Future Directions in Dynamic Materials and Interactions Basic Research: An Air Force Perspective

December 2013

Jennifer L. Jordan
Program Officer
AFOSR/RTE
Air Force Research Laboratory

Integrity ★ Service ★ Excellence

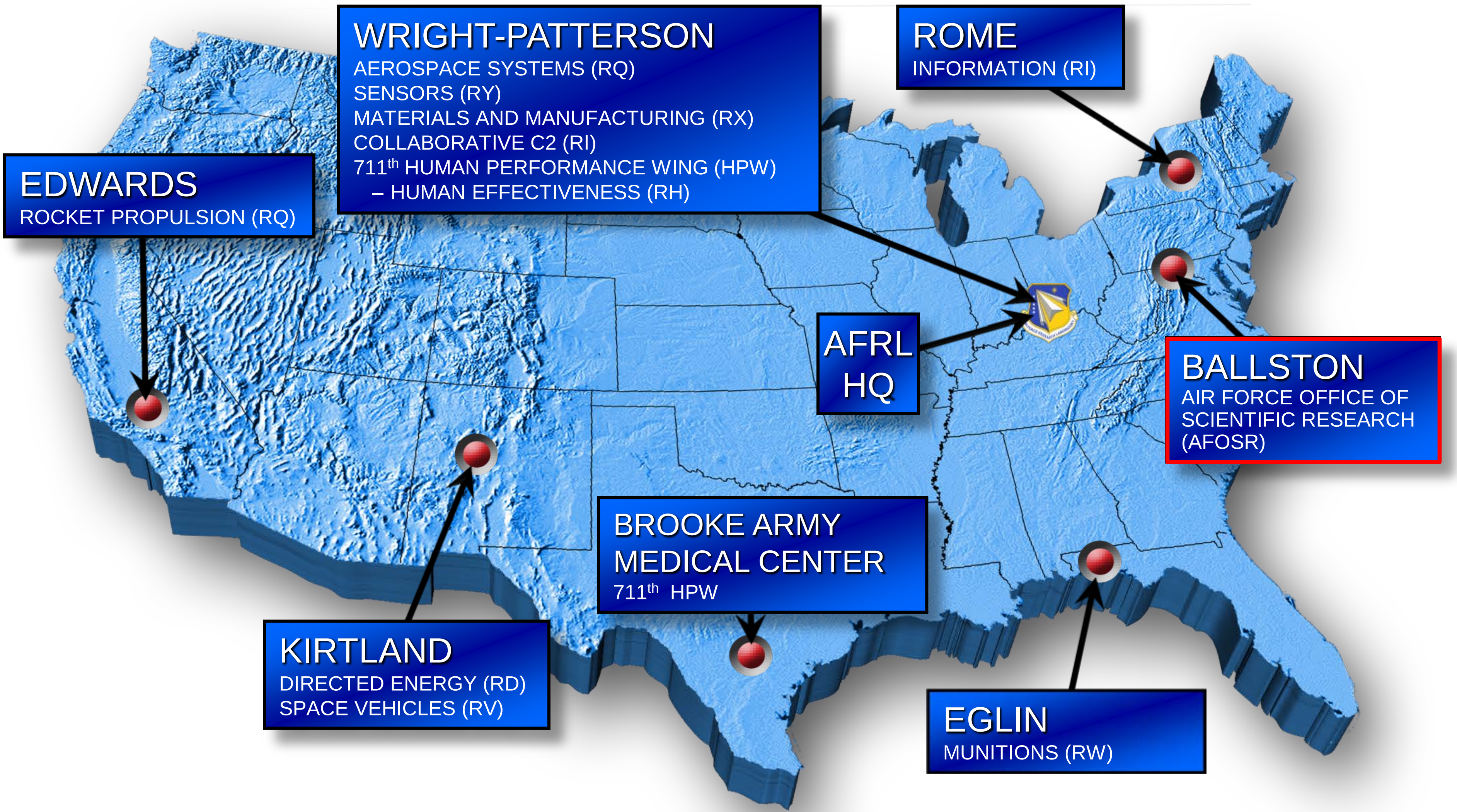
BASIC RESEARCH:
A MILITARY NECESSITY

"The first essential of the airpower necessary for our national security is preeminence in research. ***The imagination and inventive genius of our people-in industry, in the universities, in the armed services, and throughout the nation must have free play, incentive, and every encouragement."***

Gen. Henry "Hap" Arnold, 1944

AFRL Organization

Major AFRL Facilities



40 Sites World-Wide

DoD Research Categories

6.1

BASIC RESEARCH

Produces New Knowledge

6.2

APPLIED RESEARCH

Develops New Technologies

6.3

ADVANCED TECHNOLOGY DEVELOPMENT

Test and Demonstrations

AFOSR Mission

AFOSR discovers, shapes, and champions basic science to profoundly impact the future Air F...

- Identify B... ...ies
- ... ...Research for Air
- ... ...echnologies to DoD and Industry

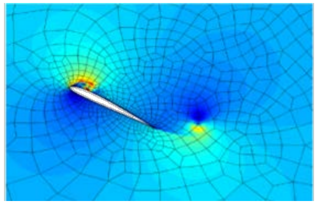
Creating the Scientific Base to Make Current DoD Systems and Practices Obsolete

TODAY'S BREAKTHROUGH SCIENCE FOR TOMORROW'S AIR FORCE

Basic Research Tech Divisions

RTA

Dynamical Systems & Control

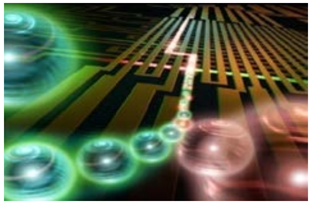


Research Areas

Dynamics and Control
Mathematical and Computational Cognition
Robust Computational Intelligence
Computational Math
Optimization and Discrete Mathematics
Test and Evaluation
Flow Interactions and Control
Multi-Scale Structural Mechanics & Prognosis

RTB

Quantum & Non-equilibrium Processes



Research Areas

Atomic and Molecular Physics
Plasma and Electro-Energetic Physics
Remote Sensing and Imaging Physics
Multi-Scale Modeling
Electromagnetics
Ultrashort Pulse Laser-Matter Interactions
Biophysics
Laser and Optical Physics

RTC

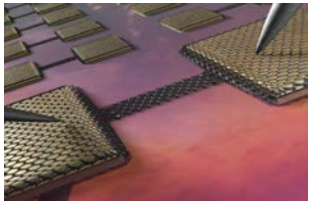
Information, Decision, & Complex Networks

Research Areas

Systems and Software
Complex Networks
DDDAS
Information Operations and Security
Trust and Influence
Robust Decision Making in Human
Science of Information, Computation and Fusion
Sensing, Surveillance, Navigation

RTD

Complex Materials and Devices

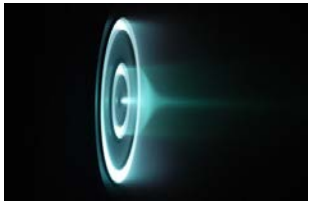


Research Areas

Natural Materials and Systems
Extremophiles
Low Density Materials
Surface and Interfacial Science
GHz-THz Electronics
Mechanics of Multi-functional Materials & Microsystems
Organic Materials Chemistry
Optoelectronics and Photonics
Aerospace Materials for Extreme Environments
Quantum Electronic Solids

RTE

Energy, Power, and Propulsion



Research Areas

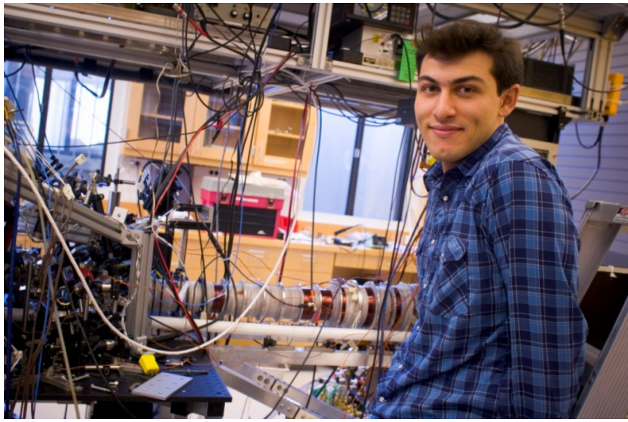
Molecular Design and Synthesis
Molecular Dynamics and Theoretical Chemistry
Space Power and Propulsion
Multiscale Modeling and Computation
Human Performance and Biosystems
Energy Conversion and Combustion Sciences
Aerothermodynamics and Turbulence
Space Sciences
Thermal Sciences
Sensory Information Systems

- AFOSR was recently reorganized to:
  - Maintain a strong 6.1 focus
  - Improve scientific quality across the organization
  - Improve collaboration across research areas

AFOSR Supports Tomorrow's S&Es

National Defense Science and Engineering Graduate Fellowship (NDSEG)

- 3-year scholarship program to increase the numbers of PhDs in science and engineering fields
- Funds tuition, fees, etc. and $31K stipend/year
- No service commitments
- More info: http://www.asee.org/ndseg



David Kaz, Harvard
Physics PhD Candidate
2006 NDSEG AF Scholar

Science, Mathematics, and Research for Transformation (SMART)

- Career opportunity after graduation
- Funds tuition, fees, etc. and stipend
- Additional details at http://smart.asee.org/

Awards to Stimulate and Support Undergraduate Research Experience (ASSURE)

- Provide undergraduates with research opportunities in S&E fields of DoD interest
- http://www.wpafb.af.mil/library/factsheets/factsheet.asp?id=9333

AFOSR Supports World-Class Research

- **Core Programs – Discipline-oriented portfolios that primarily support single-investigator grants.**
  - Broad Area Agency Announcement (BAA) is open at all times – but some portfolios may have review deadlines
  - Grant size and duration (up to 5 years) determined by PM
- **Young Investigator Program (YIP)**
  - Designed to develop long-term relationships with leading early career PIs
  - Highly competitive; proposals due annually in September
  - 3-year Grants ~$120k/yr
- **Multidisciplinary University Research Initiative (MURI)**
  - Achieve significant scientific advances
  - Capture attention of top researchers
  - Encourage multidisciplinary collaboration
  - Up to $1.5M/yr for five years
- **Defense University Research Instrumentation Program (DURIP)**
  - Supports acquisition of major equipment to augment current or develop new research capabilities
- **Small Business Technology Transfer (STTR)**
  - Supports small business/university collaborations

- 1181 extramural research grants at 227 universities
- 239 intramural research projects at AFRL, USAFA, AFIT
- 149 STTR small business - university contracts
- 500 fellowships; 1390 grad students, 570 post-docs on grants

www.afosr.af.mil

Dynamic Materials and Interactions Portfolio

- **Description:** Fundamental, basic research into the dynamic **chemistry and physics** of complex materials, particularly energetic materials.

Thrust Areas

Shock and Detonation Physics

Structure and Composition of Energetic Materials

Material Spectrum →

Explosive	Reactive Material, Structural Energetic, etc.	Novel Energetic Materials
Organic explosive crystals, fuel and oxidizer additives with binder; optimized for detonation	Metal-metal and metal-metal oxide reactions	Core-shell nanoparticles; Energetic Co-Crystals; Poly-nitrogen

Composites and polymers

Thrust Areas

Shock and Detonation Physics

- Damage, Hot Spots, and Initiation - Mesoscale Diagnostics
- Dynamic Reacting Interfaces
- Metastable, High Pressure Phases
- High Strain Rate and Shock Response of Polymers, Composites and Geologic Materials

Structure and Composition of Energetic Materials

- Prediction of Viscosity and Microstructure in Highly Loaded Suspensions
- Shock Loading of Energetic Crystals
- New Energetic Materials
- Influence of External Fields

Virtual Design Studio Vision

Virtual Design Studio for Energetics: Predictive computational tool for explosive and reactive material formulation on your desktop

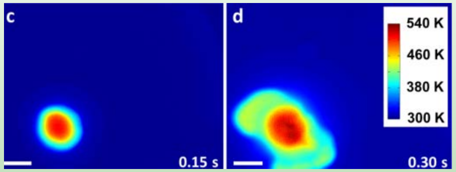
Development (6.3)
Industry and AFRL

- Future AF requirements
- Virtual Design Studio produces explosive formulations to meet requirements

Applied Research (6.2)
AFRL and Industry

- Virtual Design Studio software development
- Validation experiments on real, complex explosive formulations

Basic Research (6.1)
Academia and AFRL



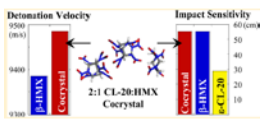
- Fundamental physics and chemistry of energetic material response to mechanical, thermal, and other loading

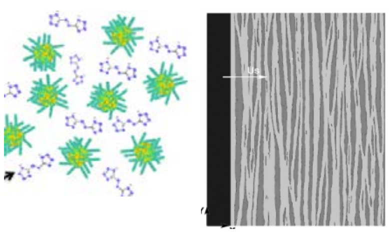
Virtual Design Studio
Basic Research

Future AF Needs and Requirements

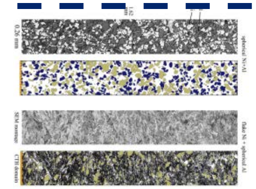
Focused Energy Storage and Delivery

Applied Research

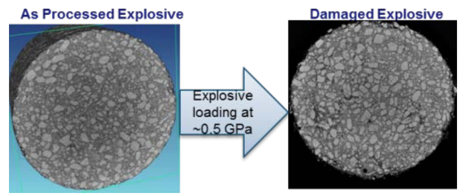




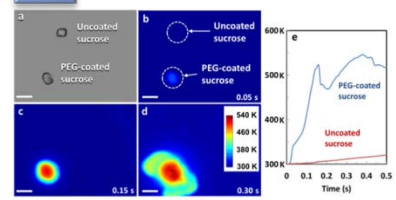
New Energetic Materials



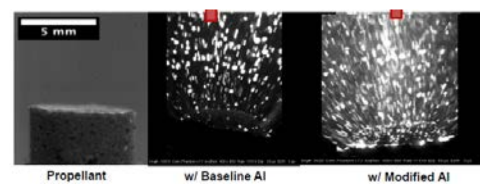
Processing-Structure Relationships



Mechanical Response



Initiation

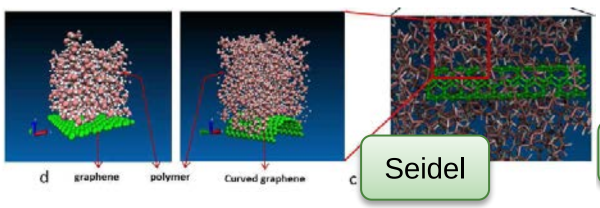


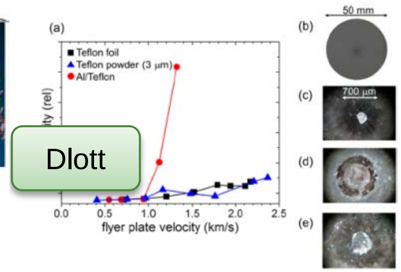
Reaction Propagation

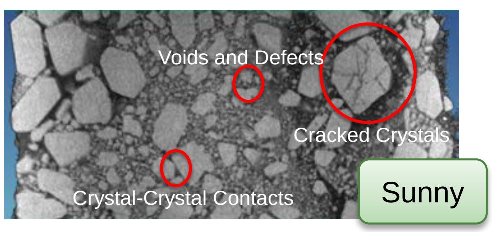
Moving Energetics Science from Empiricism to Analytic, M&S Based Discipline

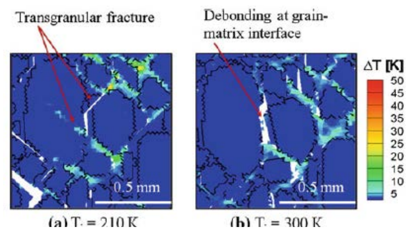
Shock and Detonation Physics

Damage, Hot Spots, and Initiation Mesoscale Diagnostics

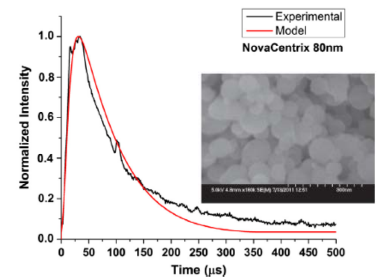








Dynamic Reacting Interfaces



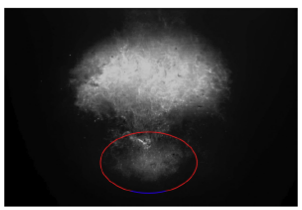


Fig. 4. H-10 particle fields moving from top to bottom, at 44.7 cm from charge surface, 2.5 ms post detonation. A small particle cloud (in red) ahead of the main particle body may be due to acceleration of very small particles to near gas velocity at early time. Upon close inspection some threads or regions of high particle content can be seen to be forming within the cloud. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

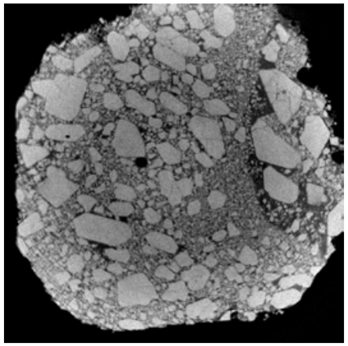
- Role of hot spots at multiple length scales including processing defects and defects due to mechanical/thermal stimuli
- Dynamic experimental techniques at relevant spatial and temporal scales to validate models
- Incorporation of relevant chemistry into mesoscale and continuum theories and models

- Understanding role of interaction between hot product gases and reacting interface
- Explosively driven multi-phase flow
- Aluminum particle burning/combustion

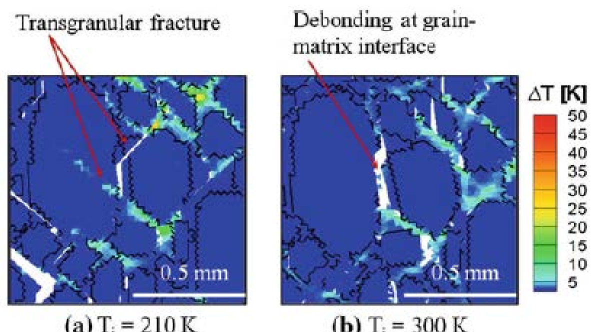
Allen, D., H. Krier and N. Glumac "Heat transfer effects in nano-aluminum combustion at high temperatures." Combustion and Flame(0).
Barua, A. and M. Zhou (2012). "Computational analysis of temperature rises in microstructures of HMX-Estane PBXs." Computational Mechanics: 1-9.
Jenkins, C. M., R. C. Ripley, C.-Y. Wu, Y. Horie, K. Powers and W. H. Wilson (2013). "Explosively driven particle fields imaged using a high speed framing camera and particle image velocimetry." International Journal of Multiphase Flow **51**(0): 73-86.
Zheng, X., A. D. Curtis, W. L. Shaw and D. D. Dlott (2013). "Shock Initiation of Nano-Al+ Teflon: Time-Resolved Emission Studies." The Journal of Physical Chemistry C **117**(9): 4866-4875.

Damage, Hot Spots, and Initiation Mesoscale Diagnostics

Static 3D Microstructure

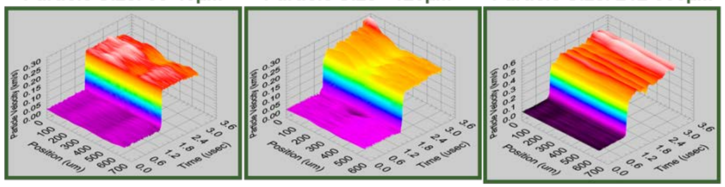


Mesoscale Models



Dynamic Experimental Techniques

Sieved HMX (Fine) Particle Size: 38-45µm	HMX--Holsten Particle Size ~120µm	Sieved HMX (Coarse) Particle Size: 212-300µm



Non-Reactive Wave - no evidence of growth	Highly Localized Energy Release	Highly Reactive Wave (note velocity scale)

Courtesy of Dr. L. Chhabildas

What is the characteristic length scale for hot spot formation?
How do hot spot size and temperature depend on mesostructure?
How are simulations affected when chemical processes are introduced, particularly at interfaces?
When does a hot spot become a deflagration/detonation?

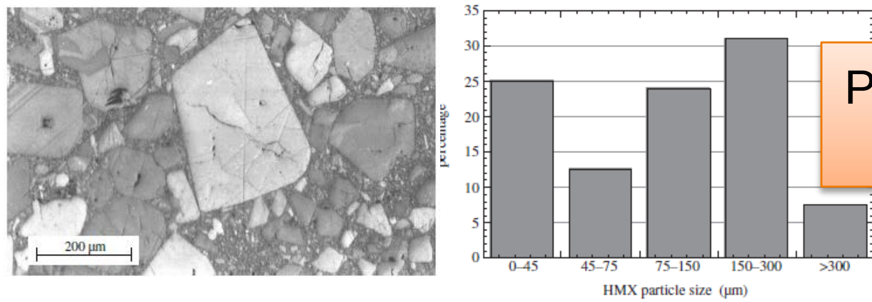
Barua, A. and M. Zhou (2012). Computational Mechanics: 1-9.

Damage, Hot Spots, and Initiation

Experimental Hotspot Measurement

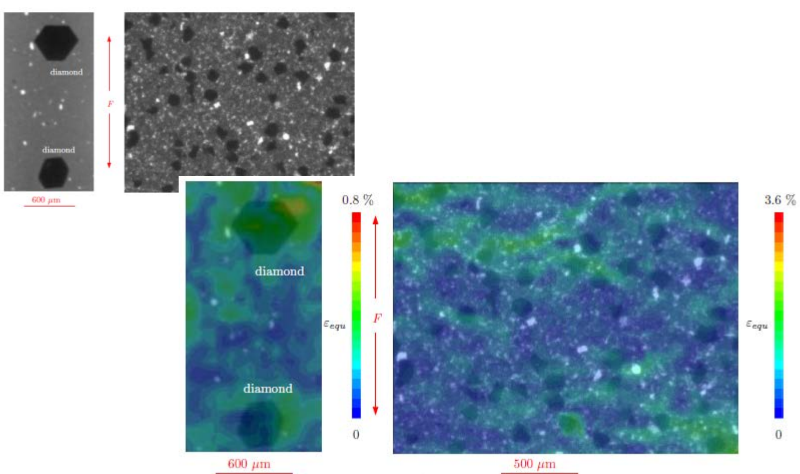
What is the characteristic length scale for hot spot formation?
How do hot spot size and temperature depend on mesostructure?

Microstructural Characterization

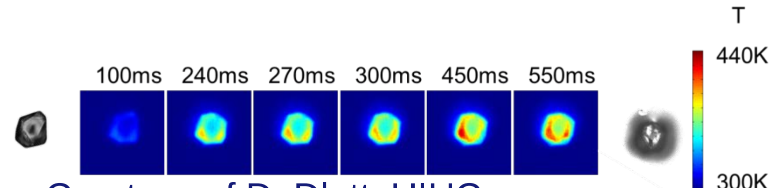


Property distributions are key!

Micromechanical Characterization



Microfunctional Characterization



Courtesy of D. Dlott, UIUC

"At present, hotspot sizes and temperatures cannot be measured experimentally." – Barua, et al.

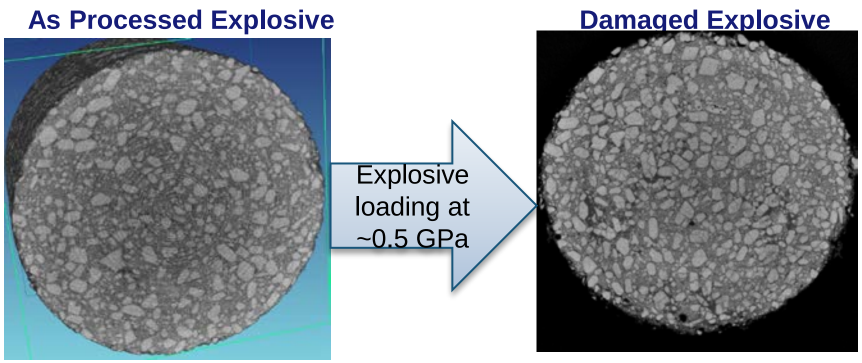
Barua, A., S. Kim, Y. Horie and M. Zhou (2013. Journal of Applied Physics **113**(6).
Crostack, H.-A., J. Nellesen, G. Fischer, U. Weber, S. Schmauder and F. Beckmann (2008). Proceedings of SPIE. **7078**.
Rae, P. J., H. T. Goldrein, S. J. P. Palmer, J. E. Field and A. L. Lewis (2002). Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences **458**(2019): 743-762.

Damage-Sensitivity Correlations in Explosives

Microstructural characterization – effect of shock loading on explosive initiation.

New testing techniques allow for characterization and recovery of explosive samples

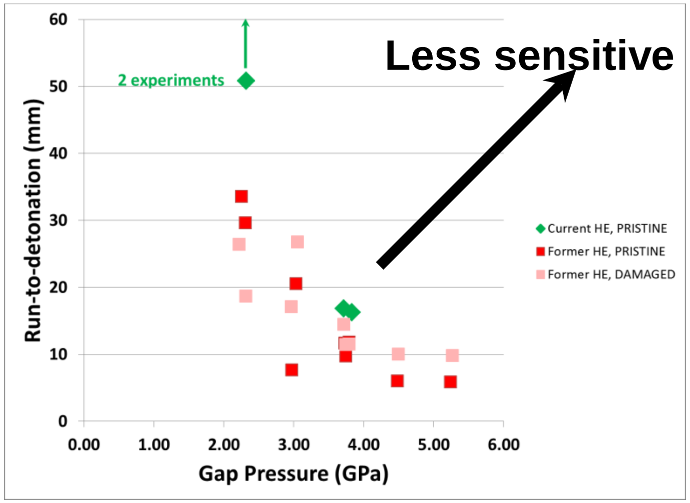
Damage to explosives due to impact can make them more likely to initiate. Previous techniques for inducing damage were used as screening tools; the loadings were complex and samples could not be recovered safely.



- Well-controlled damage will be generated (Instron, Hopi Bar, Shock Wave Apparatus) and samples can be recovered
- Techniques will be able to estimate damage generated due to mechanical impacts

Dr. George Sunny
Research Engineer, AFRL/RWME
•SMART Scholar Recipient, 2008
•Ph.D. in Mechanical Engineering from Case Western Reserve University, 2011

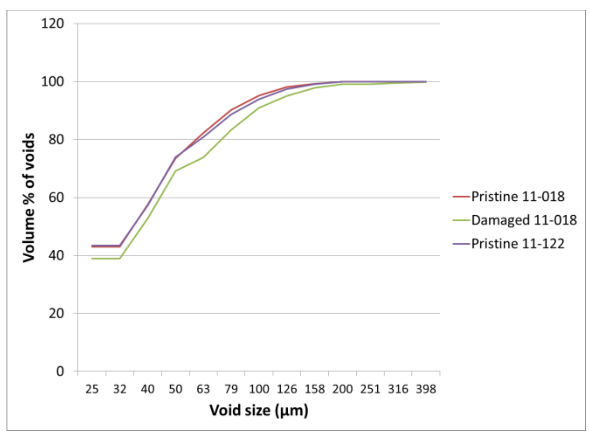
Damage-Sensitivity Correlations in Explosives



Modified gap test experiments on pristine and damaged explosive provide insight into how damage affects sensitivity of explosive

Recent experiments on a new plastic bonded explosive indicate further reduction in sensitivity

More and larger voids are present in damaged samples compared to pristine samples



Pressures of 0.5 GPa are sufficient to damage samples by increasing void size and quantity, but higher gap pressures (3.5-6 GPa) prevent the voids from affecting sensitivity.

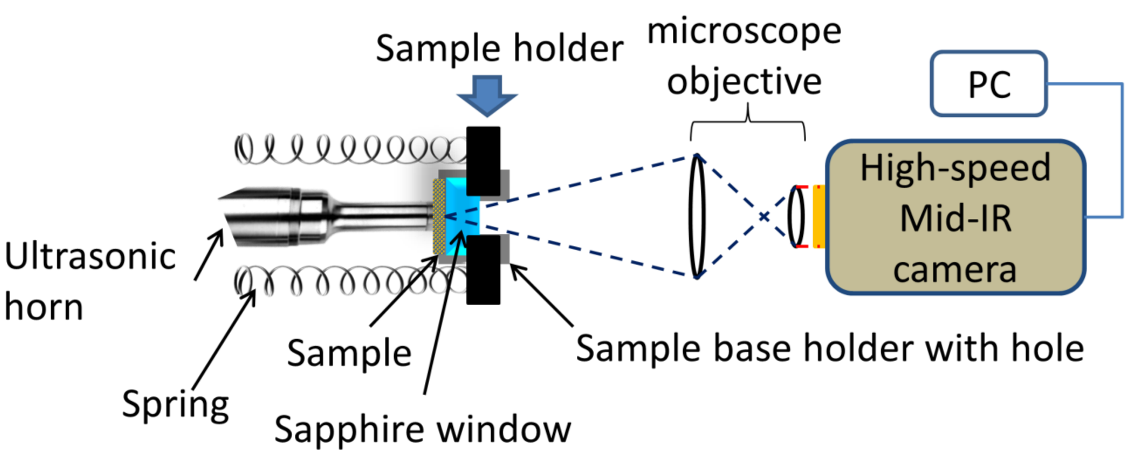
Fast infrared microscopy of hot spots

Microfunctional characterization – in situ temperature measurements.

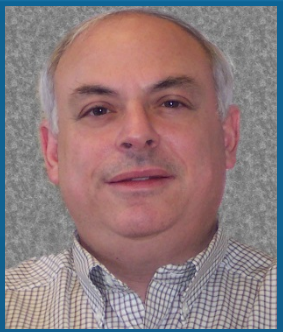
IR microscope sees hot spots in real time

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

First application: ultrasound excitation of EM simulants



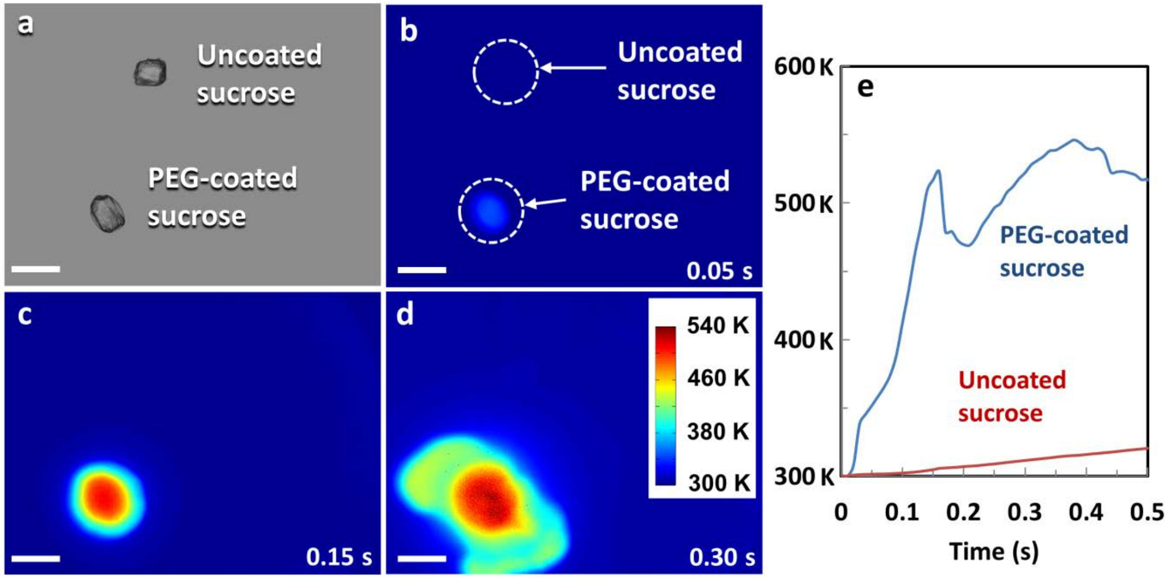
- Observe hot spots in real time with IR microscopy
- Create hot spots in samples with engineered microstructures by ultrasound, lasers or high-speed impacts
- Understand how microstructural elements give rise to hot spots to inform simulations and to design safer EM



Dana Dlott, Ph.D.
William H. and Janet G. Lycan Professor of Chemistry

- 2013 Recipient of ACS Award in Experimental Physical Chemistry
- Past chair, APS Division of Shock Compression
- Fellow of APS, OSA, AAAS

Ultrasound creates hot spots at crystal/polymer interfaces



Two sugar crystals were embedded in a polymer exposed to 17 kHz ultrasound. One crystal was coated with PEG, a lower-viscosity polymer. During the next few hundred milliseconds, only the PEG-coated crystal was heated significantly, showing how the viscosity at polymer/crystal interfaces controls acoustic hot spot generation.

This work establishes a clear connection between microstructure and hot spot formation and provides a roadmap for controlling the effects of ultrasound on complex solid materials.

Multiscale Modeling and Characterization of the Effects of Damage Evolution on the Multifunctional Properties of Polymer Nanocomposites

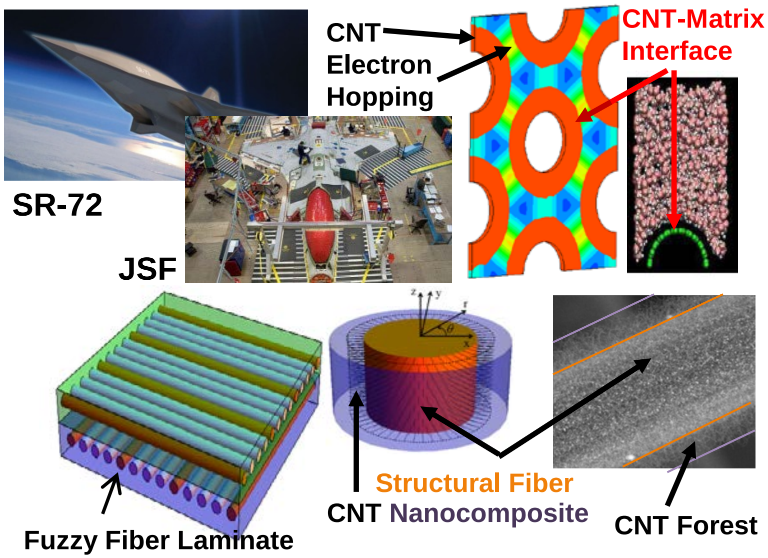
Micromechanical characterization – embedded sensors for damage detection

VirginiaTech
Invent the Future

Headline: Nanomaterials as Embedded Damage Detection in Composites

A Multiscale Approach to Tailored Sensing & Prognosis

Through understanding and controlling the dispersion of carbon nanotubes, we seek to develop aerospace composites with embedded real-time deformation and damage sensing.



- Key Challenge: understand how nanoscale effects between individual nanotubes become macroscale measurable quantities within the composite.
- Approach: concurrent multiscale modeling which transitions electromechanical and damage effects from nano- to macroscale [1,2]
- Eventual Outcome: Transition from scheduled maintenance or post-flight NDE to on-board structural health monitoring

Dr. Gary D. Seidel
Assistant Professor, Aerospace and Ocean Engineering

- Associate Fellow AIAA
- Chair, Materials TC, AIAA
- 2010 Recipient of ORAU Junior Faculty Powe *Award*

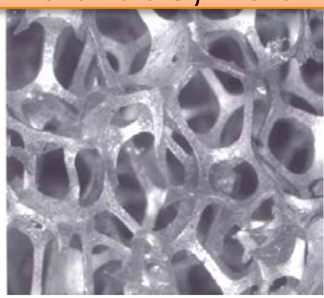
[1] Chaurasia, A. and Seidel, G.D., Journal of Intelligent Material Systems and Structures, 2013
[2] Chaurasia, A, Ren, X.. and Seidel, G.D., Proceedings of the ASME 2013 Conference on Smart Materials, Adaptive Structures and Intelligent Systems.

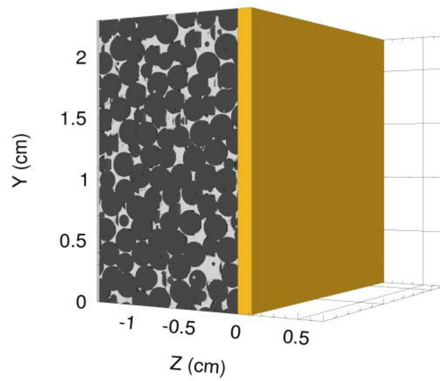
Damage, Hot Spots, and Initiation

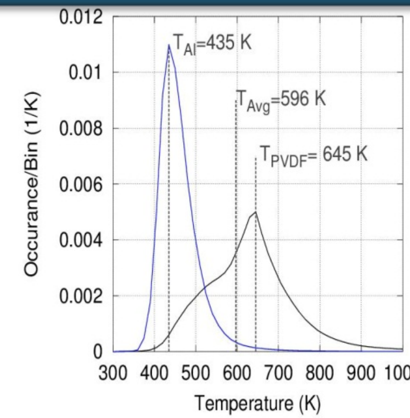
Chemical Processes

How are simulations affected when chemical processes are introduced, particularly at interfaces?

Chhabildas, Lab Task

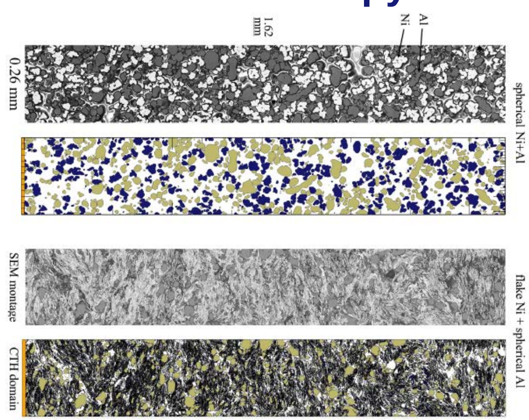


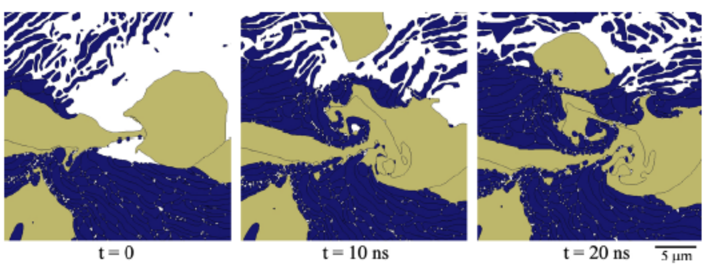




Geometry imported from microscopy/ XCMT scans

Computational T distribution due to impedance mismatch





Dynamically changing microstructure

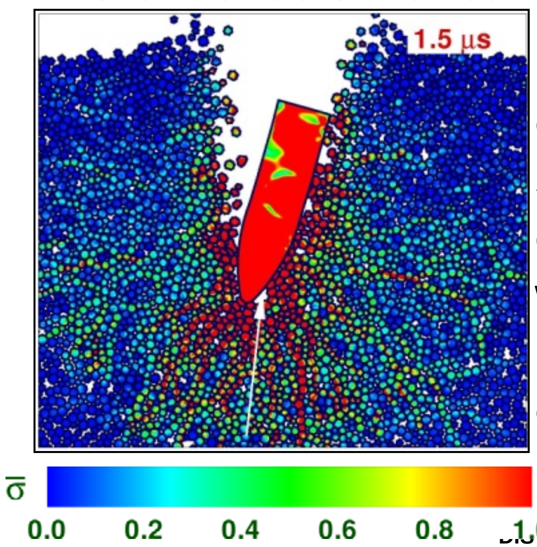
Eakins, D. E. and N. N. Thadhani (2008). Acta Materialia **56**(7): 1496-1510.

Dynamic High-Pressure Behavior of Hierarchical Heterogeneous Geological Granular Materials

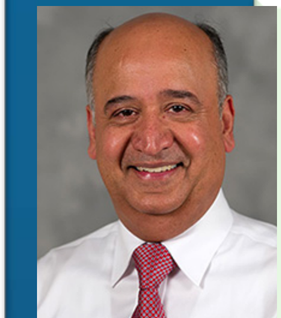
Inert experiments and models to understand shock propagation through heterogeneous materials

Geological granular materials (soils) exhibit spatially- and temporally-random shock-propagation characteristics

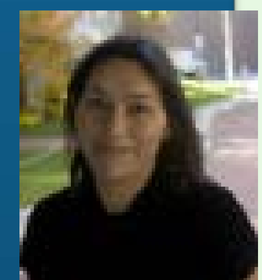
Inhomogeneous grain-to-grain (force-chain) load transfer due to anisotropic response of dry/wet soil under dynamic loading contributes to interface friction and other material-inherent effects that can influence projectile instability



GOAL: Determine shock propagation characteristics in dry & wet high purity **sand** of extremes of particle sizes to establish effects of phase transitions, wave dispersion, friction, inter-particle interactions through instrumented experiments and meso-scale modeling



Dr. Naresh Thadhani, Professor & Chair, MSE Georgia Tech Fellow of APS & ASM

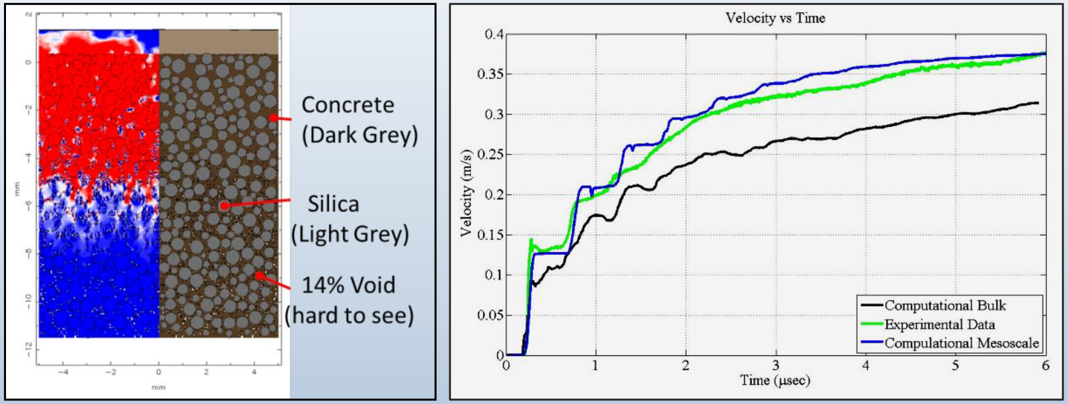


Dr. Sarah Stewart, Professor, EPS, Harvard PECASE Awardee

Dr. John Borg, Associate Prof, ME, Marquette University Sigma Xi Rising Star

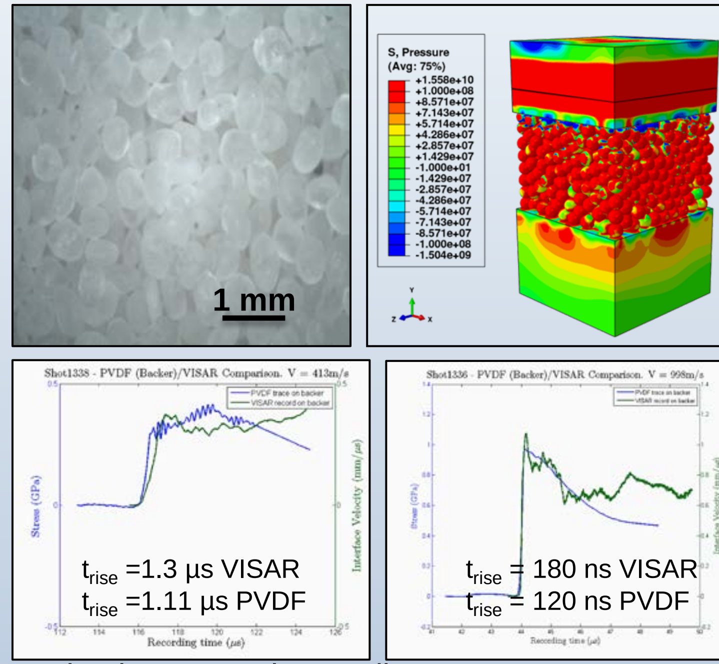
Dynamic High-Pressure Behavior of Hierarchical Heterogeneous Geological Granular Materials

Meso-scale simulations correlated with time-resolved measurements are essential for understanding shock-wave interactions in heterogeneous granular materials



Meso-scale simulations on CorTurf capture Hugoniot state and release response significantly better than continuum simulations

- Coupling 2-D/3-D meso-scale simulations with time-resolved measurements of shock-wave profiles in pure sand allow studies of particle size and moisture effects
- Shock-materials interactions due to inter-particle friction, particle fracture/deformation, and phase changes will be determined through controlled studies
- Most significant will be the establishment of the shock-compression response of soils (heterogeneous granular materials) as a function of hierarchy and properties

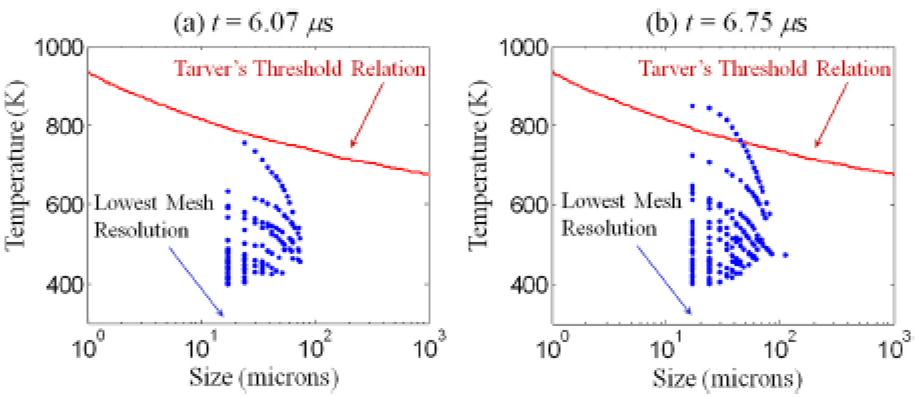


Shock-propagation studies on ~500 μm mono-sized 99.8% SiO_2 sand show 3-D meso-scale simulations capturing force-chain and other complex interactions; Measured wave profiles show long rise times making shock-compressibility effects difficult to establish.

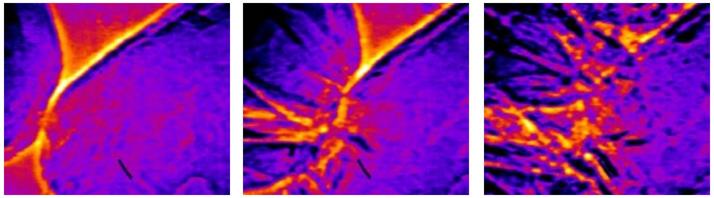
Damage, Hot Spots, and Initiation

Hot Spot Transition

When does a hot spot become a deflagration/detonation?

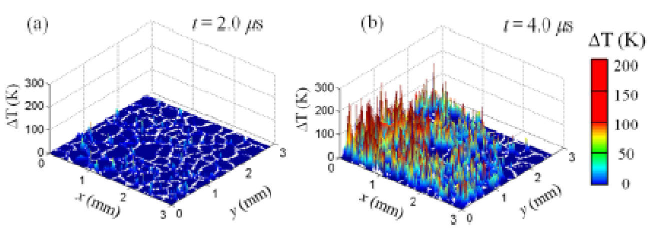


State-of-the-art mesoscale simulations consider "go, no-go" criteria



Courtesy of W. Chen, Purdue

Experiments measuring real time hot spot size and temperature



Mesoscale simulations predicting hot spot propagation based on localized chemistry

Barua, A., S. Kim, Y. Horie and M. Zhou (2013). Journal of Applied Physics **113**(18).
Barua, A., S. Kim, Y. Horie and M. Zhou (2013). Journal of Applied Physics **113**(6).

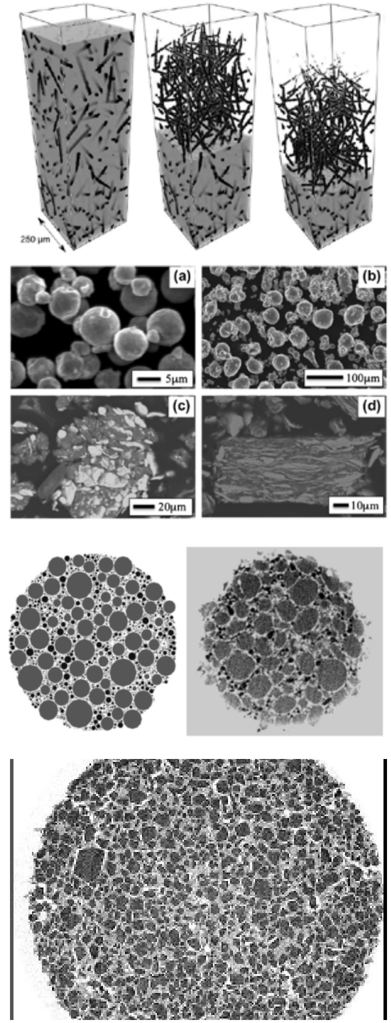
Dynamic Reacting Interfaces

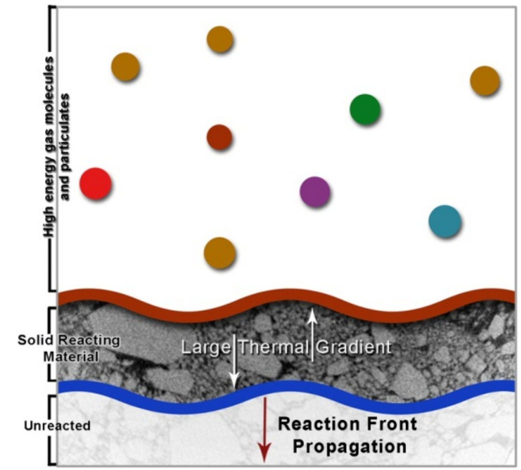
Ablative Materials

Reactive Materials

Propellants

Explosives





Non-equilibrium condensed phase reactions proceeding at finite rates that are highly temperature, pressure and flow configuration dependent

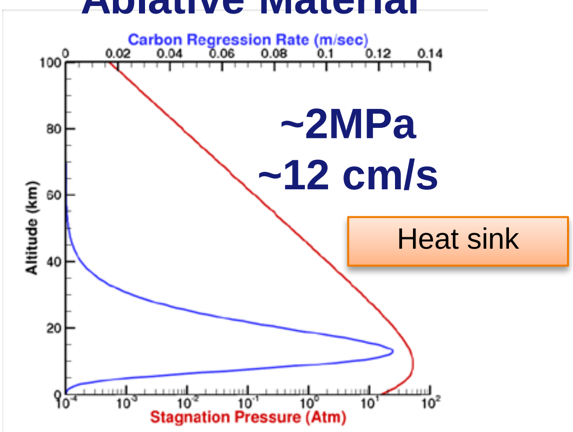
Flis, W,, DE Technologies, Inc., www.virtualacquisitionshowcase.com/document/445/briefing.
Kanigan, D., PhysOrg, http://phys.org/news/2011-09-nasa-successfully-five-segment-solid-rocket.html.
Melvin, J. Reuters, http://www.reuters.com/article/2009/09/06/us-arms-usa-idUSTRE5851XH20090906

DISTRIBUTION STATEMENT A – Unclassified, Unlimited Distribution (88ABW-2013-4951)

Dynamic Reacting Interfaces

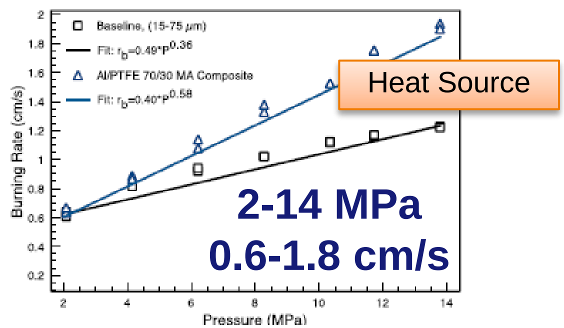
Similar Rates and Pressures

Ablative Material



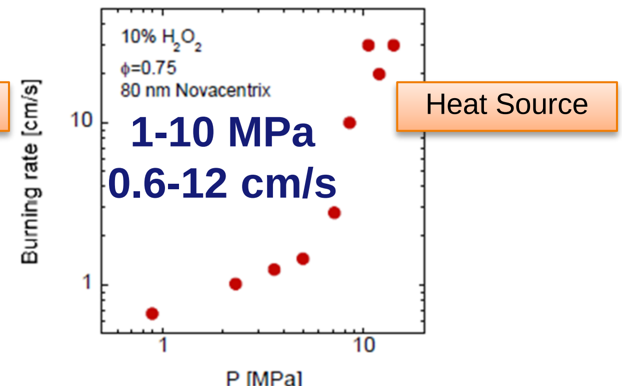
Courtesy of I. Boyd

Al/PTFE Reactive



Courtesy of S. Son

Al/Ice Propellant

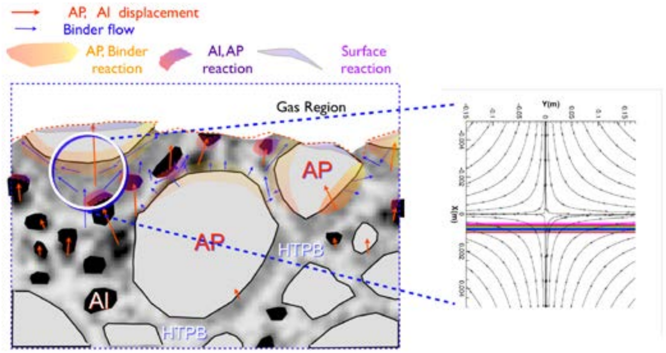


Courtesy of Yetter, Son, and Yang

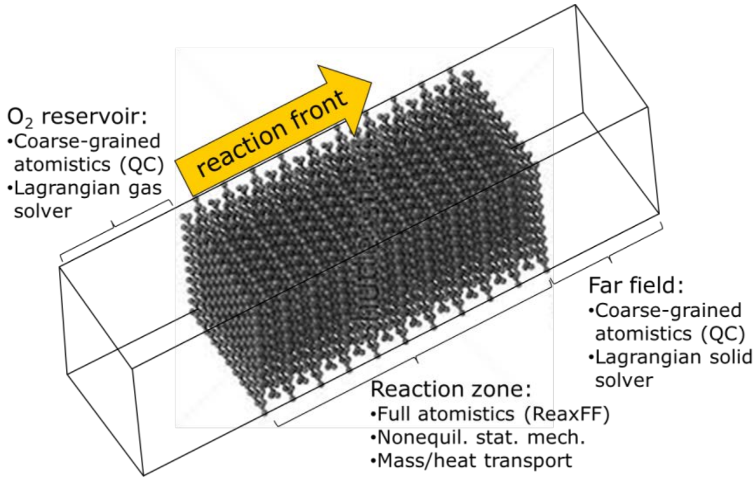
Energy and mass transport across an interface occurring at comparable pressures and reaction rates

Dynamic Reacting Interfaces
Theory, Modeling and Simulation

Going beyond empirical models for reaction propagation in solids (Matalon & Stewart, UIUC)

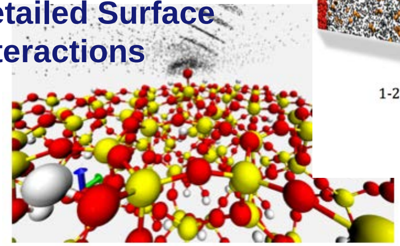


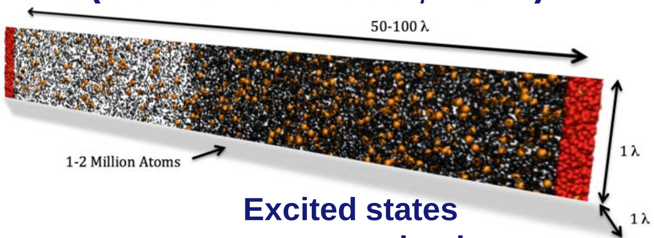
Linking atomistic-to-mesoscale simulations (Ortiz, CalTech)



Detailed simulations of gas kinetics and surface interactions (Schwartzentruber, MURI)

Detailed Surface Interactions





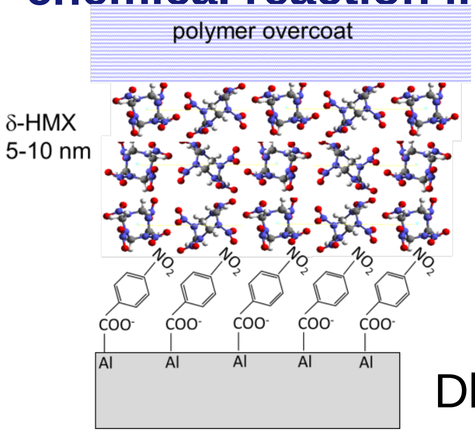
Excited states across a shock wave

How to determine the rate-dependent chemical, physical, and fluid mechanics processes occurring within the interface region?

Dynamic Reacting Interfaces

Probing the Interface Region Experimentally

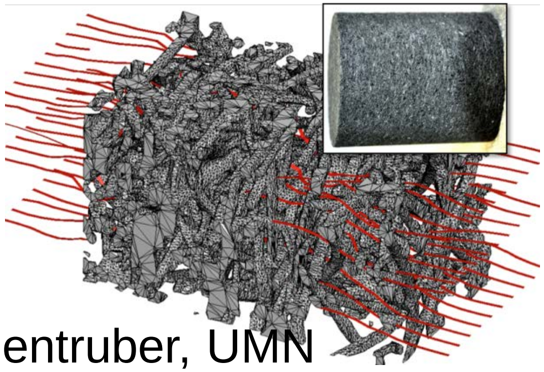
Experiments scaled to probe the chemical reaction in the interface zone



Not an actual detonation, but molecules behind the shock front don't know the difference

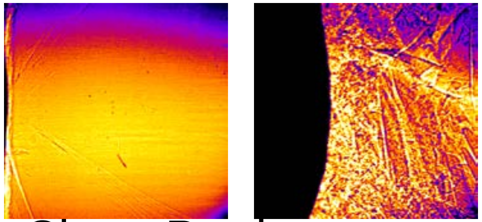
Dlott, UIUC

High-T diffusive and reactive flow from microstructure

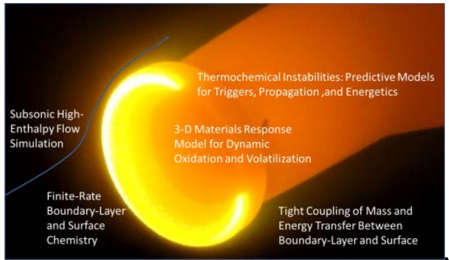


Schwartzentruber, UMN

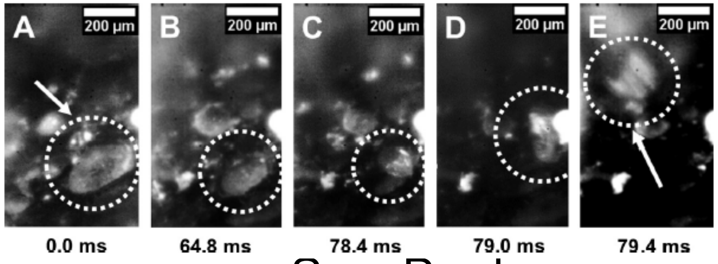
Visualization of reacting interface region



Chen, Purdue



Schwartzentruber, UMN



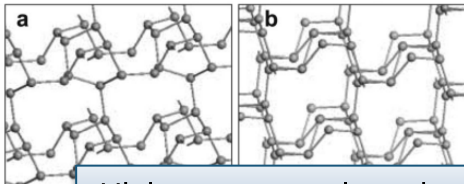
Son, Purdue

Need new experimental methods to reveal fine scale physics at the interface

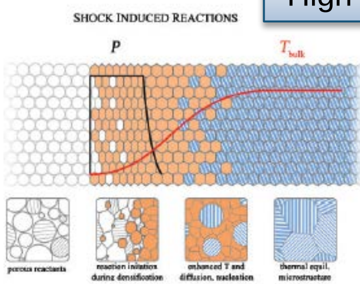
Shock and Detonation Physics

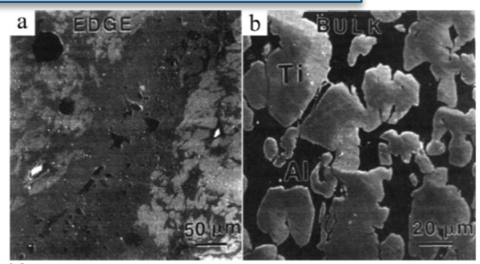
Metastable, High Pressure Phases

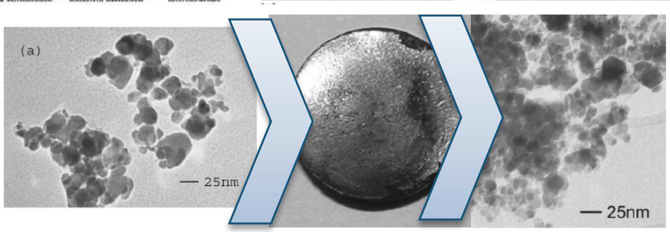
SBIR



High pressure polymerization



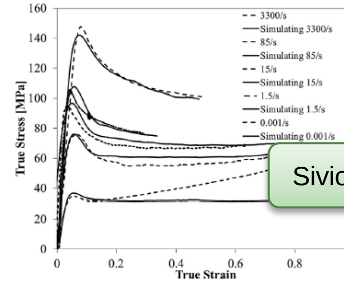




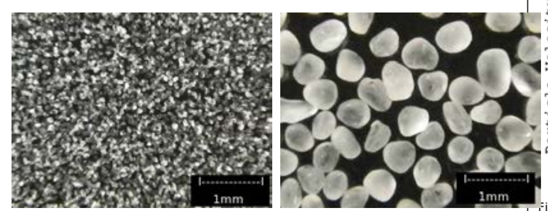
- High pressure phases
- Shock induced synthesis of materials
- Consolidate powders without recrystallization or decomposition, e.g. Bulk nanomaterials

High Strain Rate and Shock Response of Polymers, Composites and Geologic Materials

Center of Excellence



Siviour



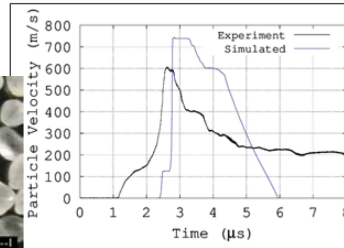


Fig. 10. Comparison of experimental and simulated VISAR trace on cortuf concrete at 1560 m/s impact velocity.

Thadhani, Stewart, and Borg

- Constitutive relationships for complex materials
- New diagnostics to understand local deformation in materials
- Understanding of effect of strain rate and temperature

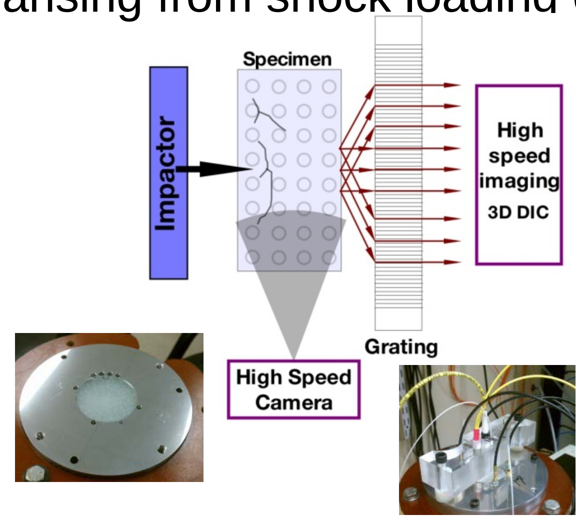
Dai, C. and N. N. Thadhani (2011). "Shock-compression response of magnetic Fe3O4 nanoparticles." Acta Materialia **59**(2): 785-796.
Eakins, D. E. and N. N. Thadhani (2009). "Shock compression of reactive powder mixtures." International Materials Reviews **54**(4): 181-213.
Kendall, M. J. and C. R. Siviour (2013). "Experimentally simulating adiabatic conditions: Approximating high rate polymer behavior using low rate experiments with temperature profiles." Polymer **54**(18): 5058-5063.
Thadhani, N. N., S. Dwivedi, G. Kennedy, D. Scripka, S. Stewart and J. Borg (2013). High-Pressure High-Strain-Rate Behavior of Hierarchical Heterogeneous Materials - Integrated Multi-Scale Modeling and Experimental Studies. Atlanta, GA, Georgia Institute of Technology.
Zahariev, F., S. V. Dudiy, J. Hooper, F. Zhang and T. R. Webb (2006). "Systematic Method to New Phases of Polymeric Nitrogen under High Pressure." Physical Review Letters **97**(15): 155503.

High-Rate Deformation Physics

Shock wave propagation in heterogeneous materials → Impact resistant structures

Heterogeneous Materials offer a New Paradigm for Shock Mitigation

Shock loading experiments on heterogeneous particulate composites are being conducted to understand the physics of energy and momentum transfer. Optimized heterogeneous materials can be used to disperse momentum and energy arising from shock loading due to impact/blast on structures.



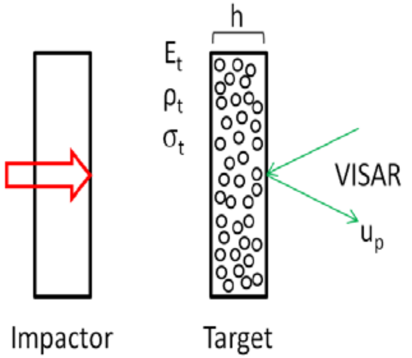
- Shock loading studies can lead to novel microstructures for designing impact resistant structures.
- Identify origins of dispersion and dissipation.
- Shock experiments can provide new insights regarding physics of scattering, damage and wave interactions in composite solids.

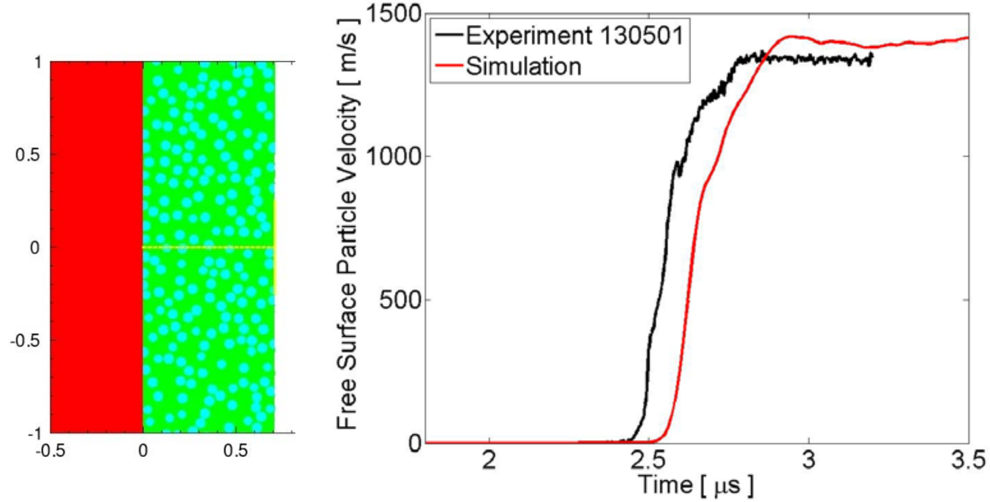
Dr. Guruswami Ravichandran
John E. Goode Jr. Professor
- Intl. Academy of Engineering
- Fellow, AAM, ASME, SEM
- 2013 Recipient of *A.C. Eringen Medal* – for contributions to engineering science
- Chevalier Palmes Academique, France

Shock Response of Composites

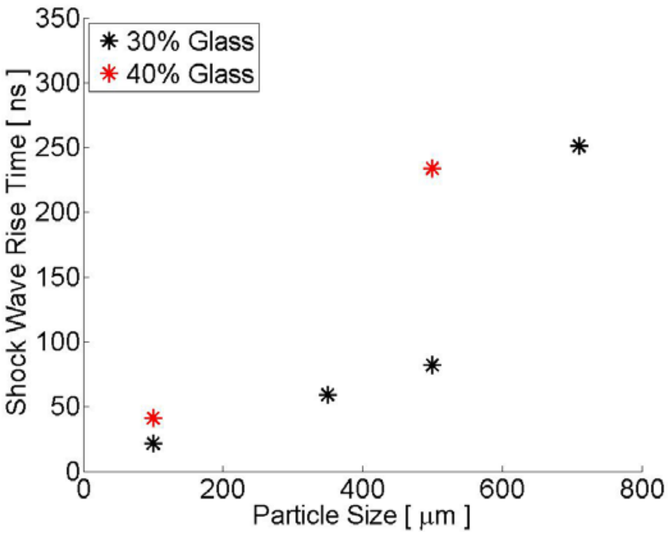
Shock experiments reveal that the rise time and strain-rate are proportional to the particle size in the heterogeneous particulate composites.

- Shock wave experiments were conducted on 30 and 40% volume fraction glass reinforced PMMA composites
- Scattering increases the rise time of the shock wave and increases the effective viscosity of the composite





CTH simulation of experiments and comparison of shock profiles in PMMA/Glass particulate composites



Shock rise time as a function of particle size and volume fraction of glass in composites

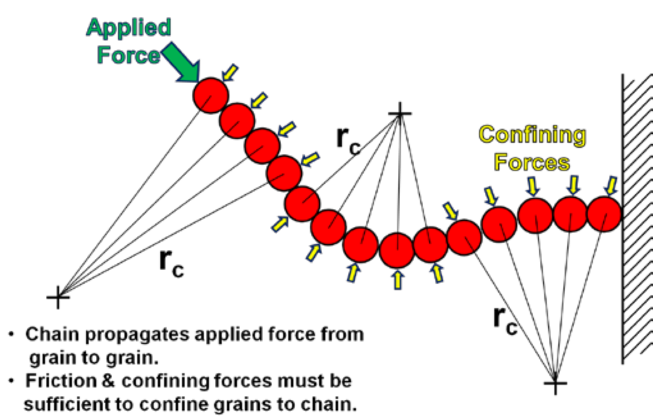
Particulate Meso-Scale Mechanics Diagnostics

Experimental techniques to understand granular geologic materials

“*Meso-scale Measurements Key for Big Problems*”

Particulate response dominated by heterogeneities

Statistically-expressed, length/time-scale-dependencies of particulate/granular media in dynamic compaction and flow



- Isolated force-chain dependencies dominate load bearing response
- Localizations require meso-scale diagnostics* and statistically rich sample basis
- Meso- to continuum unification theory and validation

Init. PI: Dr. Cooper
Final PI: Dr. Lambert

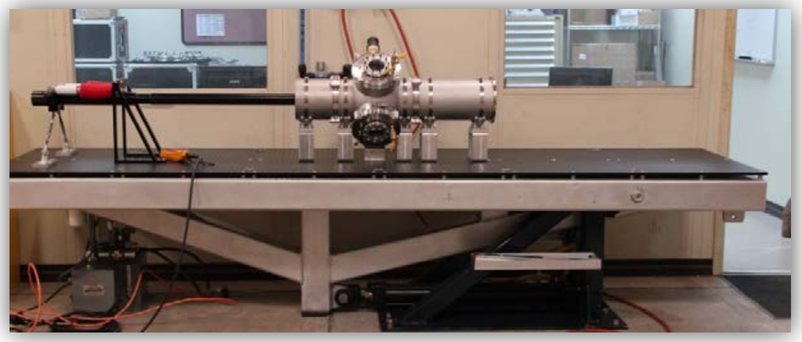
Lead, Ordnance Sciences Core Tech Competency (RW)

- Fellow, AFRL
- President, Hypervelocity Impact Society
- Board, Int’l Ballistics Society
- 2010 AFMC Science and Eng. Tech. Award

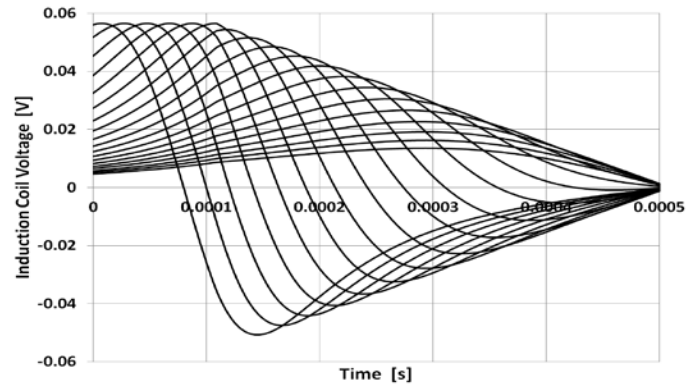
*Tansel IN, Reding B, Cooper WL, Lagrangian Point State Estimation with Optimized, Redundant Induction Coil Gages, Exp Mech (DOI 10.1007/s11340-013-9714-9)

Established PMMD Capability

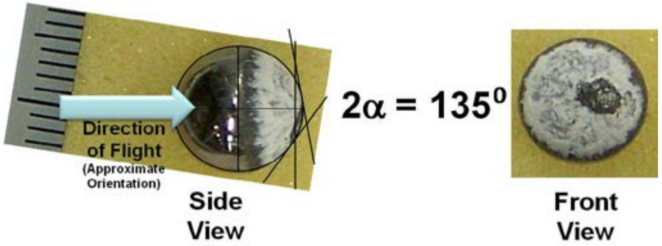
Suite of diagnostics capability for heterogeneous particulate response states; unique for optically opaque media with μs response.



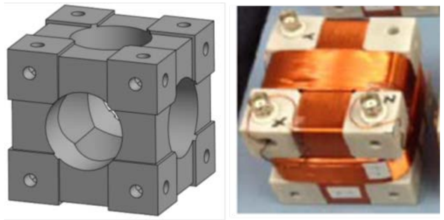
Dynamic launch and diagnostics expt'l bed



Lagrangian point state estimation with optimized, redundant induction coil gauges (accuracy to 0.2 mm)



Particulate crush up and compaction for false nose effects*



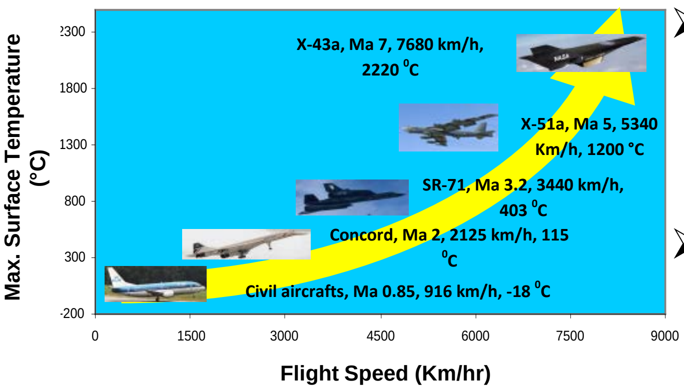
Remote sensing of 5 deg of freedom state measurement [x,y,z,θ,γ,V]

*Cooper W.L., Communication of Stresses by Chains of Grains in High-Speed Particulate Media Impacts, SEM XI International Congress & Exposition on Experimental and Applied Mechanics, Uncasville, CT, June 13-17, 2011

Response of Aerospace Materials to Shock Loading and Extreme Environments

High temperature, high strain rate loading of aerospace structural materials

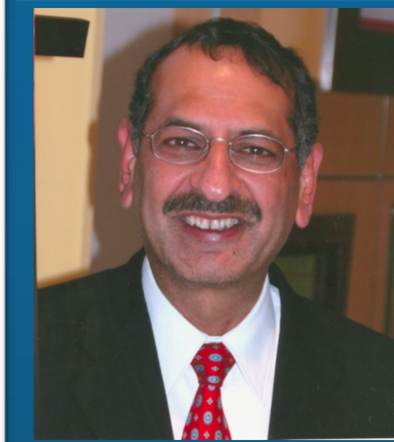
Investigation of Novel Aerospace Materials:



Maximum Surface Temperature vs. Flight Speed

- Fundamental understanding of deformation and damage behavior of aerospace materials under combined extreme thermo-mechanical loadings.
- Fill research gap using state of the art experimental investigation of aerospace materials.

- Physics interpreted from this research will be of immense value to aerospace and defense agencies pursuing the use of integrated multifunctional materials for high temperature applications.
- The obtained results will be useful to predict the performance and structural integrity under a combination of extreme mechanical and thermal environments.



Dr. Arun Shukla

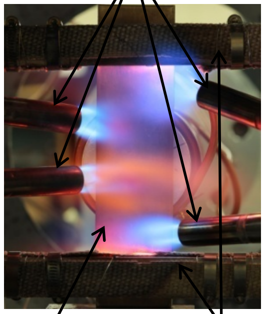
Simon Ostrach Professor

- Member, Executive Committee, Applied Mechanics Division, ASME (2012-2017)
- Fellow of ASME,SEM and AAM
- Murray Medal, SEM 2011

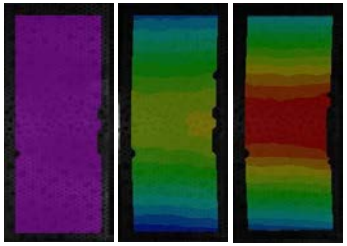
Response of Aerospace Materials to Shock Loading and Extreme Environments

Accomplishments over the last year:

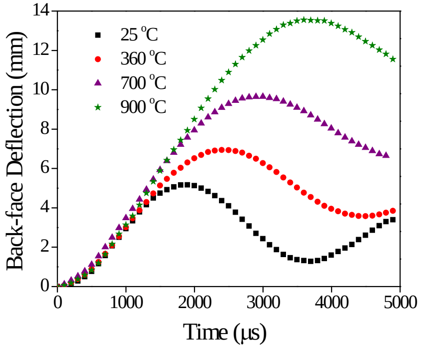
- A unique experimental setup was established for studying materials under shock wave loading at temperatures up to 1000 °C.
- High-speed image capturing technique was modified and utilized in conjunction with digital image correlation (DIC) to obtain real-time full-field deformation of materials under dynamic loadings at elevated temperatures (up to 1000 °C).
- The response of Hastelloy X was evaluated as a function of temperature under shock wave loading.



High temperature setup



DIC information on deflections of Hastelloy X at 900 °C



Mid-point out-of-plane deflections obtained from above DIC data.

Scientific Significance:

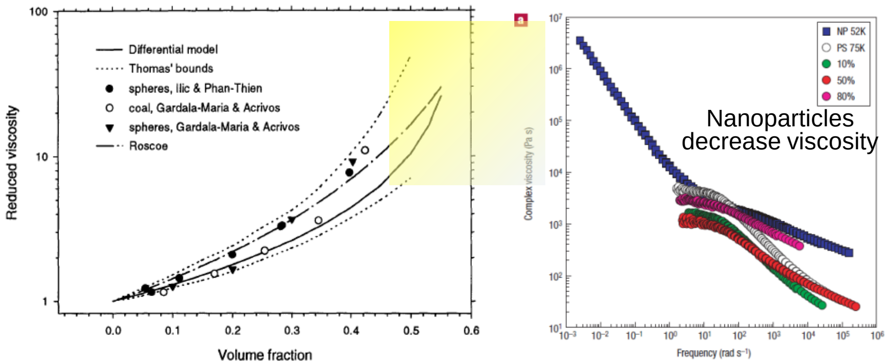
- The developed experimental setup and data capturing technique can be used to evaluate the performance of various high temperature capable materials under extreme environments.

Publication:

- Abotula, S., Heeder, N., Chona, R., Shukla, A. "Dynamic Thermo-mechanical Response of Hastelloy X to Shock Wave Loading". *Experimental Mechanics*, 2013. DOI 10.1007/s11340-013-9796-4.

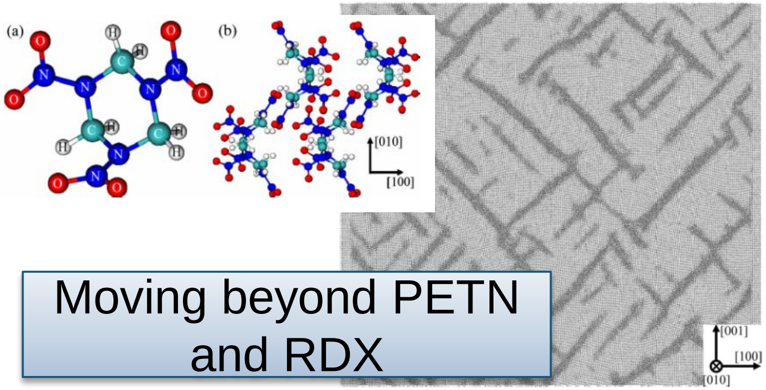
Structure and Composition of Energetic Materials

Prediction of Viscosity and Microstructure in Highly Loaded Suspensions



- Highly loaded solids >70% by volume
- Multiple particle sizes, shapes, materials (surface chemistry)
- Cohesive strength and defect development

Shock Loading of Energetic Crystals

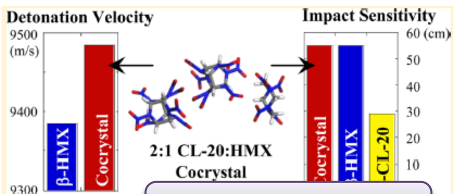


- Molecule/crystal structure response to shock loading
- Formation of stress concentrations resulting in chemical reaction in materials

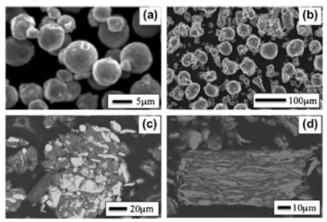
Cawkwell, M. J., T. D. Sewell, L. Zhang and D. L. Thompson (2008). "Shock-induced shear bands in an energetic molecular crystal: Application of shock-front absorbing boundary conditions in molecular dynamics simulations." Physical Review B **78**: 014107.
Mackay, M. E., T. T. Dao, A. Tuteja, D. L. Ho, B. V. Horn, H.-C. Kim and C. J. Hawker (2003). "Nanoscale effects leading to non-Einstein-like decrease in viscosity." Nature Materials **2**: 762-766.
Phan-Thien, N. and D. C. Pham (1997). "Differential multiphase models for polydispersed suspension and particulate solids." Journal of Non-Newtonian Fluid Mechanics **72**: 305-318.

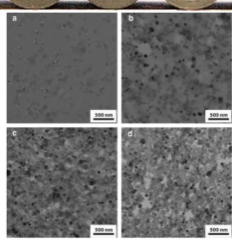
Structure and Composition of Energetic Materials

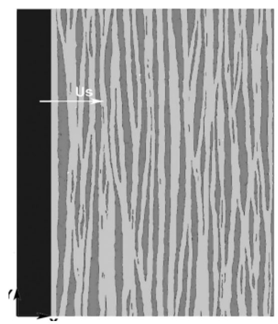
New Energetic Materials



2013 Army MURI





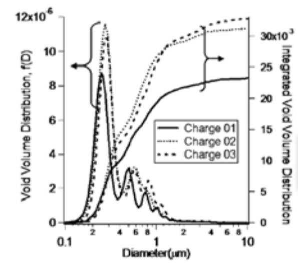


- Formulation and characterization of reactive materials with designed microstructures to enhance energy release rate
- Reduced sensitivity or increased performance processing techniques, e.g. co-crystals

Influence of External Environment

http://blog.hwtm.com/2012/05/modern-chic-silver-and-pink-bridal-shower/

http://homedeconomics.blogspot.com/2009/02/blog-carnival-jello-part-1-failure.html



TATB ratchet growth

- Effects of thermal cycling on composite microstructure
- Surface treatment and bonding of explosive crystals and binder
- Effects of external fields on reaction rate

Bolton, O., L. R. Simke, P. F. Pagoria and A. J. Matzger (2012). "High Power Explosive with Good Sensitivity: A 2: 1 Cocrystal of CL-20: HMX." Crystal Growth & Design **12**(9): 4311-4314.
Crouse, C. A., C. J. Pierce and J. E. Spowart (2012). "Synthesis and reactivity of aluminized fluorinated acrylic (AlFA) nanocomposites." Combustion and Flame **159**(10): 3199-3207.
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Summary

- **AFOSR - creating the Scientific Base to Make Current DoD Systems and Practices Obsolete**
  - Several funding opportunities available
- **Dynamic Materials and Interactions portfolio in development**
  - Currently emphasis in mechanics of heterogeneous materials
  - Emphasis will shift to other thrust areas over next 2-3 years

Abstract

The Air Force Office of Scientific Research (AFOSR) has the responsibility to discover, shape, and champion basic research that profoundly affects the future Air Force. AFOSR supports cutting edge research in Air Force, university, and industry research laboratories. The Dynamic Materials and Interactions portfolio seeks a fundamental understanding of the chemistry and physics of energetic materials and the dynamic behavior of complex materials, e.g. polymers and composites. The program supports cutting-edge experimental and computational-experimental studies that address key questions in these areas. The major focus areas are Shock and Detonation Physics and Structure and Composition of Energetic Materials. The program is focused on novel and fundamental studies developing the basic understanding and predictive capabilities for the chemistry and physics of energetic materials, particularly in response to mechanical, thermal, and electromagnetic stimuli. Additionally, the program investigates new energetic materials, namely processes and characterization of complex structures and microstructures incorporating energetic materials. This seminar will present an overview of AFOSR. It will then focus on current interests in the Dynamic Materials and Interactions Portfolio, namely experimental techniques to capture dynamic, high strain rate events at the mesoscale in complex, composite materials, detonation and reaction chemistry of energetic materials, and shock phenomena in complex solids.