermal and
acoustic loading; Thermally stable materials

Rapid Development
Time



Energetic materials by design; predictive multi-
scale modeling and simulation

Dynamic Materials and Interactions



Dynamic Materials and Interactions Portfolio



Description: Fundamental, basic research into the dynamic chemistry and physics of complex materials, particularly Energetic Materials (EMs).



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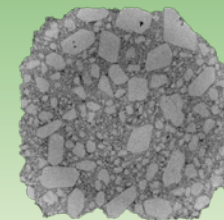
High energy density; Multifunctional materials; Insensitive

Mechanics of heterogeneous materials; Survivable energetics; Combined thermal and acoustic loading; Thermally stable materials

Energetic materials by design; predictive multi-scale modeling and simulation

Energetic Materials Science

- Predictive processing-structure-property relationships





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High energy density; Multifunctional materials; Insensitive

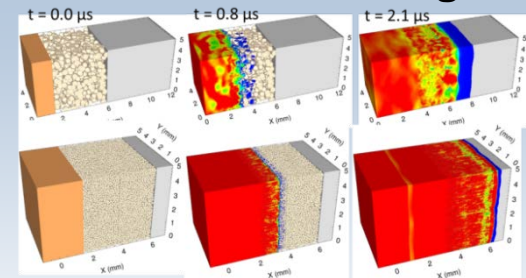
Mechanics of heterogeneous materials; Survivable energetics;

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Energetic materials by design;
predictive multi-scale modeling and simulation

Dynamics of Heterogeneous Matls

- Material structure – shock wave interactions
- Stress wave tailoring





Dynamic Materials and Interactions Portfolio



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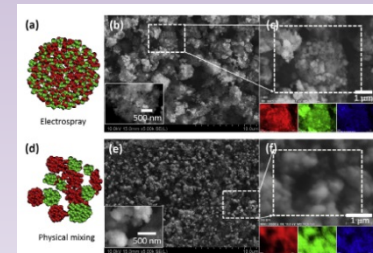
High energy density; Multifunctional materials; Insensitive

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Reactive Materials

- Enhanced energy content and improved efficiency
- New energetic mat'ls





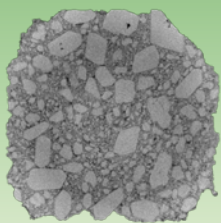
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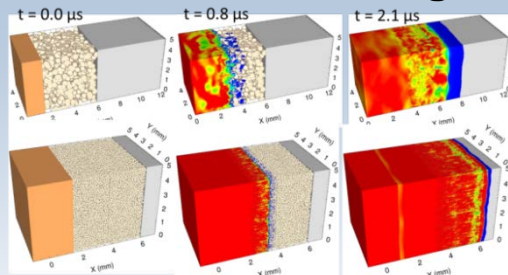
Energetic Materials Science

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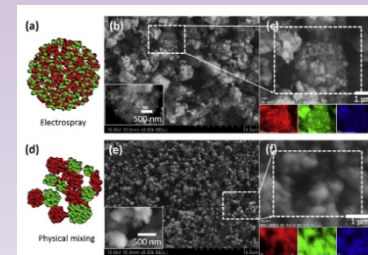
Dynamics of Heterogeneous Matls

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Reactive Materials

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Portfolio Investment Strategy





Portfolio Investment Strategy



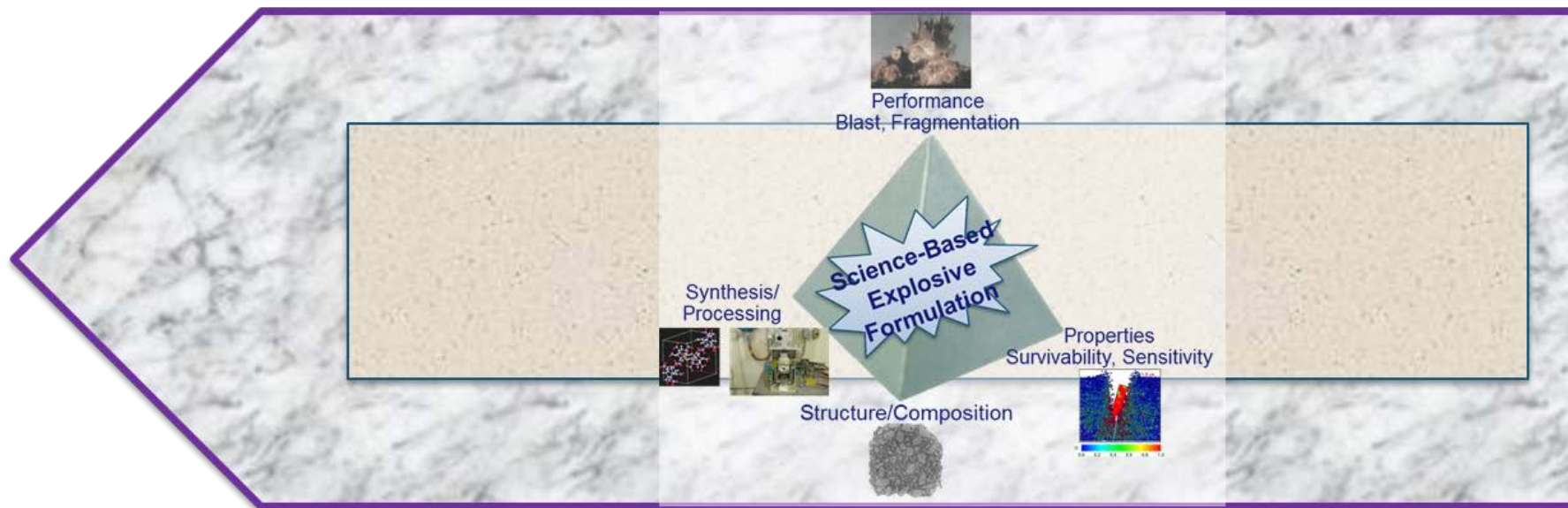
- Discover
 - Increase international collaboration through AOARD and EOARD
 - Cultivate Young Investigators as “bow wave” for key research gaps
- Shape
 - Focus funding on key research gaps – targeted each year
 - Increase Academic – TD interactions
 - Coordinate across DoD basic research (ONR, ARO, DTRA, AFOSR)
 - Coordinate with DOE through Joint Munitions Program
- Champion
 - Advocate for research, including MURI, COE, and SBIR/STTR topics



Energetic Materials Science



Boundary Conditions – Storage, delivery, use
- Thermal and Mechanical Loading
- Coupling to Target



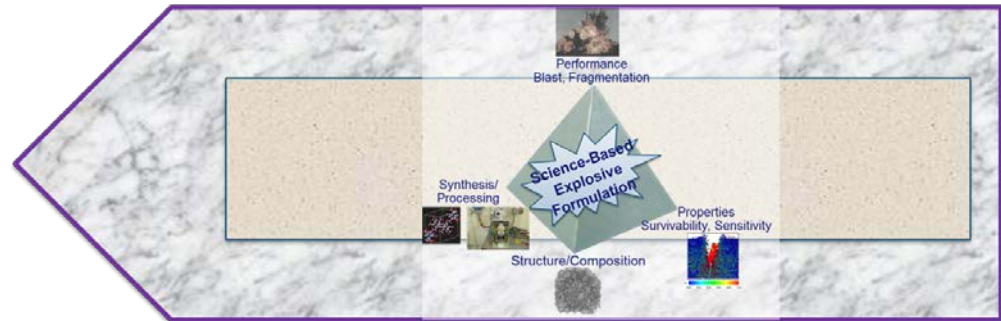


Energetic Materials Science

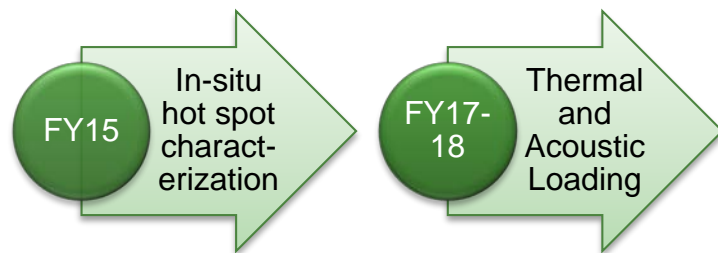


Challenge: Lack of predictive understanding requires long development times and large resource investment for new explosive formulation

Boundary Conditions – Storage, delivery, use
- Thermal and Mechanical Loading
- Coupling to Target



Investment and Way Ahead

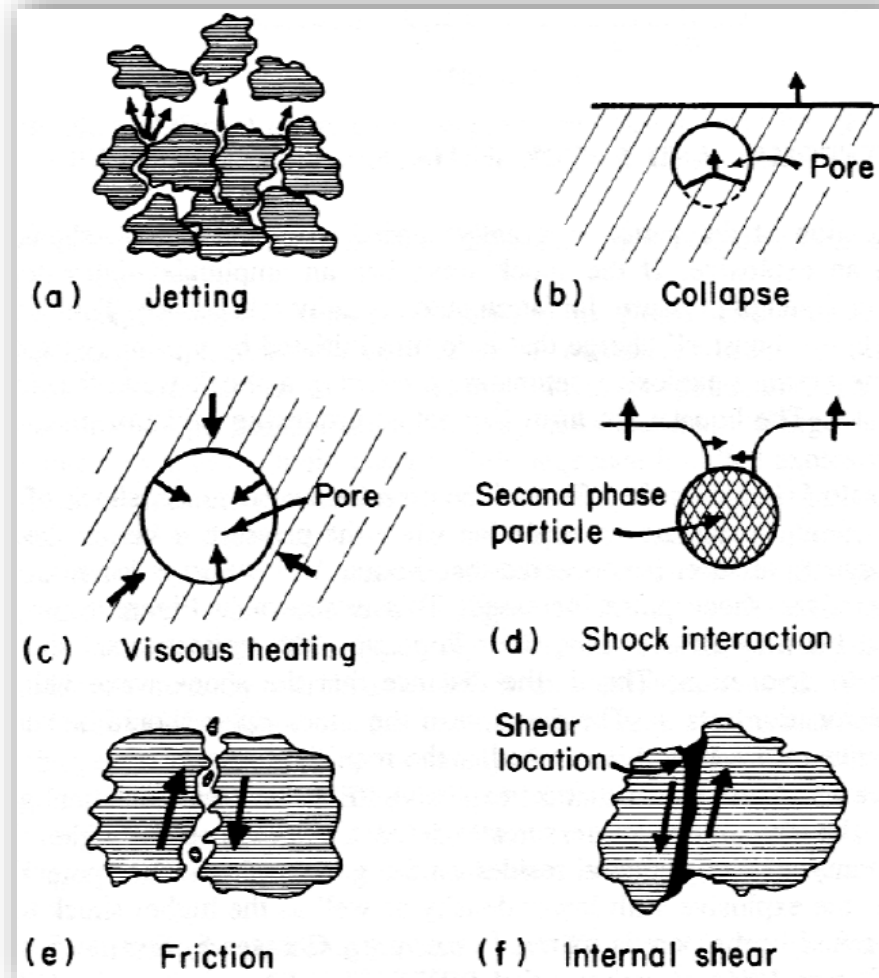


- FY15: Concentrated investment on experimental *in situ* hot spot characterization and associated mesoscale modeling; Phase II STTR on particulate mixing
- Next focus - combined thermal and acoustic load

Coupling M&S with experimentation to transform energetic materials formulation from empirical to predictive



Hot Spots in Energetic Materials

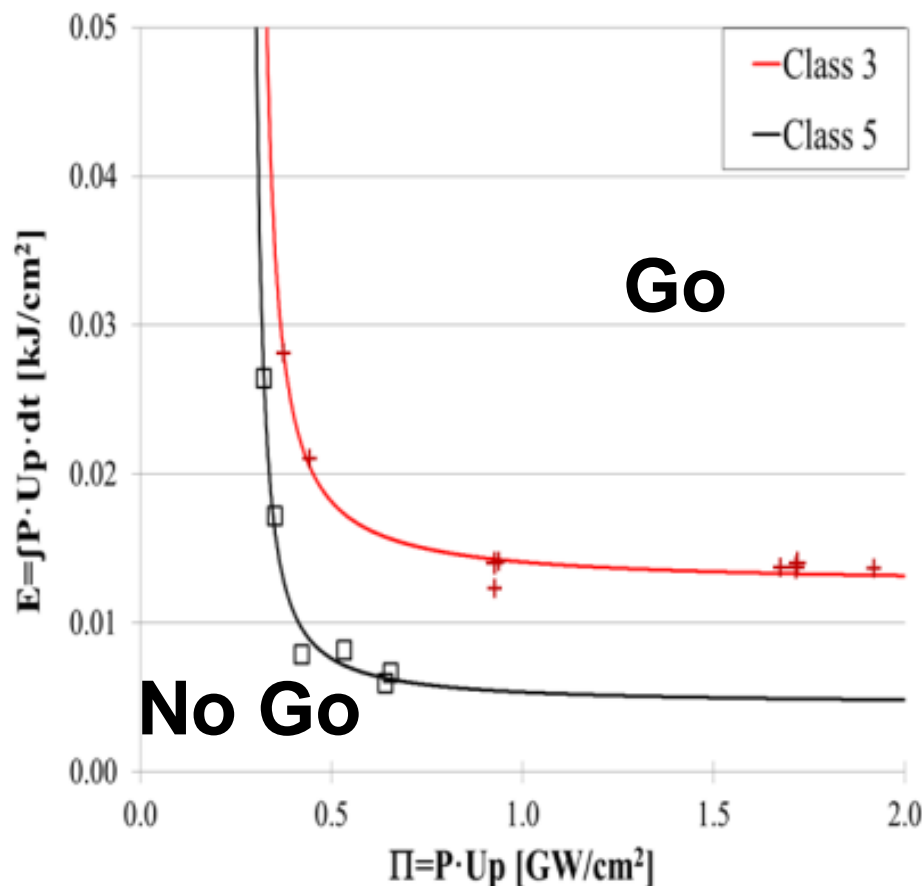
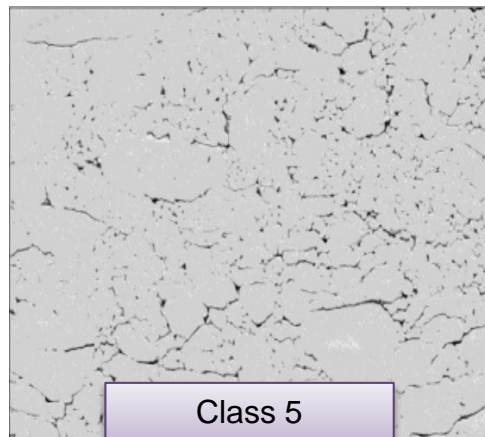


Davis, W. C. High Explosives: The interaction of chemistry and mechanics *Los Alamos Science* [Online], 1981.
Meyers, M.A., *Dynamic Behavior of Materials*.

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Mesoscale Simulations and Experiments Collaboration



Welle, Molek, Fajardo
(RW)

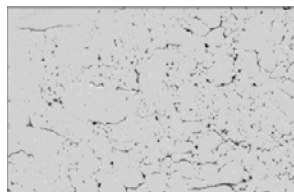
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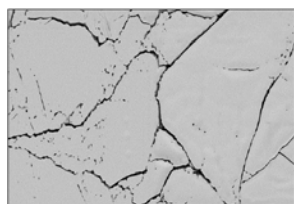
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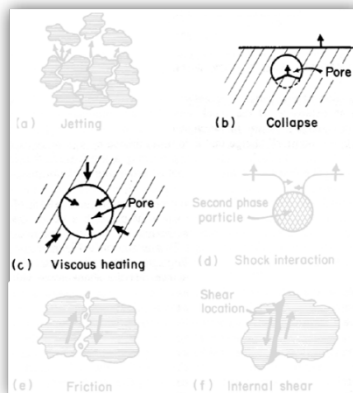


Class 5

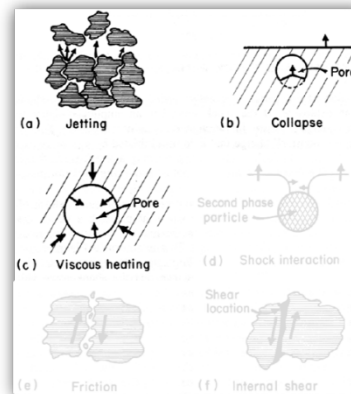


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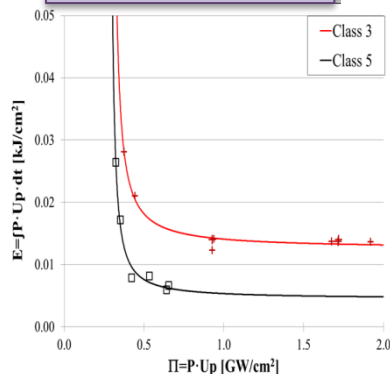
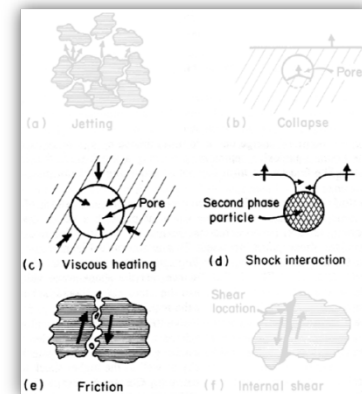
ALE3D



SCIMITAR3D



CODEX



Welle, Molek, Fajardo
(RW)

Keo Springer
Collaboration through JMP
(LLNL)

H.S. Udaykumar
(University of Iowa)

Min Zhou
(Georgia Tech)

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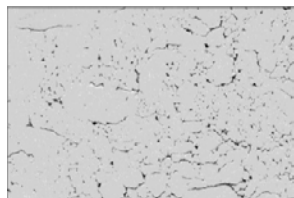
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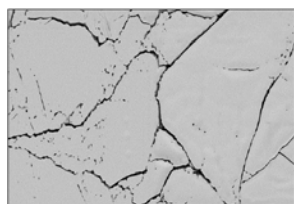




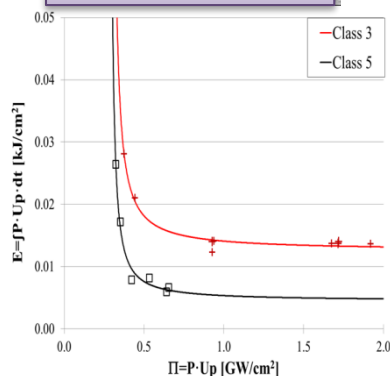
Mesoscale Simulations and Experiments Collaboration



Class 5

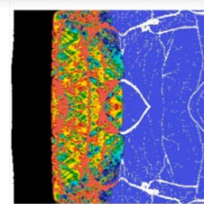
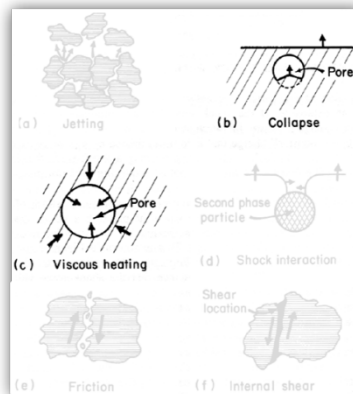


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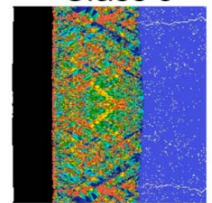


Welle, Molek, Fajardo
(RW)

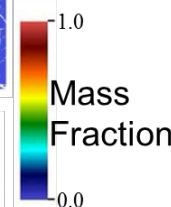
ALE3D



Class 3

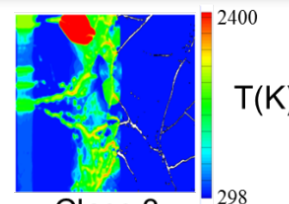
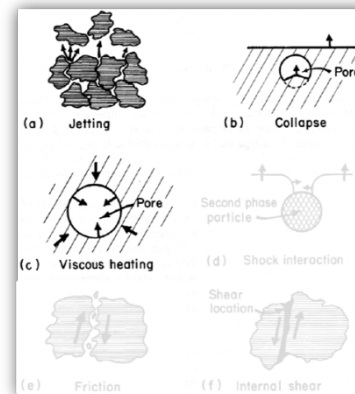


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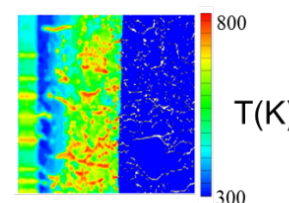


Keo Springer
JMP Collaboration
(LLNL)

SCIMITAR3D



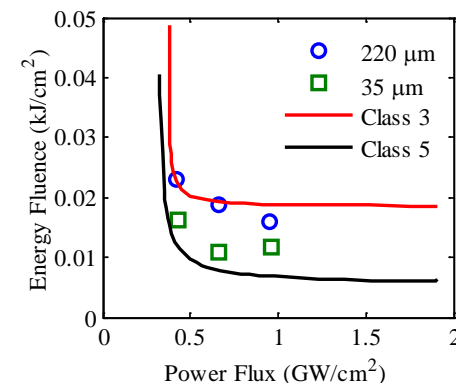
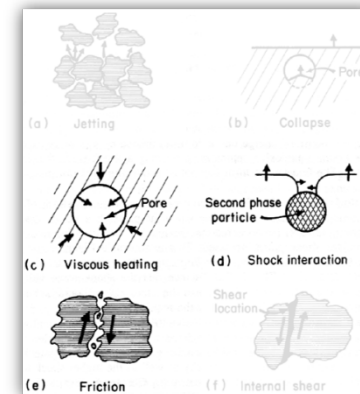
Class 3



Class 5

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CODEX



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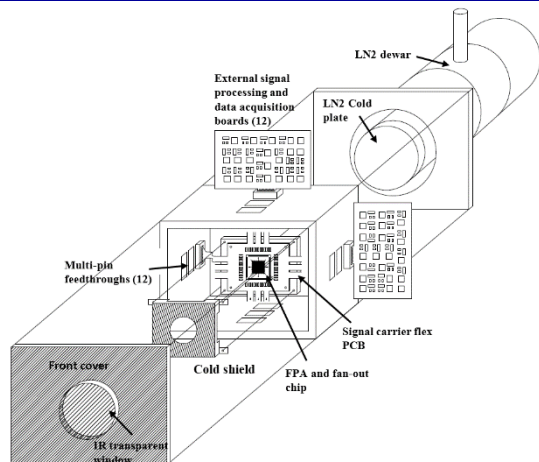
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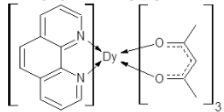


Imaging Hot Spots in Real Time Multiple Approaches

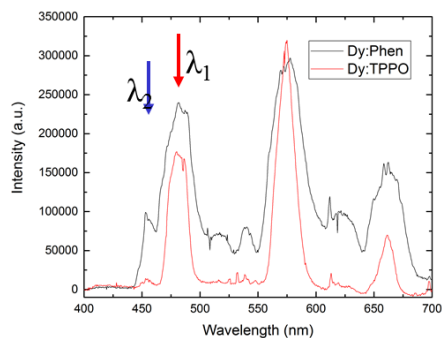
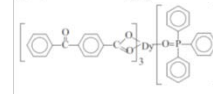


High-speed infrared microscope: acquire transient temperature field images at a rate of 10 million fps, w/ spatial resolution of $\sim 5\text{-}10\text{ }\mu\text{m}$. (Gudur, Brown)

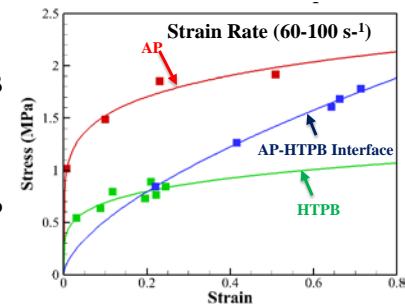
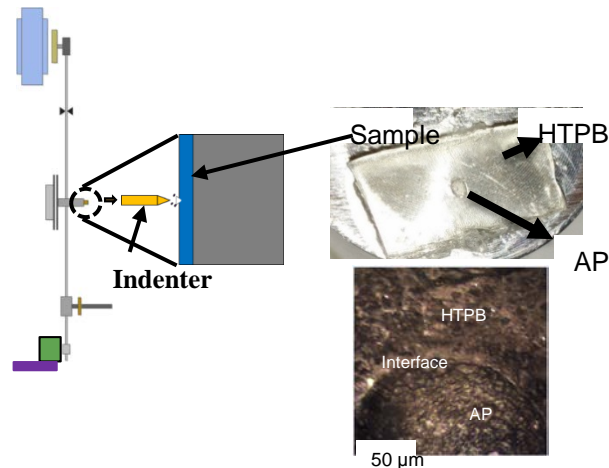
Dy(acac)₃(Phen)



Dy(4-BBA)₃(TPPO)₂



Fluorescent Thermometry: Disperse molecular temperature sensors in binder to map temperature field. (Eilers, WSU)



Interface Characterization: Dynamic properties of interfaces between energetic crystal and polymer binder. (Tomar, Purdue)



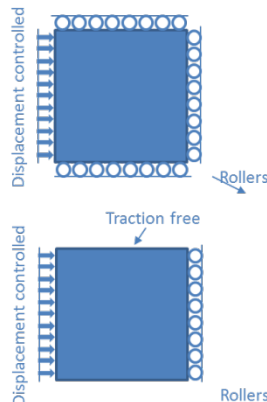
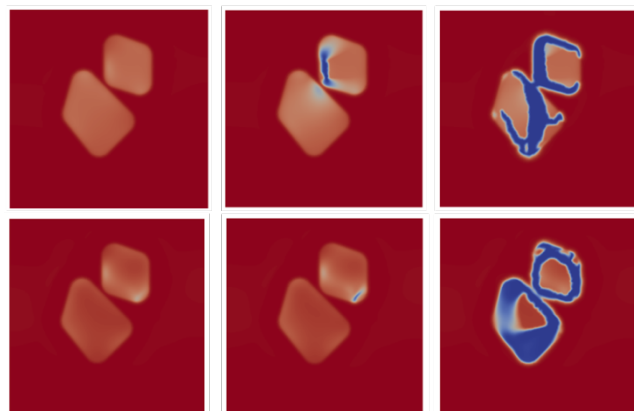
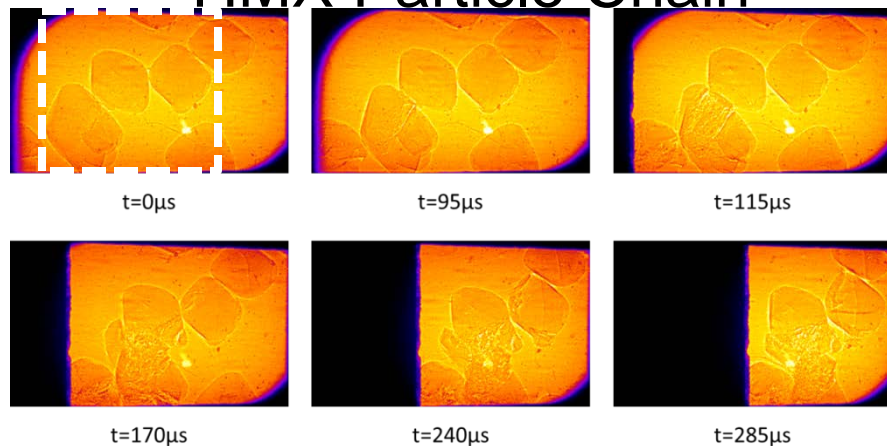
Real-time X-ray Phase Contrast Imaging: Images at particle scale under dynamic loading with simultaneous IR temperature measurements. (Chen, Purdue)



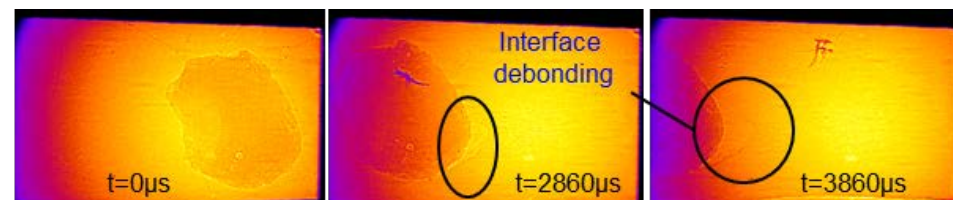
High Speed X-Ray Measurements



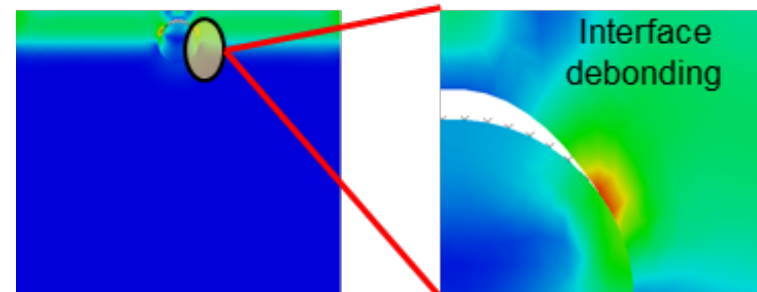
HMX Particle Chain



AP-HTPB Interface



Stress

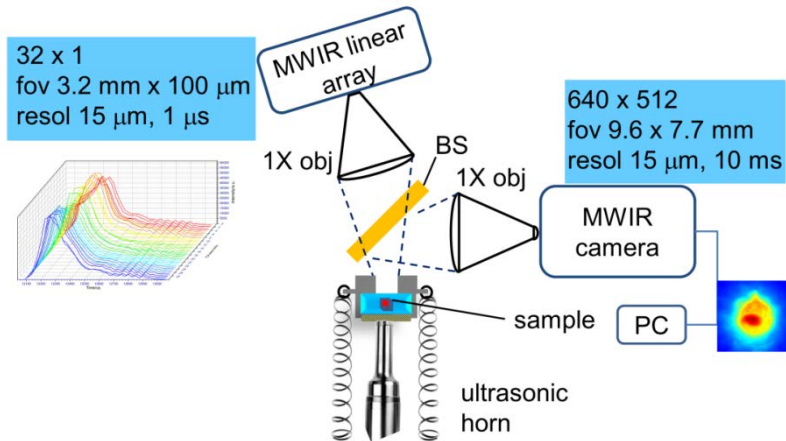


Temperature

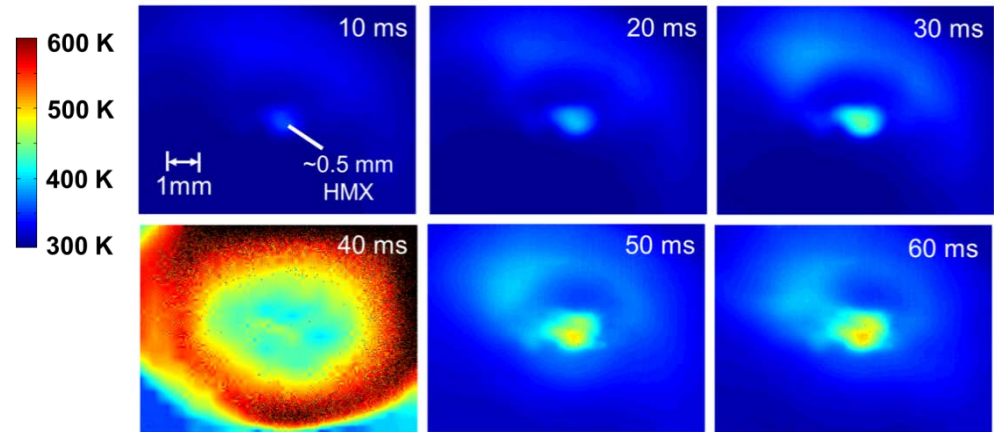




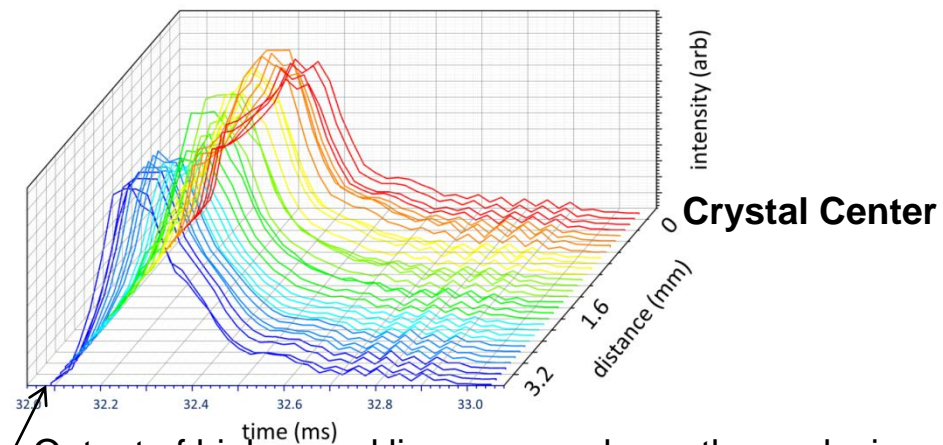
Thermal Imaging of Hot Spots



Apparatus to generate ultrasonically-induced hot spots in energetic materials



Thermal imaging movie showing a 0.5 mm HMX crystal in a polymer binder irradiated with 20 kHz ultrasound. The crystal exploded between 30 and 40 ms



Output of high speed linear array shows the explosion happened at 32.1 ms and it lasted for 200 ms. The crystal center is at 0 mm.



ARTICLE

Received 26 Sep 2014 | Accepted 9 Feb 2015 | Published 2 Apr 2015

DOI: 10.1038/ncomms7568

Ultrasonic hammer produces hot spots in solids

Sizhu You¹, Ming-Wei Chen¹, Dana D. Dlott¹ & Kenneth S. Suslick¹



(Dlott, Suslick, U Illinois)



Meso-Scale Deformation



Effect of Strain rate

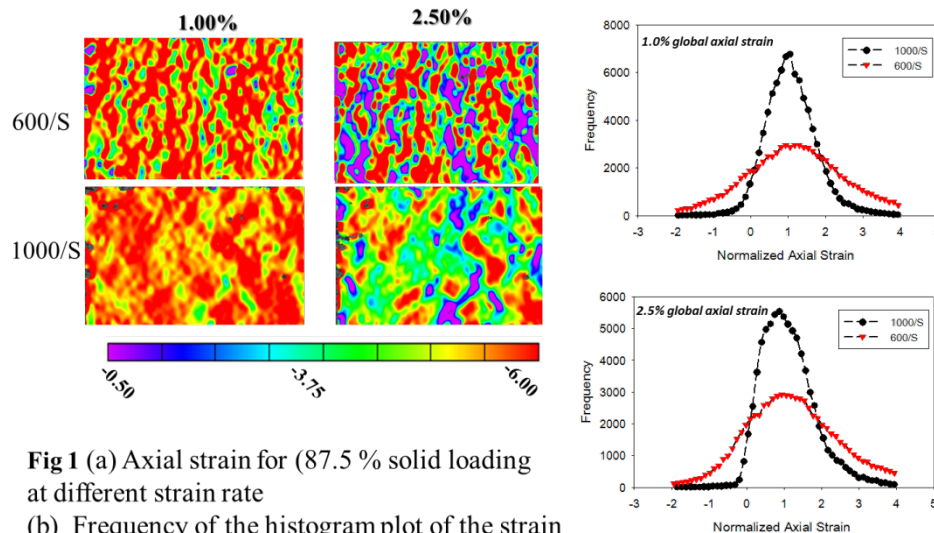


Fig 1 (a) Axial strain for (87.5 % solid loading at different strain rate
(b) Frequency of the histogram plot of the strain
Note: the narrow plot indicate less heterogeneity

Effect of Solid loading

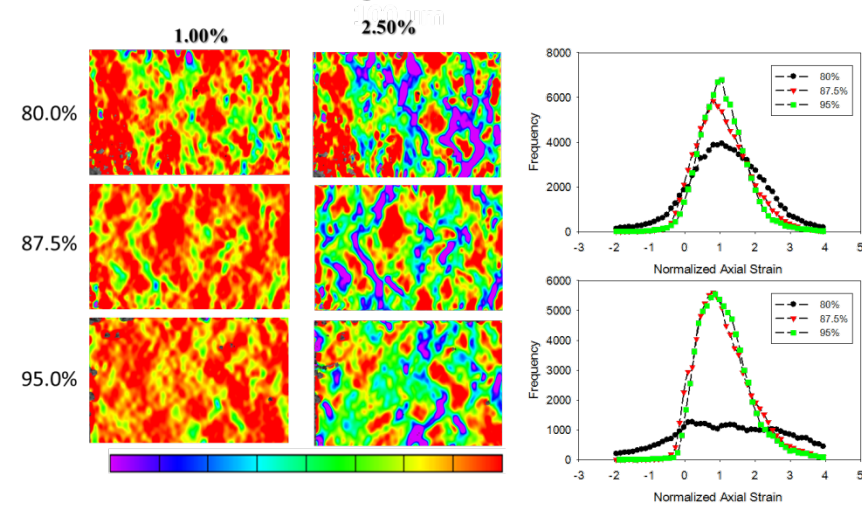
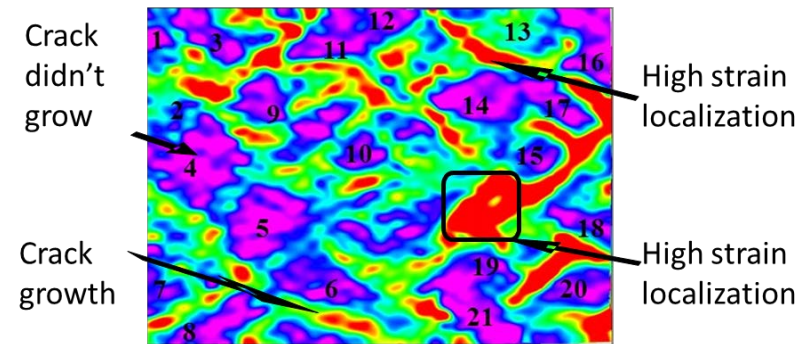
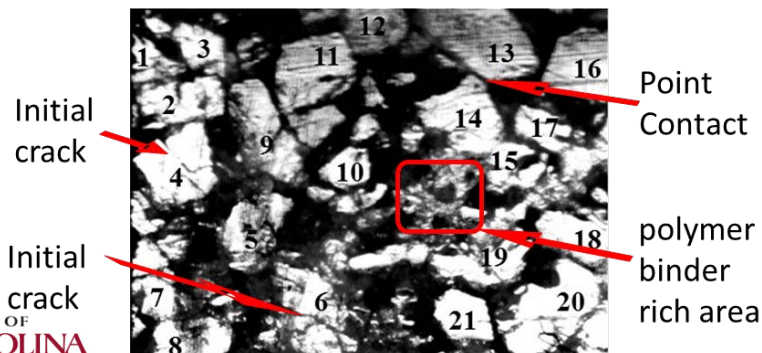


Fig 2 (a) Axial strain for different solid loading Effect of solid loading
(b) Frequency of the histogram plot of the strain
Note: the narrow plot indicate less heterogeneity



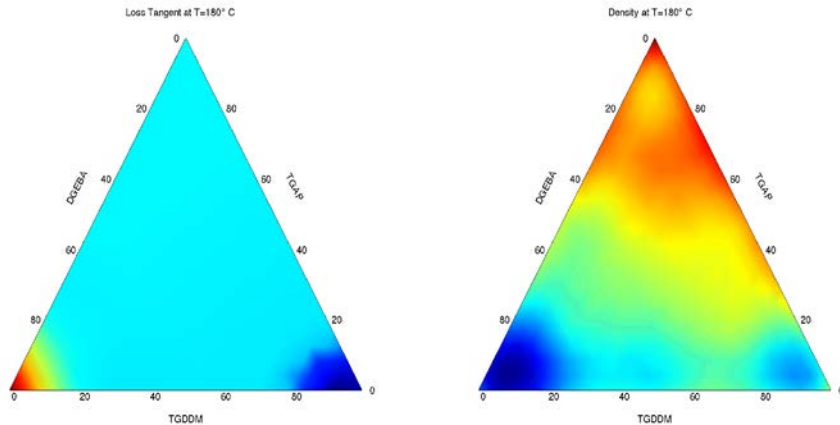
UNIVERSITY OF
SOUTH CAROLINA

College of Engineering
and Computing

(Kidane, USC)



Delving Below the Mesoscale

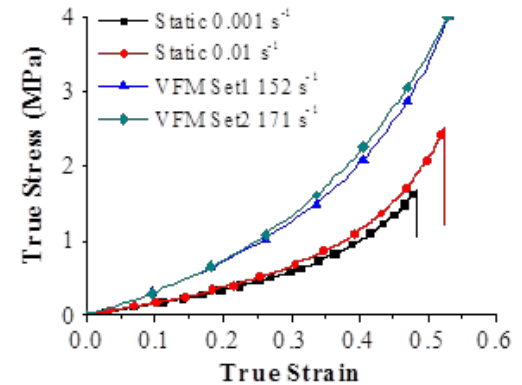
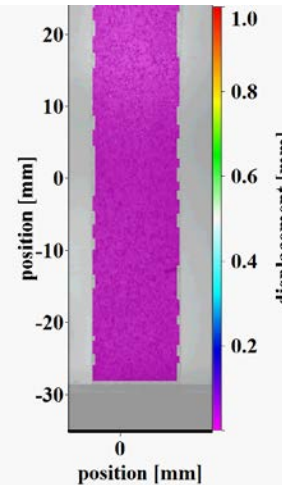


Evolution of glass transition (left) and density (right) of a ternary epoxy blend.

(Foreman, U of Sheffield)
Joint with Mat Snyder, EOARD



The University
Of Sheffield.

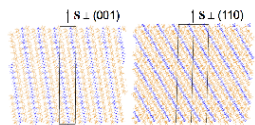


Using virtual fields method to determine high rate properties of viscoelastic polymers

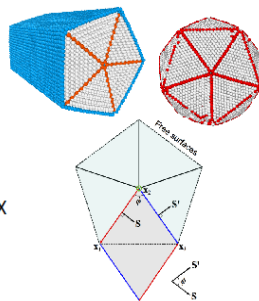


(Sivour)
Joint with Mat Snyder, EOARD

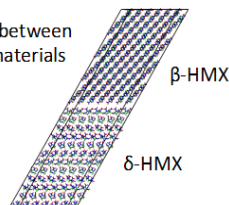
Oriented CL-20/HMX Co-Crystals



Nanostructures



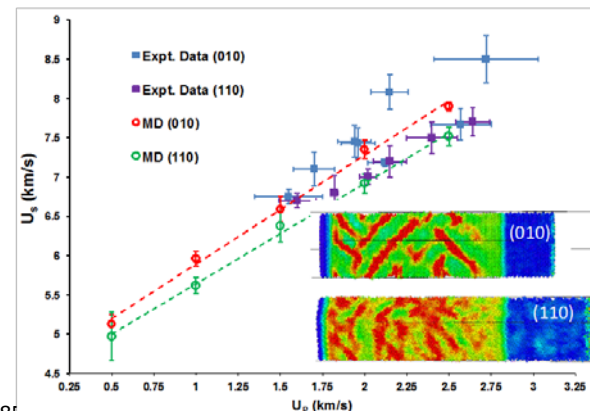
Interfaces between
different materials



(Sewell)

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U_s - U_p locus for shocks in (010)- and (110)-HMX

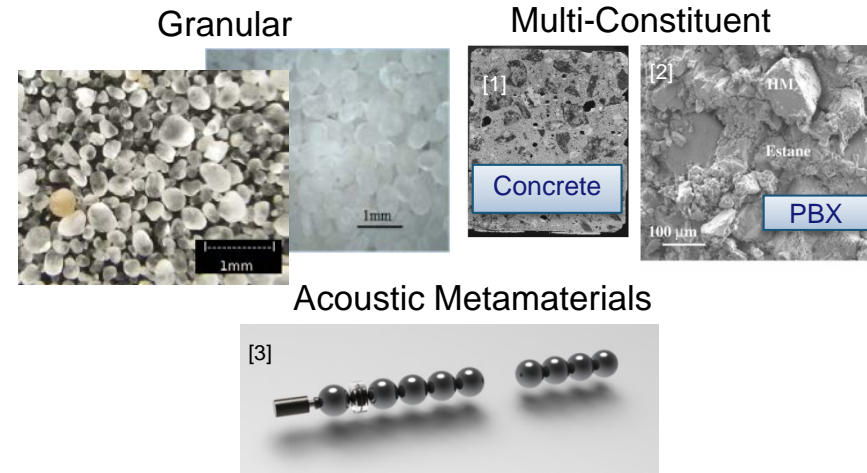




Dynamics of Heterogeneous Materials

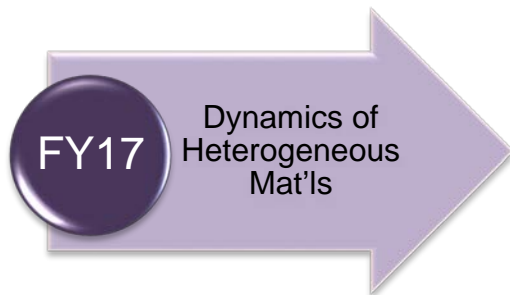


Challenge: Dynamic response of heterogeneous materials is complex and continuum response depends on the stochastic mesostructure



Investment and Way Ahead

- Center of Excellence through FY17
- Planning investment for FY17+ on manipulating stress wave propagation



Manipulate stress wave propagation through microstructure to achieve a desired output

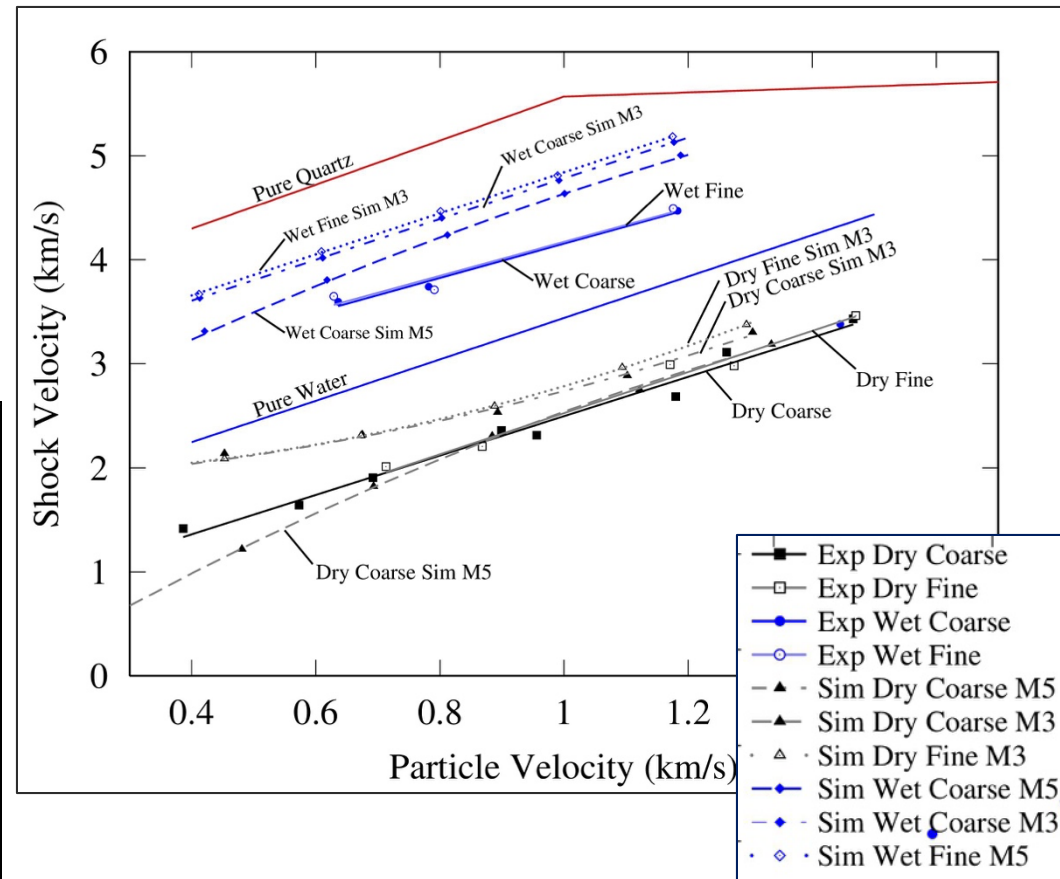
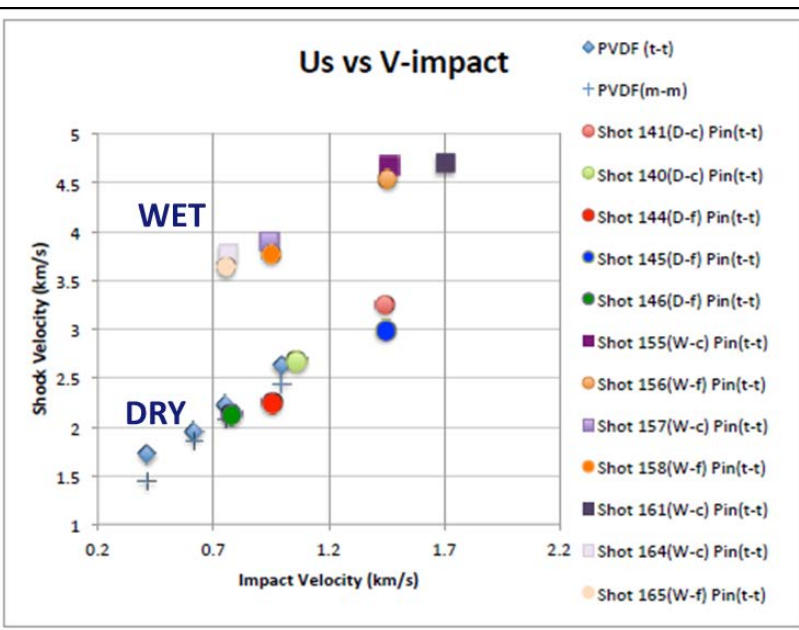
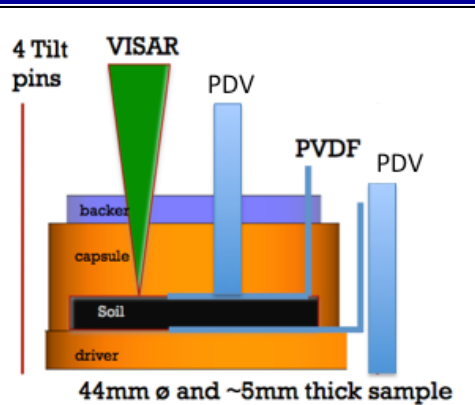
[1] <http://www.fhwa.dot.gov>

[2] M.R. Baer, *Thermochimica Acta*, 2002

[3] <http://www.mechmat.ethz.ch/research.html>



Granular Materials

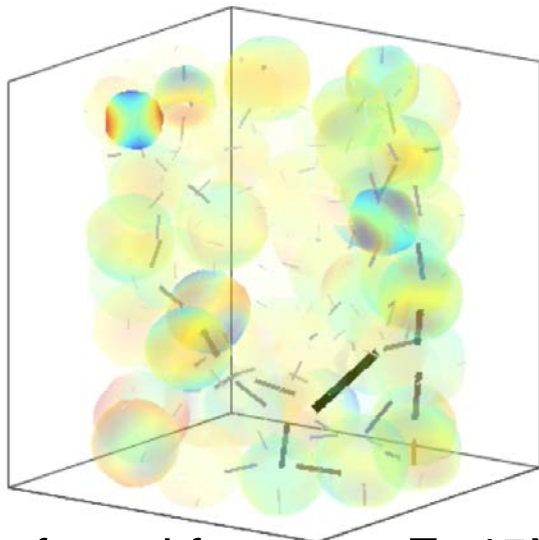
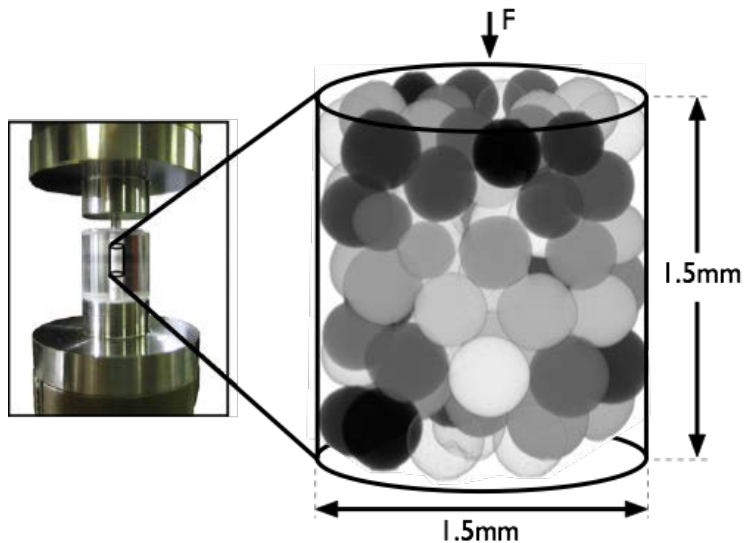


Georgia
Tech

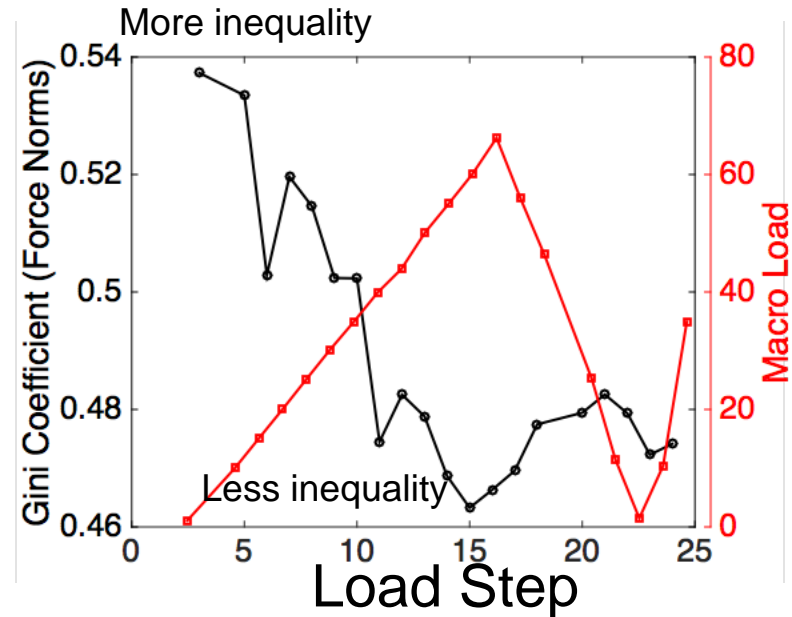




In-situ 3D Force Inference in Granular Materials



Inferred forces at $F=45\text{N}$



New quantitative inequality metrics reveal how heterogeneity changes with macro load



(Andrade)
Center of Excellence

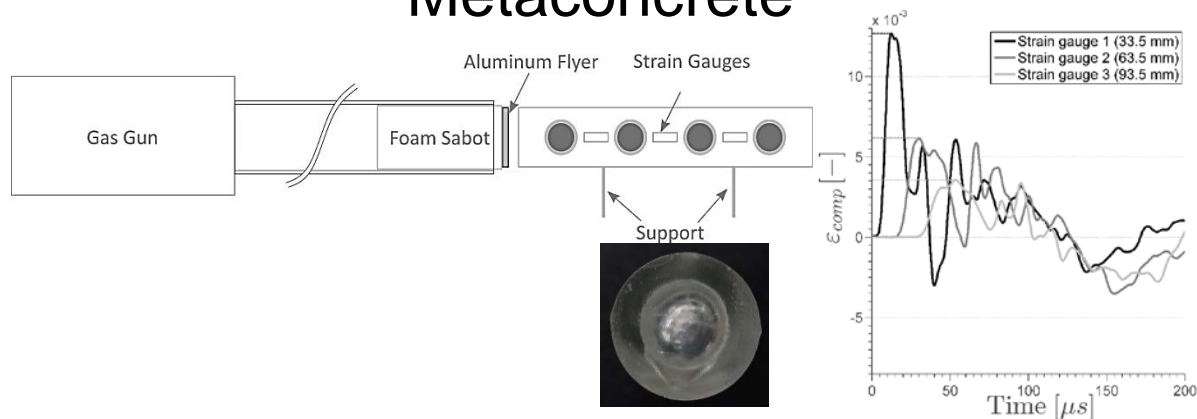




Tailored Microstructures

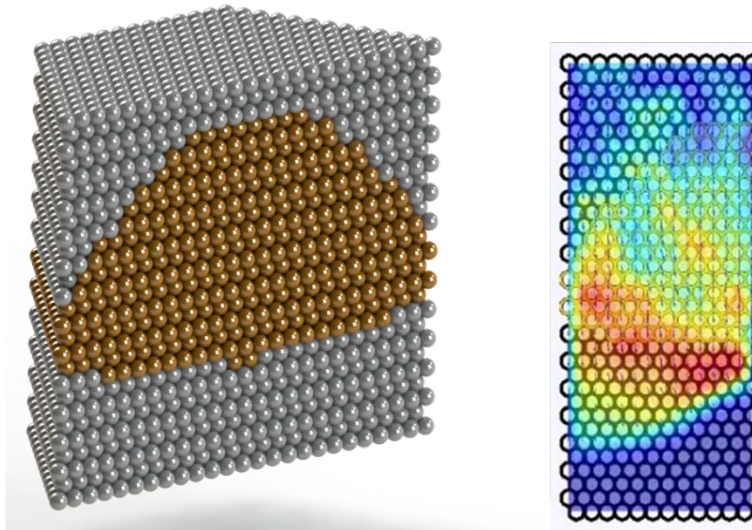


Metaconcrete



(Ravichandran, Ortiz)
Center of Excellence

Granular Crystals



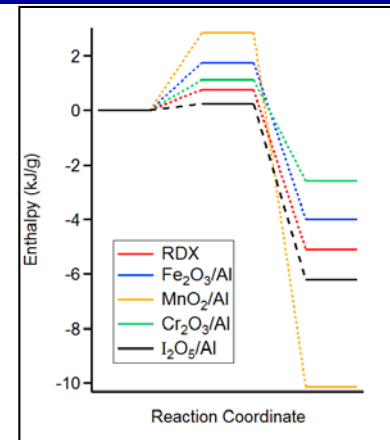
(Daraio)
Center of Excellence



Reactive Materials



Challenge: Reactive materials provide promise of increased energy density that has not been realized



Courtesy of M. Lindsay

Energy content is comparable to CHNO explosives.
Reaction time can be significantly longer.



Investment and Way Ahead

- Focused investment starting in FY16 on understanding heterogeneous reaction mechanisms, reactive multi-phase flow, and bottom-up material design

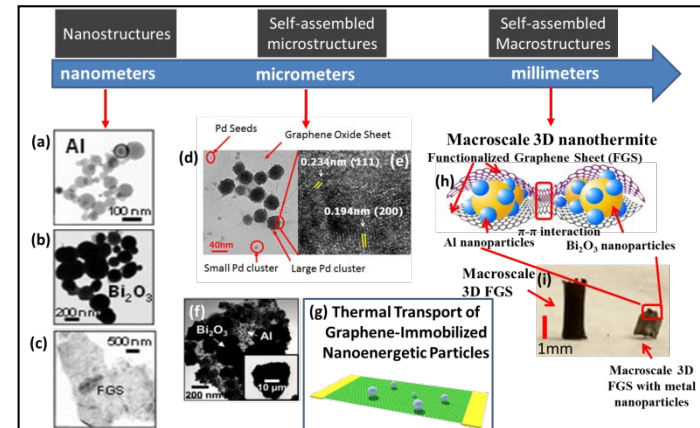
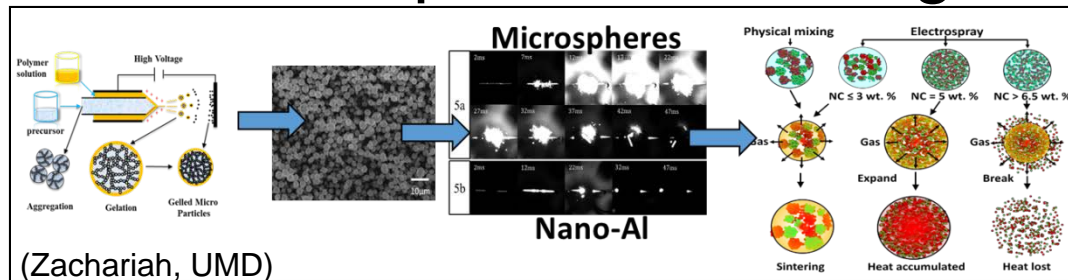
Understanding reactive materials and manipulation of output power to increase energy delivery of systems



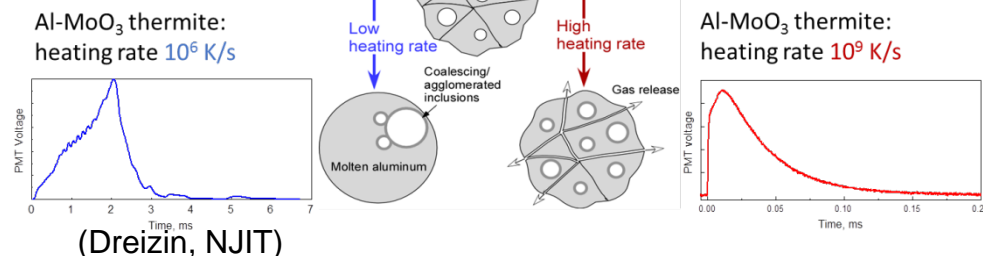
New Reactive Materials Investment



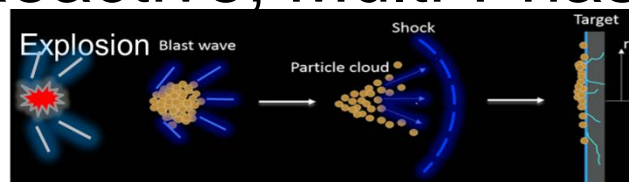
• Bottom Up Material Design



• Understanding Heterogeneous Reaction Mechanisms



• Reactive, Multi-Phase Flow



(Jacobs and Udaykumar, SDSU/Iowa)

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Summary

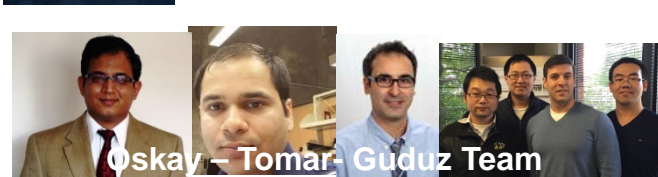
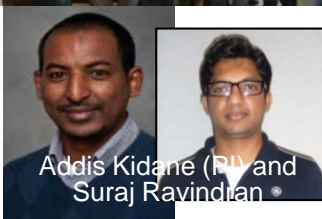
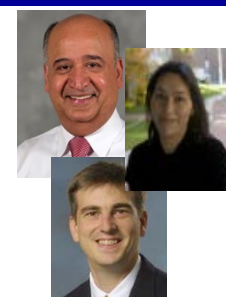


- Dynamic Materials and Interactions portfolio has three research thrusts with a focused investment strategy





Acknowledgements



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