Characterization of Shear Ignition Threshold of Energetic Materials Using Hybrid Drop Weight-Hopkinson Bar

Presented to:

Insensitive Munitions and Energetic Materials Technology Symposium

Presented by:

Vasant Joshi

Scientist, Naval Surface Warfare Center Indian Head EOD Technology Division
Indian Head, Maryland, USA

Seville, October 21-24, 2019

Capt. Scott H. Kraft, USN
Commanding Officer

Mr. Ashley G. Johnson, SES
Technical Director

Background

- Insensitive munitions are needed to prevent accidental ignition in transportation and handling
- Characteristics of hazard scenario of energetic material usually include a significant amount of shear which result in hot spots leading to ignition
- Quantifying sensitivity to shear in a specific composition is essential in developing insensitive munitions

Motivation

- Experimental data on mechanical properties at different strain rates for pre-ignition conditions and shock data are available for modeling of PBXN-110 (Bernekar, APS 1995, Miller, APS 1995)
- Our recent work from Hybrid Hopkinson Bar provides substantial insight in mechanical and ignition behavior of explosives in shear
- The Hybrid Hopkinson Bar is ideally suited for model development and the real time data from experiments can be used in validation of models

Approach

- Obtain real time mechanical and ignition threshold data via Hybrid Bar experiments on small samples of a standard PBXN-110 explosive
- Conduct tests near threshold conditions with identical impact conditions, but replace load cell with sapphire window, obtain high speed thermal images and temperature-time profiles of compression cycle
- Use mechanical data (stress-strain-strain rate) and thermal data to validate model

Modeling Requirements

- Mechanical properties at different strain rates (pre-ignition conditions), needed for constitutive modeling of explosives
- Quantitative measurements for shear induced ignition against which model predictions can be validated

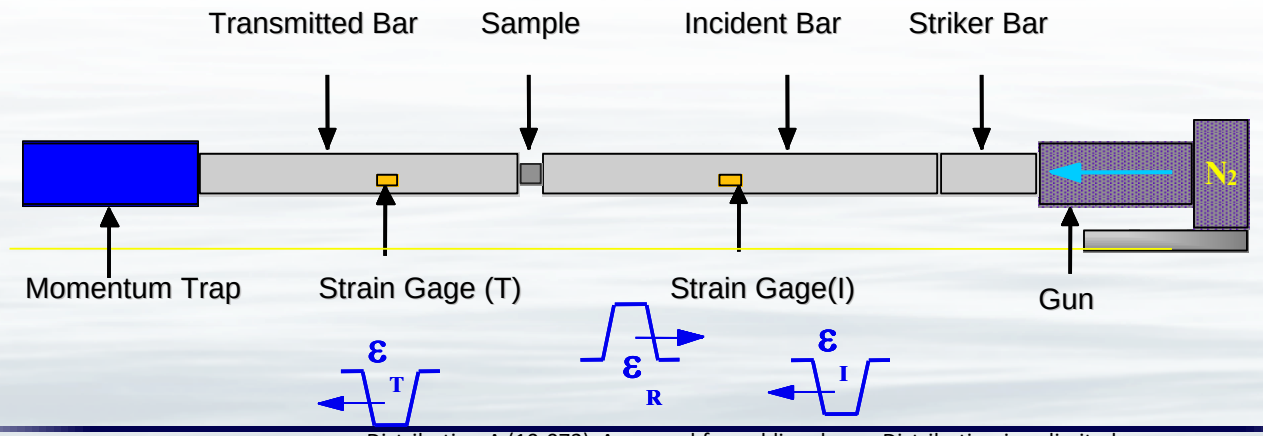
Issues in Energetic Materials

- Overall behavior of composite explosive containing hard crystals and soft binder is still very soft (visco-elastic)
- Low thermal conductivity of composite (as compared to metals) results in faster heat localization in dynamic loading
- Composite explosives include different components with vastly different mechanical properties leading to complex ignition behavior

Mechanical Property Measurement

- Conventional Split Hopkinson Pressure Bar (SHPB)
  - Used to obtain high-strain-rates data for constitutive modeling
  - Strain up to 20%, Strain rate 250- 4000/s
  - Max strain rate limited by equilibrium assumptions, sample size works well for metals and stiff plastics

Refinements in techniques and diagnostics were needed to resolve details for explosives (Explomet 2000, JANNAF 2000, APS 2001, Det. Symp. 2006)



Issues in Hopkinson Bar

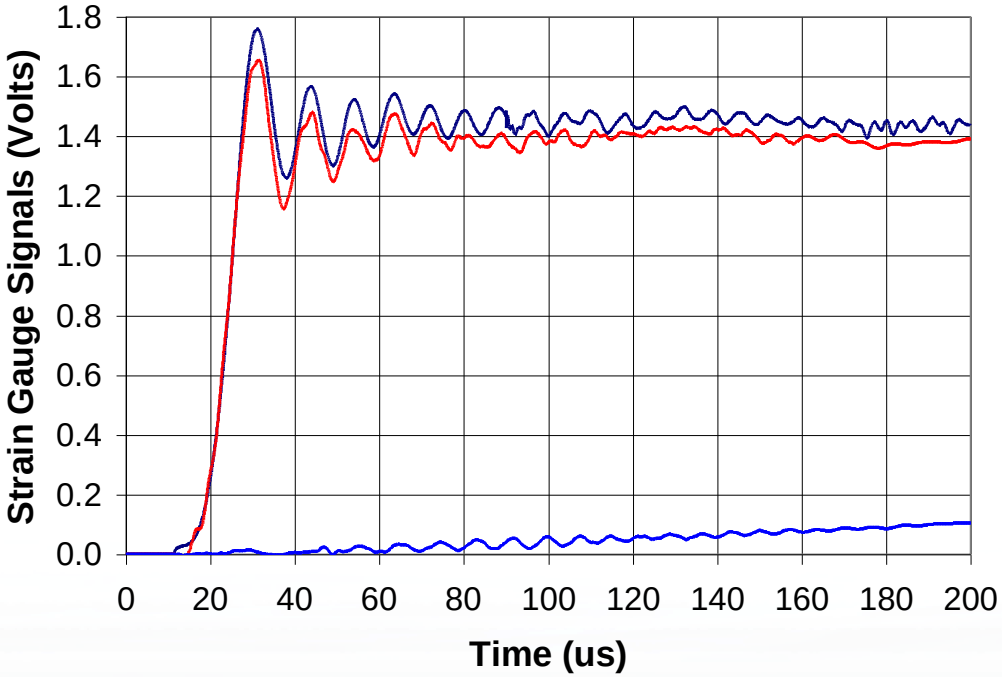
Impedance mismatch

Choice of bar - Steel, titanium, aluminum, magnesium or polymeric bar

Low transmitted signal (signal fidelity)

Choose strain gauge for required output-120, 350, 500 or 1000 ohm

Choose electronics based on gain and noise consideration excitation voltage/bridge considerations

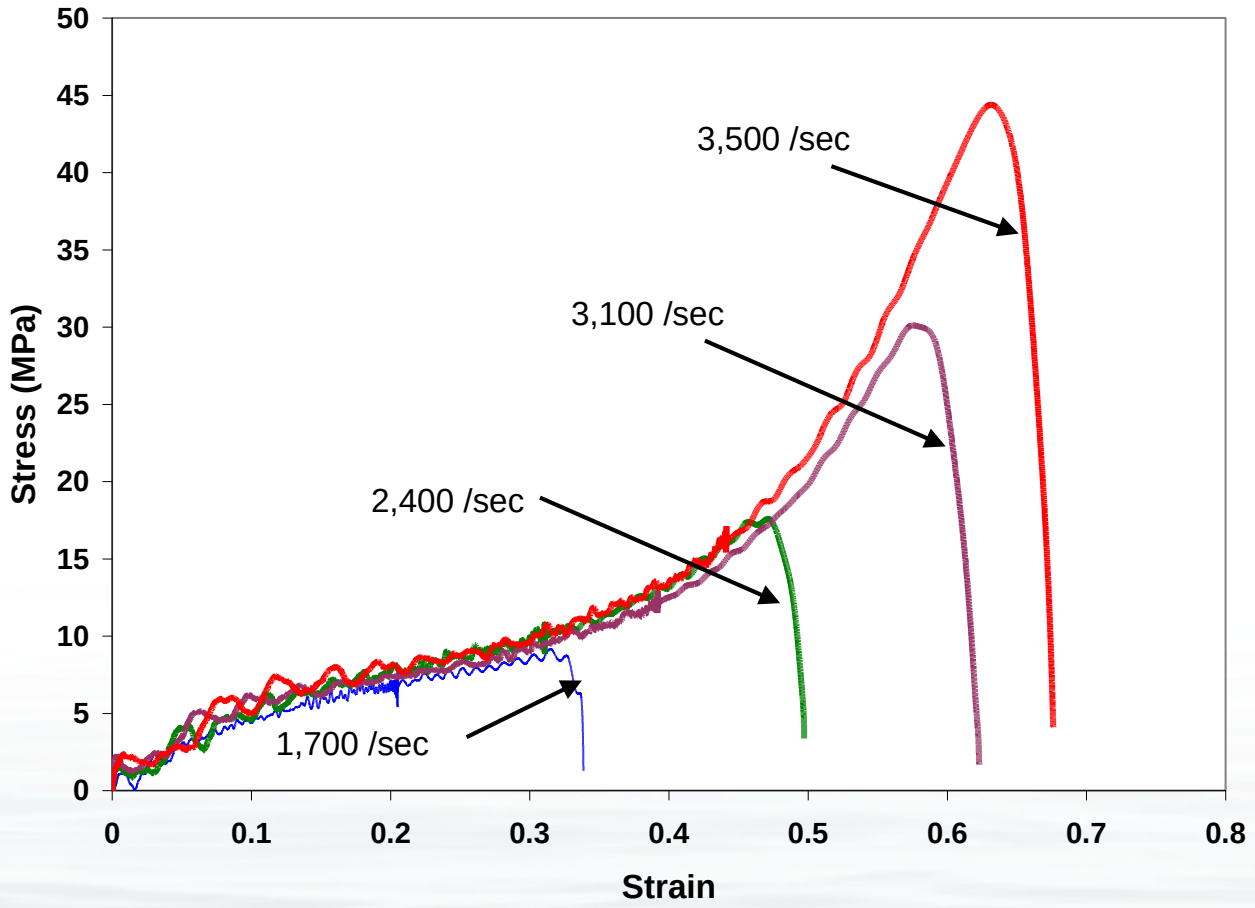


Raw Data for Soft Explosive

Material for Modeling

- PBXN-110- standard explosive
- Component- Large particle, bimodal, HMX/HTPB based composite, high solid loading
- Sample sizes restricted by the allowable diameter during test (=bar diameter)
- 4-9 mm diameter, different L/D size for each diameter

Results from Hopkinson Bar



PBXN-110, bimodal HMX/HTPB based composite explosive, APS 2001

Shear Induced Ignition

- Despite high strain rate, samples do not ignite in Hopkinson Bar tests

- Shear induced ignition requires higher strain rates to transition hot spots to reaction state

Hybrid Hopkinson Bar System

Advantages

- Most of striker energy goes into sample, thus can ignite sample
- Gas gun system drives striker to high velocity (tested up to 20 m/s)
- Strain rates an order above Hoppy Bar (~ 10^4 -10^5)
- Loading-time profile is clean
- Displacement/strain and load/stress measured directly

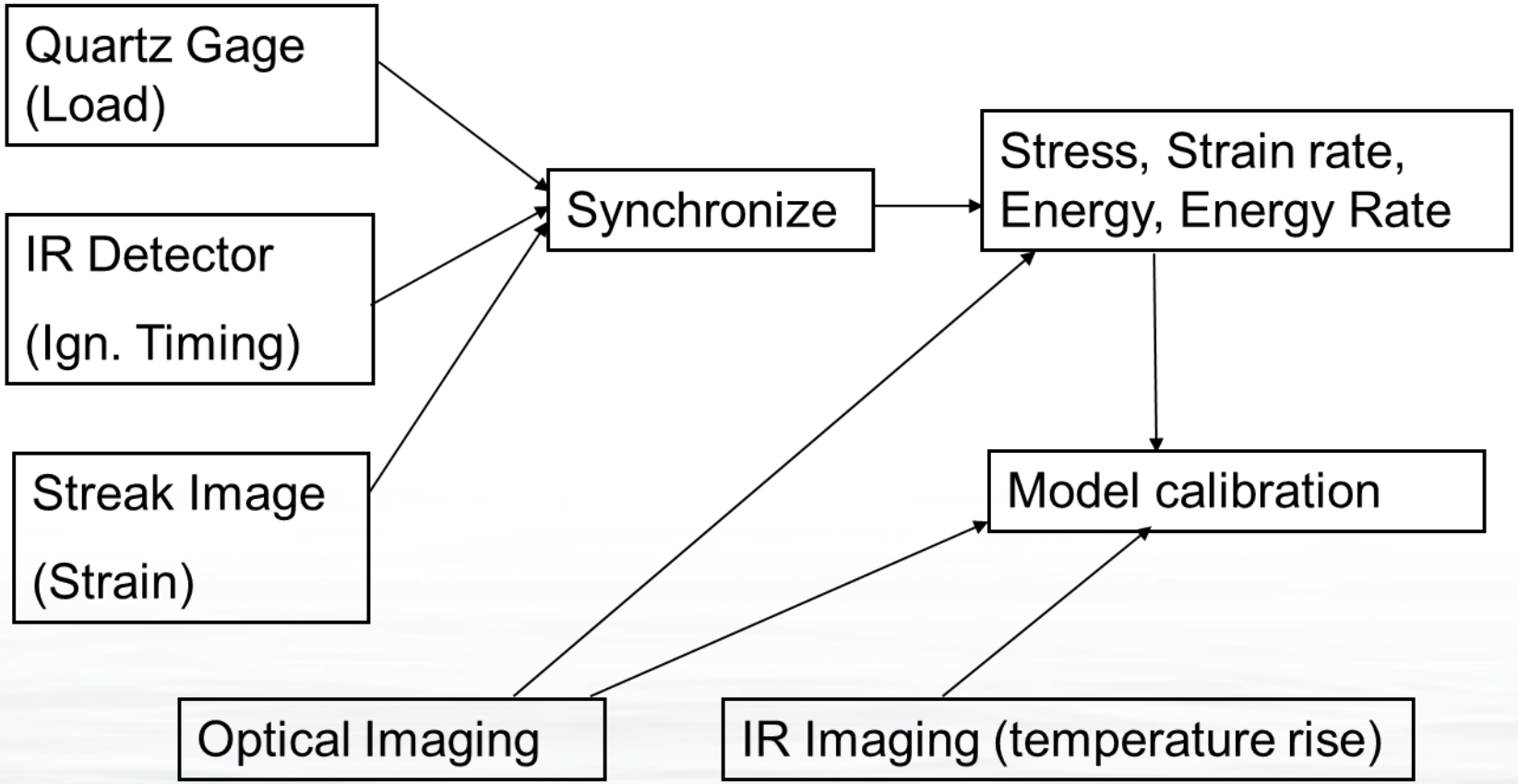
Disadvantage

- Limited sample sizes can be tested

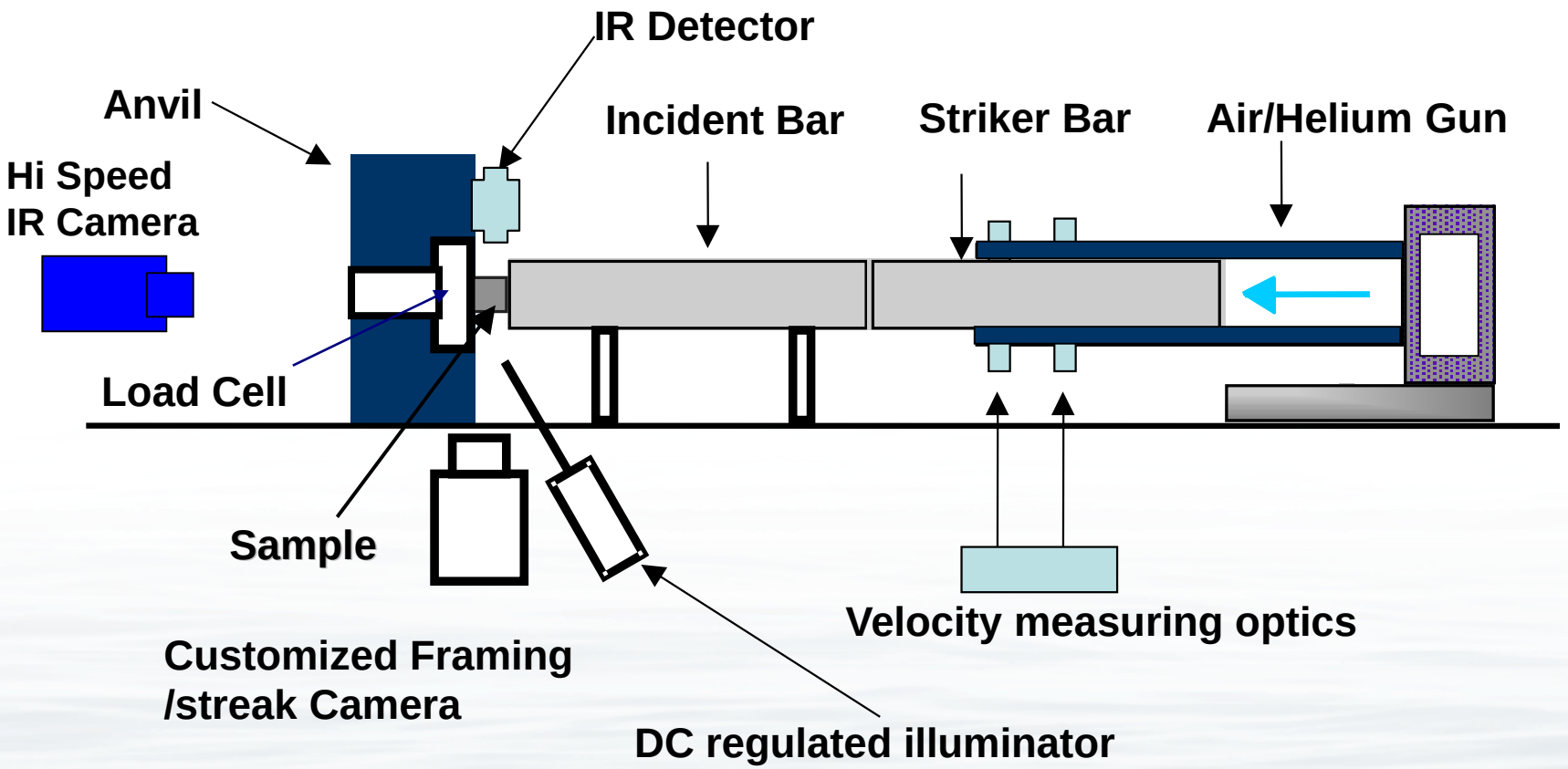
Diagnostics

- Fast imaging to replace strain measurement-optical camera
- Fast detector to identify ignition- extended NIR detector, thermal camera

Hybrid Hopkinson Bar System

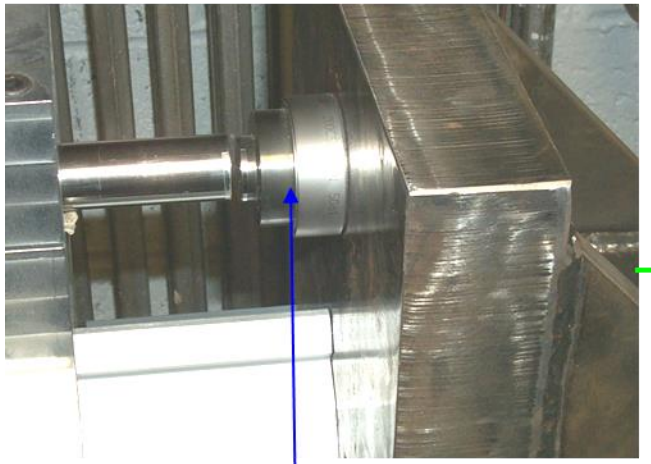


Hybrid Hopkinson Bar

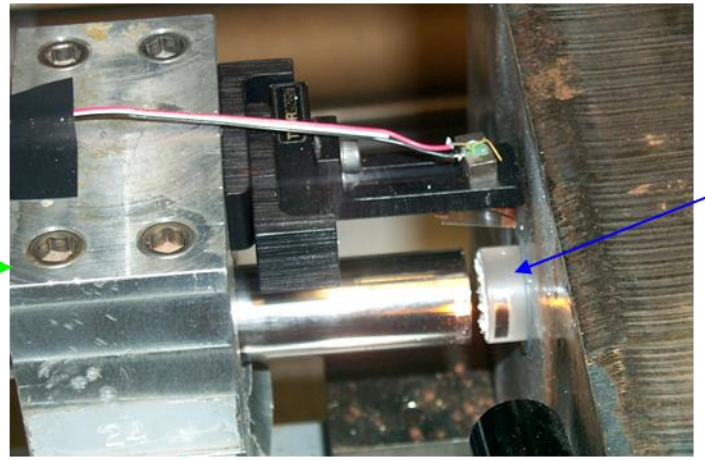


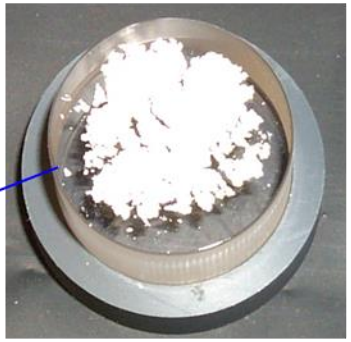
Hybrid Bar Setup

Load Cell Configuration

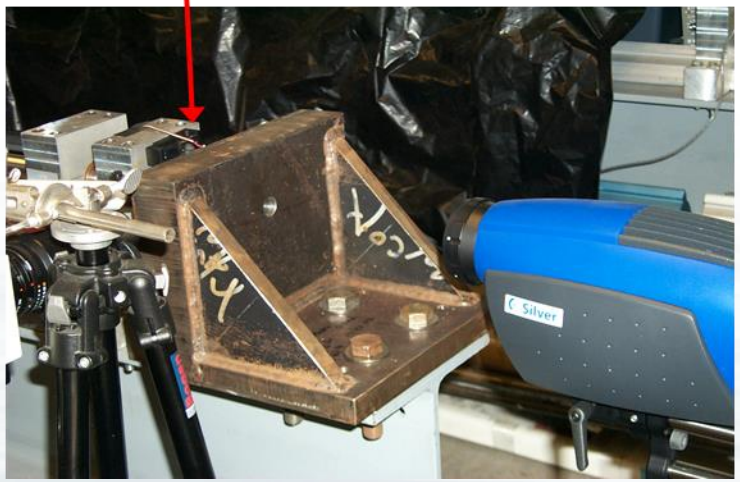


Sapphire Window Configuration

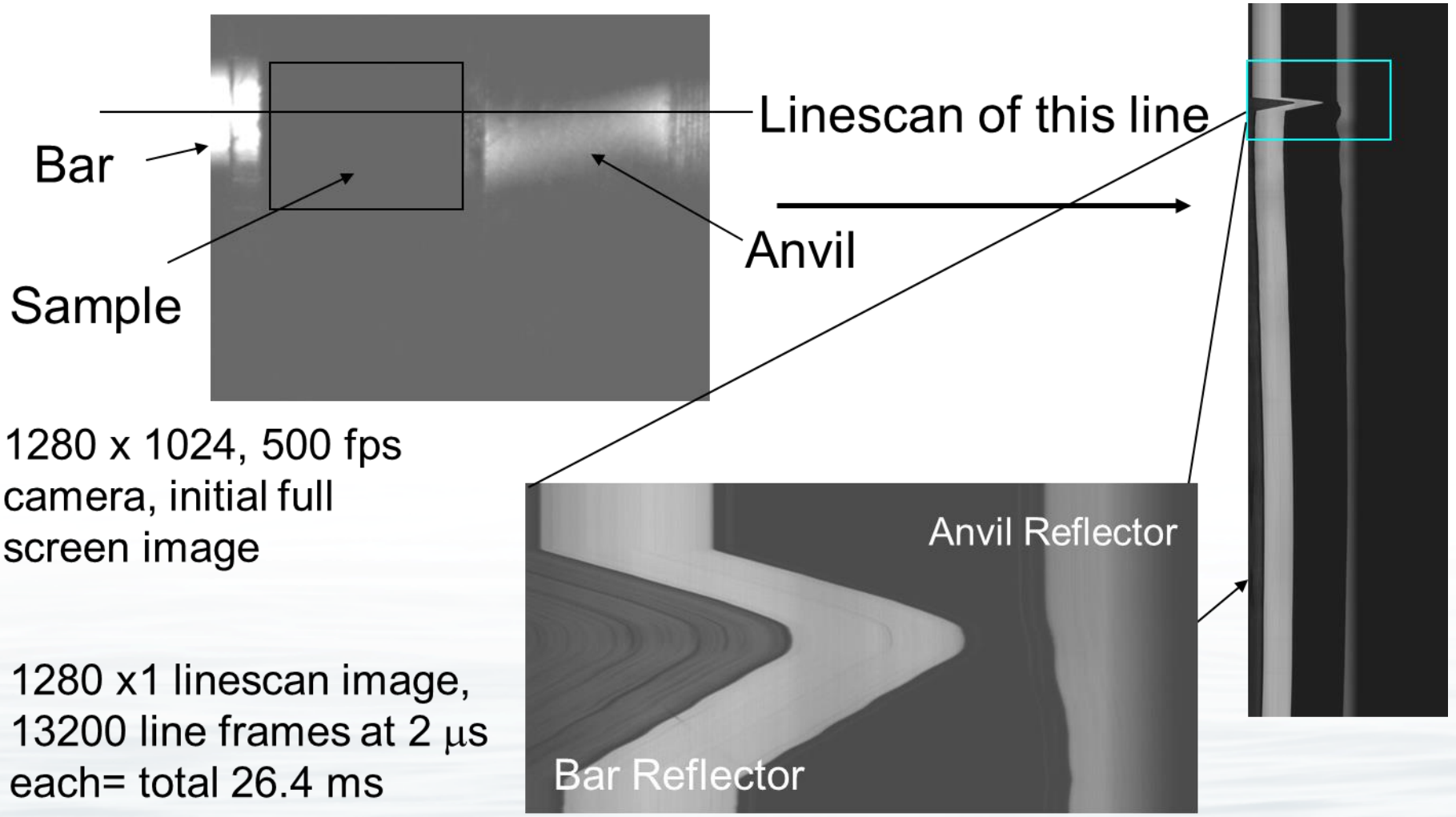




Sample



High Speed Streak Imaging



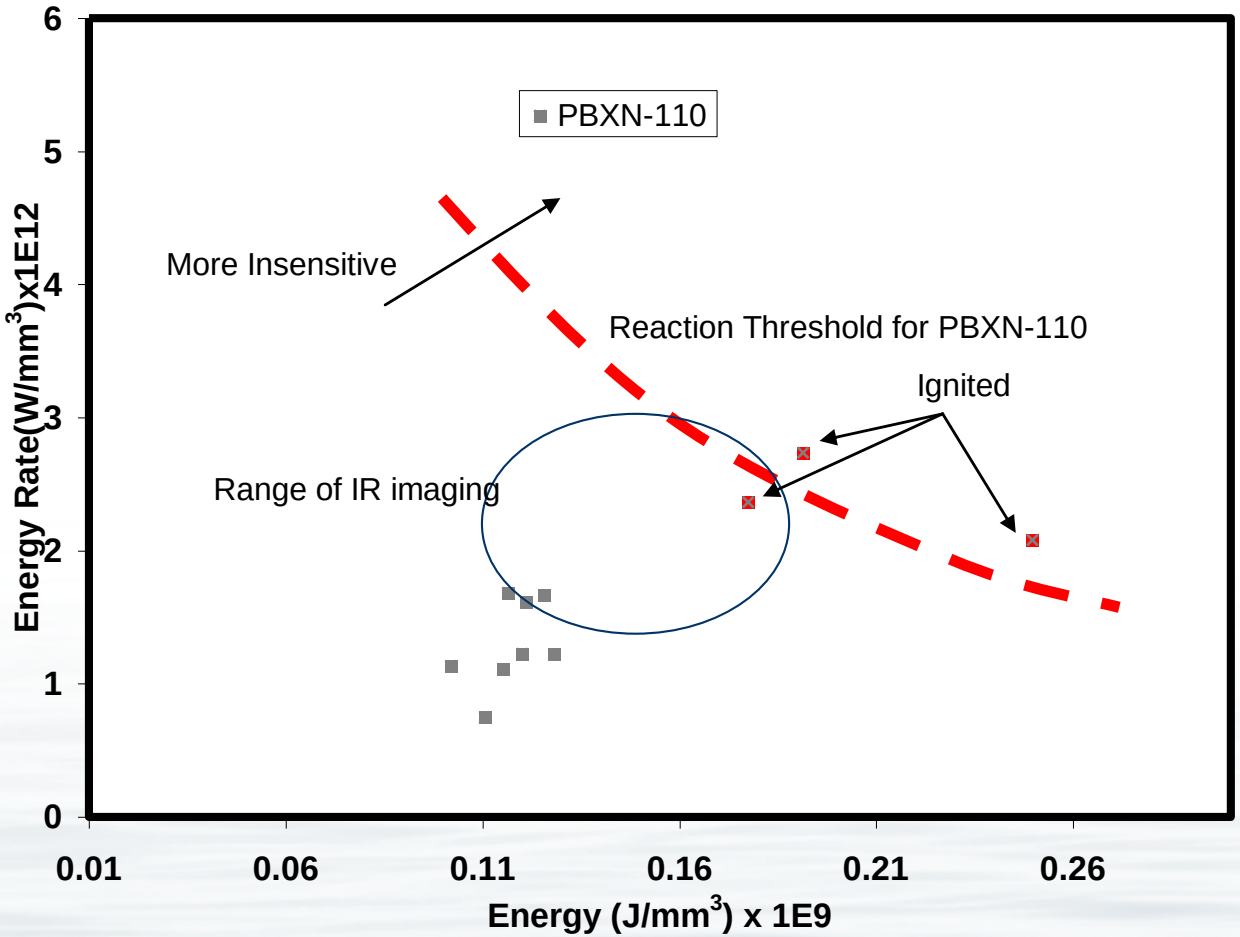
1280 x 1024, 500 fps camera, initial full screen image

1280 x1 linescan image, 13200 line frames at 2 μs each= total 26.4 ms

Experimental Results

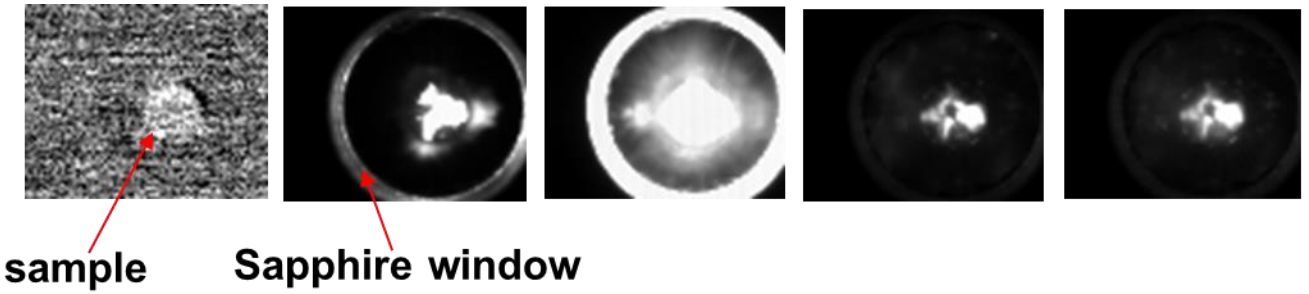
Shot #	Sample Diameter inch	Sample Thickness inch	Striker Velocity m/s	Ignition Detected	Energy (Joules/mm^3)	Energy Rate (Watts/mm^3)
110-01F	0.250	0.138	9.06	N	1.28E+08	1.22E+12
110-02F	0.250	0.138	8.40	N	1.15E+08	1.11E+12
110-07F	0.187	0.134	8.06	N	1.20E+08	1.22 E+12
110-IR01F	0.187	0.134	8.31	N	NA	NA
110-IR02S	0.187	0.134	6.19	Y	NA	NA
110-IR03S	0.250	0.138	7.39	Y	NA	NA
110-IR04S	0.250	0.138	7.38	Y	NA	NA

Ignition Threshold

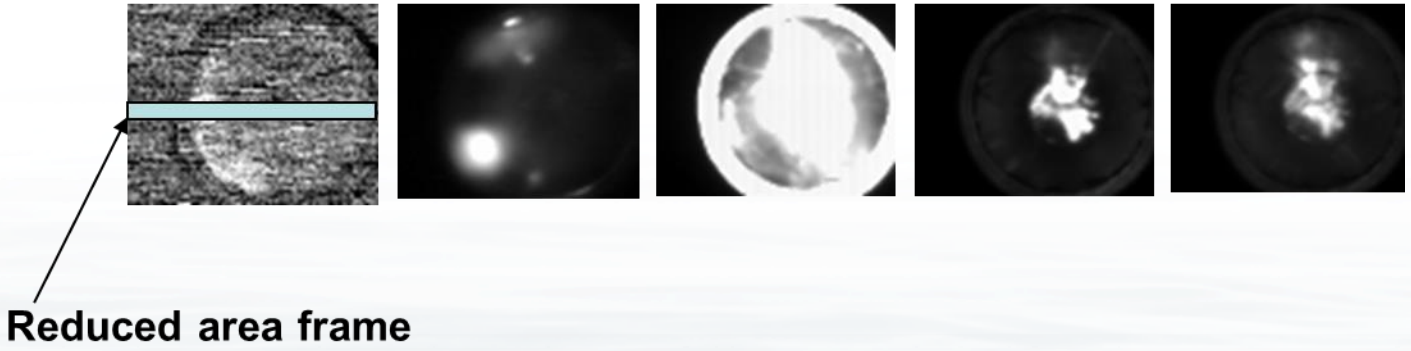


High Speed IR Images

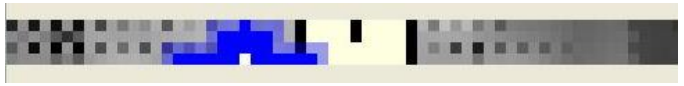
Ignited sample IR3, 3600fps (275μs), partially ignited



Ignited sample IR4, 3600fps (275μs), partially ignited

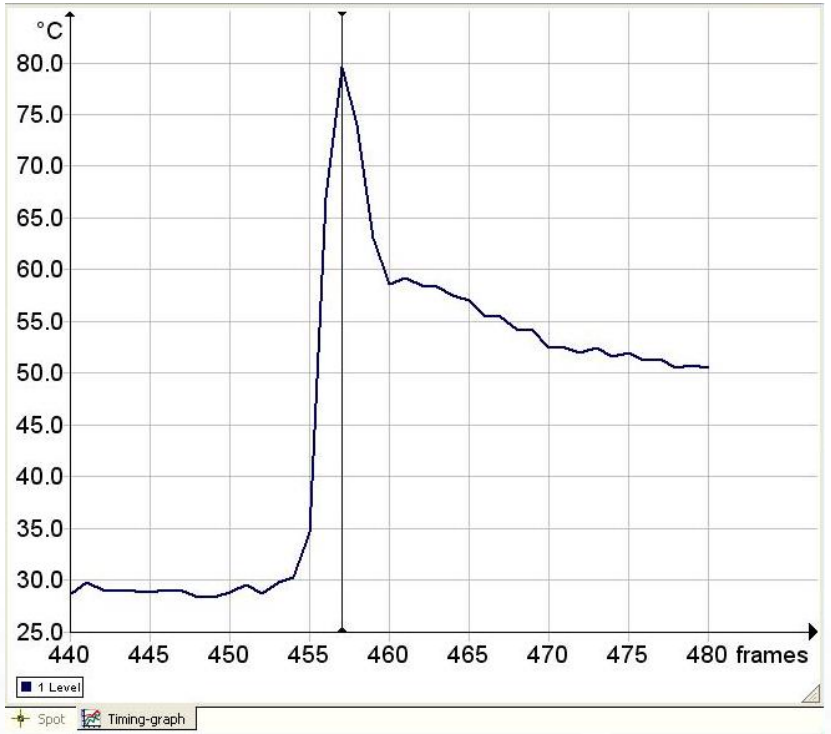


High Speed IR Profiles



64 x 4 pixels @ 20,000 fps (50μs)

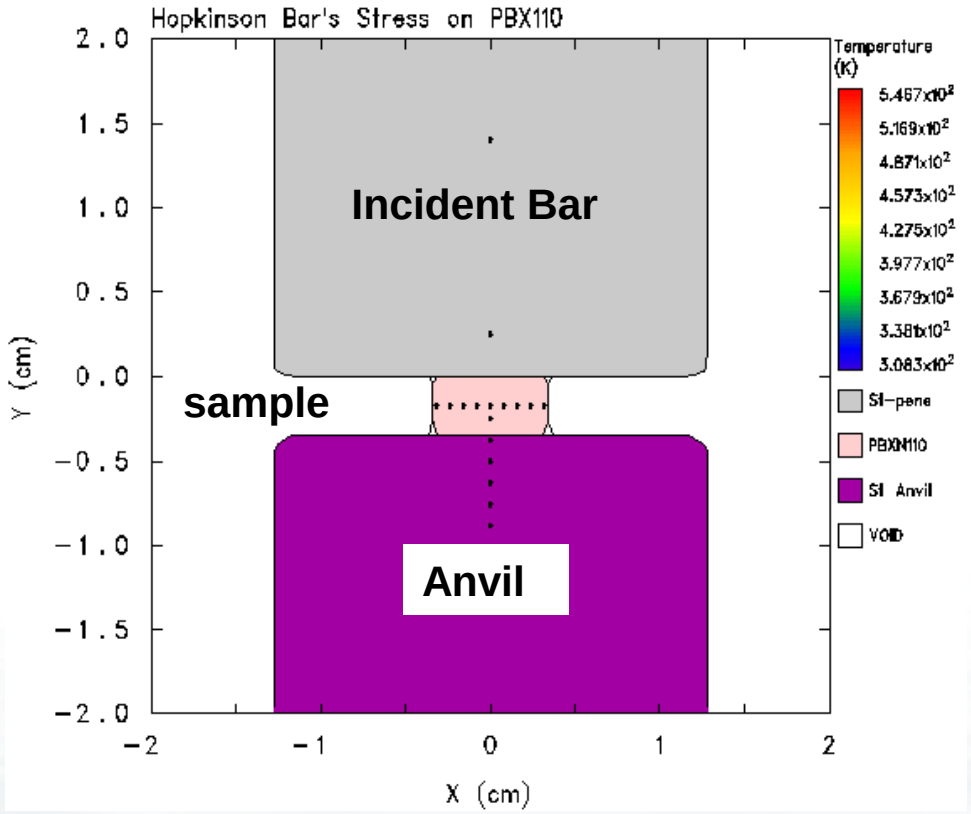
Better temporal resolution can be realized at the expense of spatial resolution by reducing the frame size



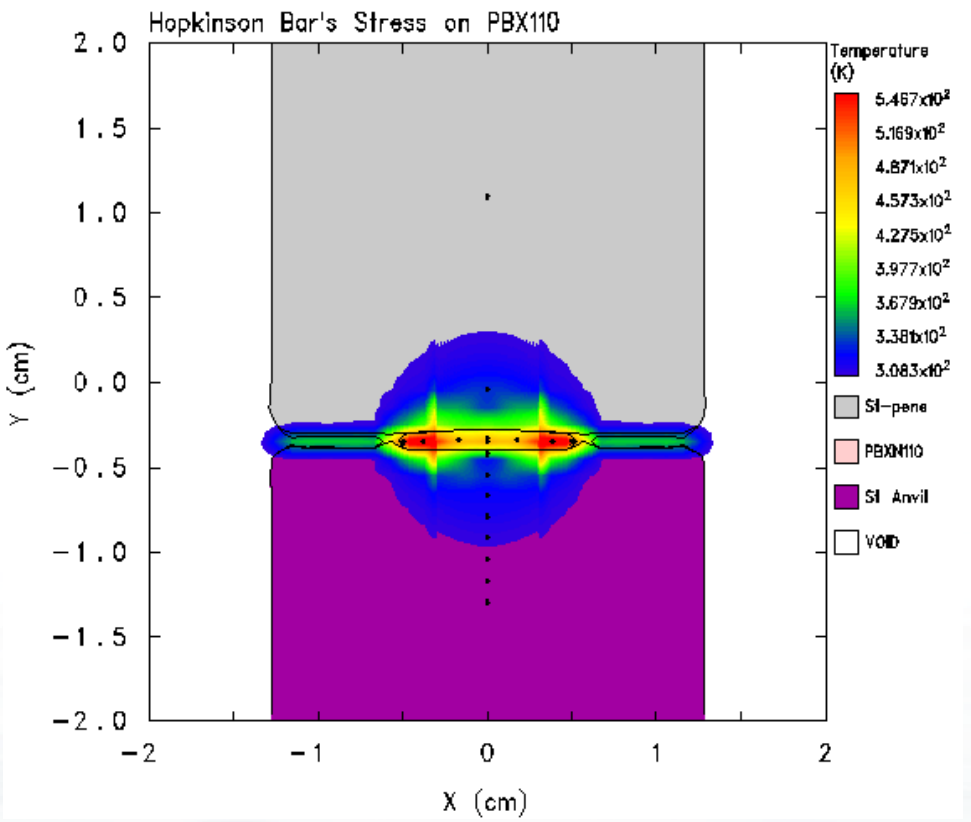
Modeling of Hybrid Experiment

- Input condition for bar velocity 8.31m/s
- Use AISI 4340 for bar and anvil
- PBXN-110 material as JC visco-plastic
- Data from experimental work
- 64 nodes across diameter

Modeling of Hybrid Experiment

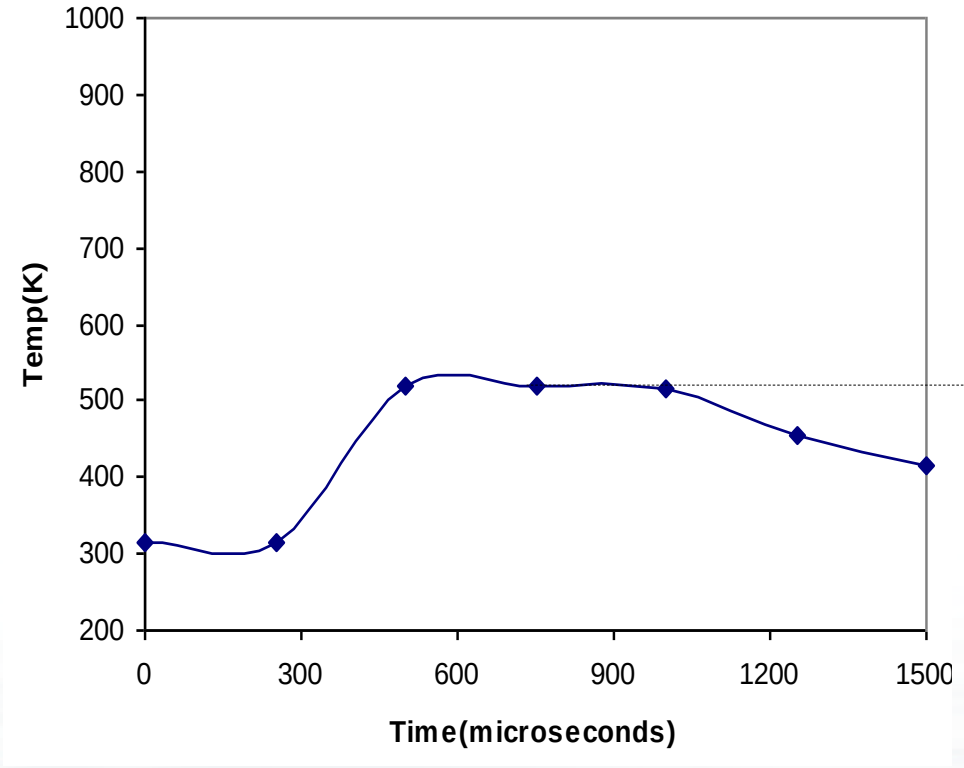


Starting of Compression Cycle

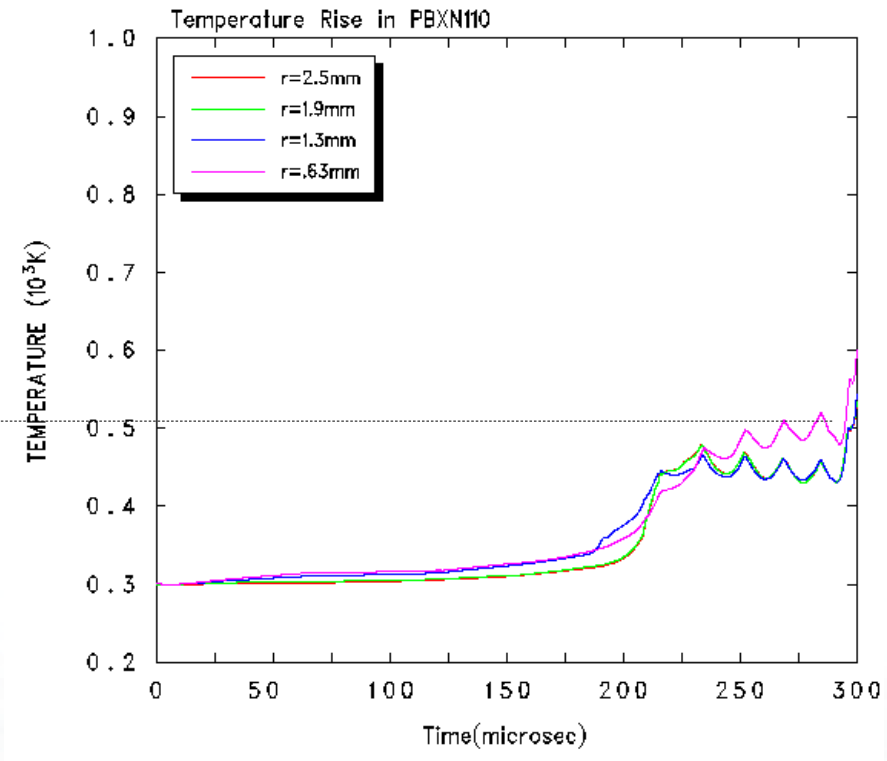


End of Compression Cycle

Modeling vs Experiment



Temperature Profile from experiment



Temperature Profile from simulation

Conclusion

- Samples of PBXN-110 explosive have been tested with Hybrid Hopkinson Bar apparatus at various thickness and velocities.
- Simultaneous high speed visible and IR images and simulations provided accurate ignition event and associated temperature rise on sample surface
- Original intent of the Hybrid Bar apparatus as a system for modeling has been fully realized as a result of simultaneous diagnostics and improvements applied to the apparatus

Acknowledgements

This work was supported by the Internal Research Program of Naval Surface Warfare Center Indian Head EOD Technology Division, Indian Head, Maryland, USA.

Support from Dr. Raafat Guirguis (experimental and data reduction) and Clint Richmond (modeling) is highly appreciated.