Combustion Analysis of Nanoenergetic Materials
Surface/subsurface propellant dynamics and nanocomposite thermite systems

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Surface and Subsurface Analysis of Energetic Materials- Issues

- Although important studies on gas-phase processes of energetic materials still remain, bottleneck to future development and understanding is in the condensed phase.
- Because of their size, nano energetic materials will burn extremely fast if dispersed in the gas-phase.
- Physical and chemical processes in the condensed phase ultimately determine the fate of nano energetic material.
- Can energetic materials be engineered at the nanoscale to control their reaction dynamics and physical properties in the condensed-phase as well as gas-phase?
Propellant Surface Temperatures and Particle Melting Temperatures

Surface Temperature during Deflagration
(Data from Kuo, Zenin, and Isihara)

Particle Melting Temperature
(Data from Pantoya et al., 2003)
Burn Rates of Al Particle Thermites and Aerosol Flames

Nanocomposite Al - MoO$_3$ Thermite (Granier and Pantoya, C&F, 2004)

Aerosol Al - Air Flame (Huang et al, 30$^{th}$ CI, 2004)
Active Aluminum as a Function of Particle Diameter

Theoretical Active Aluminum ($t_{\text{oxide}} = 2.93 \text{ nm}$)

Experimental Data

$m_{\text{Al}}/(m_{\text{Al}} + m_{\text{Al}_2\text{O}_3})$

Particle Diameter [$\mu\text{m}$]
Surface and Subsurface Analysis of Energetic Materials - Objectives

• Analyze the surface and sub-surface physical behavior of reacting energetic materials
• Analyze the chemical reactivity of the surface and sub-surface during reaction
• Compare conventionally fabricated energetic materials with nano engineered energetic materials
• Measure reaction times from mesoscale systems
• Extrapolate the microscopic observations to macroscopic engineering parameters, e.g., burn rates
Surface and Subsurface Analysis of Energetic Materials - Approach

• Reacting energetic material studies using inverted optical microscope with high speed photography, micro particle image velocimetry, micro laser induced fluorescence and micro Raman spectrometry

• In-situ studies of reacting energetic materials using environmental scanning electron microscope at surface and subsurface temperatures of bulk material
Surface and Subsurface Analysis of Energetic Materials - Experiment

- Sliced samples of energetic material heated from above by CO₂ laser or gas flame
- Various experimental configurations available for analysis of physical and chemical behavior of sub-surface
- In situ measurements or quenched samples for post AFM, SEM, EPMA analysis
Surface and Subsurface Analysis of Energetic Materials - Experiment

- Thin samples of energetic materials heated in cell of FEI Quanta 200 Scanning Electron Microscope simulating surface processes during reaction
  - \( T < 1273 \text{ K} \), slow heating rate (300°C/min), other heating mechanisms will be investigated for higher heating rates
  - EDS and WDS available
  - Seeking FEI Quanta 200 FEG for higher resolution and higher temperatures; interaction with Pam Kaste of ARL
Combustion Analysis of Nano Metallic - Metallic Oxidizer Systems: Issues

• Metallic – metallic oxidizer (thermite) systems are a good source of thermal energy, but have limited mechanical energy
• Mismatch in physical and chemical properties between metallic fuel and fuel binders and energetic oxidizers create delayed and separate reaction stages
• Integrated nanocomposite thermite particles may be desirable from performance and sensitivity criteria
• Gas production from thermite systems can be increased by selective choice of mixture composition
Combustion Analysis of Nano Metallic-Metallic Oxidizer Systems: Objectives

- Formulate and study the reaction dynamics of nanocomposite thermite systems
- Investigate systems that produce significant gas at high-energy release rates
- Determine the effect of composition and physical characteristics of the trapped gas, initial temperature, and pressure on regression rates of mixtures
- Design and test nanocomposite ingredients fabricated by team members, e.g., nanoparticle metal fluorocarbon composites to enhance gas production in thermite reactions
Combustion Analysis of Nano Metallic - Metallic Oxidizer Systems: Experiments

• Optical Combustion Chamber
  – Ignite thermite mixture or pressed pellet to study effect of pressure, initial temperature, trapped gas effect
  – High-speed video records to determine regression rate
  – Pyrometer to measure the surface temperature of the condensed phase products
  – LIF to measure presence of AlO

• Thermite Reactor
  – Study the effect gas composition and diffusive characteristics
  – Photodetectors to determine regression rate of the luminous front
  – Fast-response pressure transducers to measure the local dynamic pressure
Interactions with MURI Team

- Combustion experiments for analysis and design of nano engineered energetic materials emphasizing subsurface and surface propellant measurements and thermite systems
- **Materials Group**: Integration of nano-structured energetic materials (NSEMs) into meso and macro scale systems for testing and analysis; based on engineering analysis, suggest desirable features and designs of NSEMs, identify most favorable ingredients and composition ratios
- **Simulation Group**: Use knowledge gained from simulation group for design of nano engineered energetic materials; provide system data for design of multiscale modeling studies
- **Dynamics Group**: Knowledge of reactive behavior on short time and small length scales important to understanding of meso and macro scale experiments; identify processes and parameters that require further study at sub micro scales
- **Engineering Group**: Complementary analysis, coordinated modeling and experiments at the meso and macro scales
- **MURI Team**: Jointly identify model systems for synthesis, analysis and characterization
Thank you for your attention
Combustion Analysis of Nano Metallic - Metallic Oxidizer Systems: Output

- Visual records and observations of the burning process of a family of thermite mixtures
- Regression rates of these mixtures as a function of trapped gas composition and physical properties, initial temperature and pressure, and pellet TMD
- Pressure-time profiles during regression process as of function of axial location
- Surface temperature of the molten products
- High-resolution micrographs of the recovered condensed-phase products