Small Scale Testing of Energetic Materials

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Testing new energetics candidates – What do we want to know?

- For an RM or propellant
  - Temperature dependent ignition characteristics (kinetics)
  - Rate of energy release
  - Rate of gas release
  - Sensitivity

- For an HE
  - Detonation performance
    - TNT equivalence
  - Sensitivity
Why small scale testing?

- Much easier to make 1 mg than 1 g or 1 kg
- Rapid screening of new materials
- Parametric studies
  - Elucidate underlying physics
- Keep costs down
  - Materials
  - Handling
  - Capital costs
- Minimize handling and safety issues
Main issue w/small scale tests - SCALABILITY

- Does what we learn from 50 mg test samples translate to 50 kg devices???
  - Do generic scaling laws really translate to the miniature scale?
    - Ideal explosives scale better than non-ideal explosives
  - Residence times and time/temperature histories typically do not.
    - Velocities don’t increase with charge diameter.
- Scalability must be addressed before planning a matrix of small scale tests.
If results don’t scale directly, what good are small scale tests?

- Reaction kinetics should remain independent of scale
  - Ignition delays, combustion times

- Small scale results can validate key kinetics in numerical models, which can then address scaling issues
Critical Reaction Measurables for Novel (non-ideal) Energetic Materials

- Ignition delay as a function of
  - Temperature & rate of temperature increase
  - Ambient pressure
  - Ambient oxidizer concentration

- Rate of energy release
  - Same independent variables as ignition

- Information on reacting system
  - Intermediate species & sequence of appearance
  - Temperature distribution around system
Some small scale approaches of note using $m < 1$ g (incomplete list)

- Brill’s T-jump + FTIR methods
- Dreizin’s hot wire and laser ignition techniques
- Zachariah hot wire in mass spectrometer
- Settles HE shadowgraph blast scaling
- Kuo, Parr and others using flame insertion
Our Approach to Measuring Relevant Kinetics

- Heterogeneous shock tube
- 1 mg sample size
- High heating rates $10^7$/K sec.
- High temperatures possible (3000 – 4000 K)
- Microsecond or better time resolution
- Fully controllable oxidizer composition
Shock Tube Operation

Particle Injector

Test Gas

End wall

View ports

$t = -200$ us

8.5 atm
2650 K

$t = +10$ us

$t = +200$ us

Combustion

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Sample Trajectory Modeling

Graph showing:
- Distance from Endwall (m) vs. Time (µs)
- Velocity (m/s) vs. Time (µs)
- Temperature (K) vs. Time (µs)

Key events:
- Shock Hits Particles
- Shock Hits Endwall
- Ignition
Shock Tube Diagnostics
High Speed Pyrometry & Photometry

![Graph showing normalized intensity and temperature over time](image)

- **Normalized Intensity (a.u.)**
- **Temperature (K)**
- **Time (µs)**

- Induction Time
- Burn Time
- 3-color Temperature
- 514 nm
Spectroscopic Measurements of Al & AlO

![Graph showing spectroscopic measurements of Al and AlO with peaks at specific wavelengths.](image-url)
PETN Explosion
Size differences in ignition and burn time

![Graph showing intensity vs time for nano-Al and micro-Al](image)

- nano-Al
- micro-Al

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Ignition tests in shock tube

The shock tube is an extremely accurate means to evaluate ignition thresholds of advanced EMs.
Temperature Dependence

The graph shows the relationship between the inverse of the response time 1/tb and the inverse of the temperature 10^4/T for two different pressures: 8 atm (circles) and 32 atm (triangles). The data points are plotted along a straight line, indicating a linear relationship between the variables.
Explosives testing is not confined to DoD and DoE labs

- UIUC, PSU, Purdue, URI, and many others have well established explosives programs.
- Typically 50g and smaller tests are routine
- Compared to DoD facilities, university costs are typically lower and lead times are shorter.
- Still, tests are typically small scale, but diagnostic capabilities are extensive.
E.g. Settles @ PSU

- *Shock Waves, 17, 215 (2007)*
- Ideal explosives scaling to below 1 g
Instrumented Small Scale HE tests

- Reaction front tracking
- Emission/Absorption spectroscopy
- Velocimetry in plume
- Dynamic pressures for blast characterization

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Key issues with small scale tests

- Focus on fundamental physics immune to scaling – e.g. chemical kinetics

- Detailed and accurate measurements of relevant parameters under relevant conditions in appropriate time scales

- Modeling support to assist in scaling results
EXTRA SLIDES

- 38 g PBXN-9 tests at UIUC
- Aluminized RDX tests (DTRA)
- Fast Kinetics spectrometer
Five liners at ~100 µs after detonation

Cu  Ta + 2B  Ti + 2Al  Hf  Ta + 2Al
Three ways of loading aluminum powder

1. RDX + 20% Al
2. RDX + Al on surface
3. Loose Al
Test configuration

Case A: Al Powder in Detonator

Case B: Al powder outside HE

BEFORE

AFTER

Vent
PETN Booster
RDX + 20%Al

Fast Kinetics Spectrometer
Fireball

RDX
Al loose powder

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Pictures of Test Configuration

Detonator Rig and mirror
Fast Kinetics Camera and Spectrometer
Detonator Cloud
RP2 Detonator
Tunnel to choke Detonation/Load Aluminum in Tube
2” mirror, 20° off axis
UIUC Fast Kinetics Spectrometer

- Andor FK Camera
  - Up to 128 spectra in a sequence
  - Spectra taken every 1 us

- Custom f/1.4, volume phase holographic (VPH) grating (90% efficiency).
  - 4 Å resolution over 450 – 580 nm range

- UV version f/2
  - 10 Å resolution 200-600 nm
Emission & Absorption Spectroscopy

- Detailed spectral model
- Calibrated by experiment
- Time-resolved or time integrated
- $2\sigma$ temperature uncertainties below 150 K.
Shock Induced Ignition Curves: 
Al/MoO₃ Alloys from NJIT
Low Temperature Ignition Behind an Incident Shock

- At 965 K, 4:1 and 8:1 alloys ignite within 200 us.

- 16:1 alloy shows a thermal signature, but at best incomplete ignition.
Incident Shock Mode

TEST SETUP

Observation Section
Gas Mixture of Choice
Diaphragm
Hi Pressure Helium Driver
Particle Injector

PARTICLE INJECTION & DIAPHRAGM BURST

Powder mixture of desired material/cloud density
Shock of Adjustable Strength

MEASUREMENT DURING IGNITION & COMBUSTION

Observation by spectroscopy & pyrometry. Measure ignition delay and burning time.