PBXN-5 Mechanical Characterization & Proposed Constitutive Model

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Nathan Millard, Susan Smith, Daniel Peairs
L3 Defense Electronic Systems

Ericka Amborn, Craig Doolittle
Applied Research Associates, Inc.

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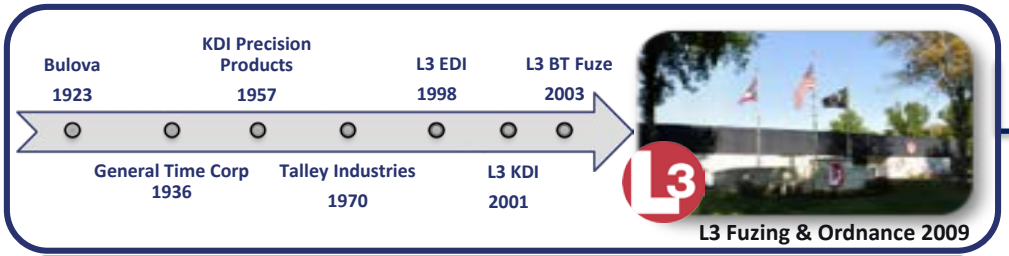
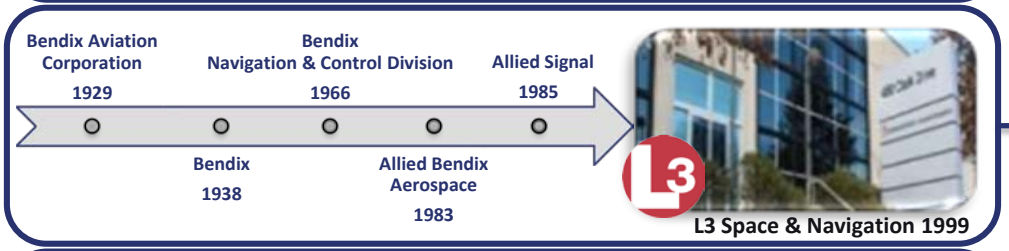
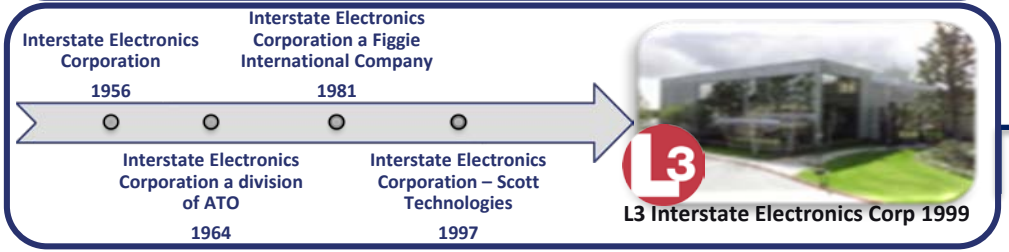
L3 Defense Electronic Systems (L3 DES)



L3 Fuzing & Ordnance 2009



L3 Space & Navigation 1999



L3 Interstate Electronics Corp 1999

Over 75 years of solving our customers' hardest problems

Presentation Overview

- Project Overview
- Test Capability
- Tests Conducted
- Comparison to Previous Data
- Model Selection
- Model Development
- Model Validation

Project Overview

- **Office of the Secretary of Defense (OSD) program addressed the design, development and improvement of prototypes or processes to meet Electronic Safe and Arm Device (ESAD) requirements**

  Objectives

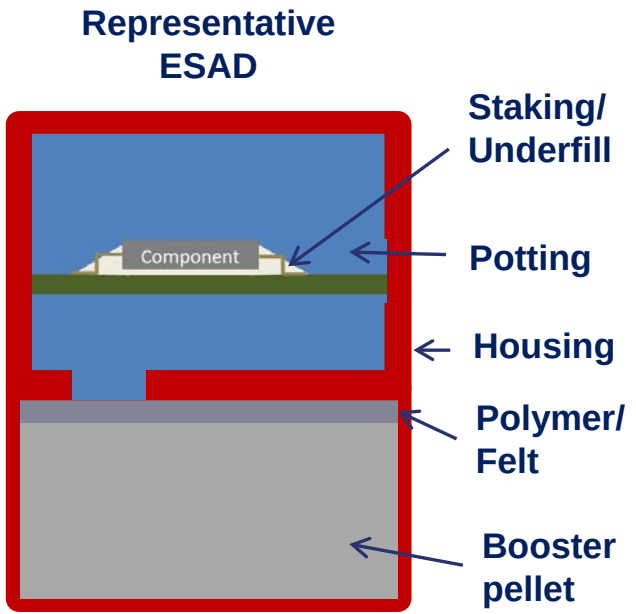
  1) **Replace legacy electro-mechanical fuzes with ESADs**
  2) **Support development of the Fuze industrial base**

- **Main commonalities across ESADs are the materials and electronic and explosive components**
- **FEA modeling is a key capability for new Fuze development**

FEA modeling requires accurate material models in the relevant environments.

Material Downselection

- **PBXN-5 selected for study**
  - **Reviewed "soft" materials used in DES designs**
  - **PBXN-5 is one of several booster materials typically used**
    - **Existing data or models requested from USG sources**
    - **Some data available from LANL**
  - **Common initiator explosive modeled under an IRAD effort**
  - **Other "soft" materials tested separately**

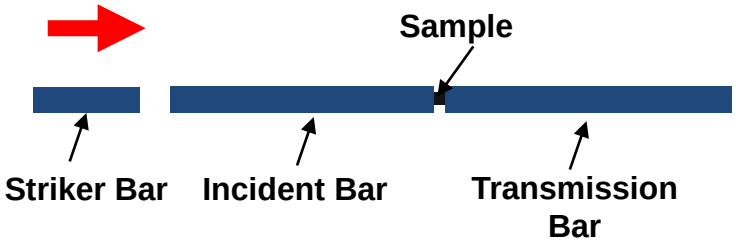


L3 DES Mechanical Characterization Capability

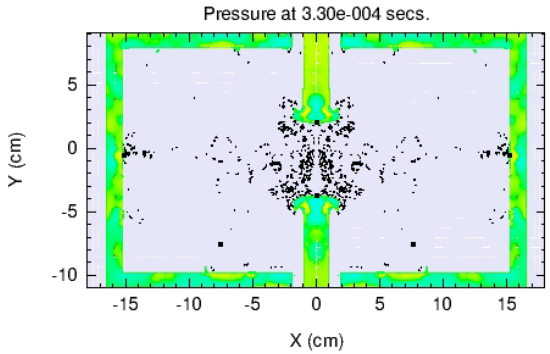
- L3 DES can handle DOD as well as ATF explosives
  - ATF license maintained to test commercial explosives as well as an approved explosives safety site plan to test DoD-regulated explosives under contracts containing DFARS Clause 252.223-7002
  - DOD certification required for most DOD funded contracts under DFARS
- Currently approved for 3.1 g HMX (on Hopkinson bar and universal tester)
  - Higher NEW possible with appropriate analysis
- Hopkinson Bar (developed as part of effort)
- Universal Tester
  - Low rate compression
  - Tension
- DMA (Dynamic Mechanical Analysis)
- TMA (Thermomechanical Analysis)

L3 Hopkinson Bar Facility

- Two Bars
  - 7075 Aluminum for softer material testing
    - 12 ft. incident bar, 8 ft. transmitter bar
  - Maraging Steel for components and hard materials
- Dual function blast box/ remote temperature chamber
  - Analysis completed in CTH to confirm test setup and blast box safety in case of unplanned detonation



L3 Hopkinson Bar

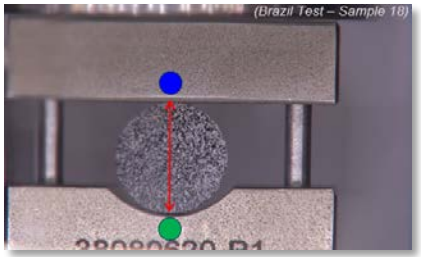


Stress generated in blast box

Universal Tester and Hopkinson Bar Setup

Admet Universal Tester
(for compression, confined compression, Brazil tests)

Hopkinson Bar
(High strain rate tests)



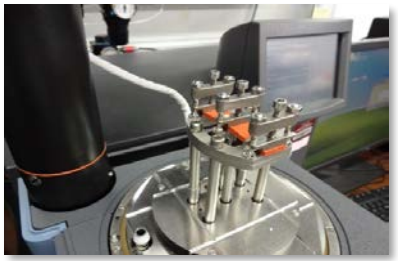
Brazil (Indirect Tension) Test

Confined Compression Fixture

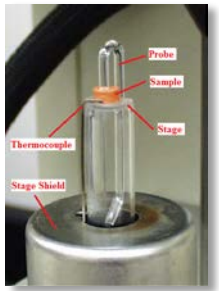
Sample in Hopkinson Bar

DMA, TMA

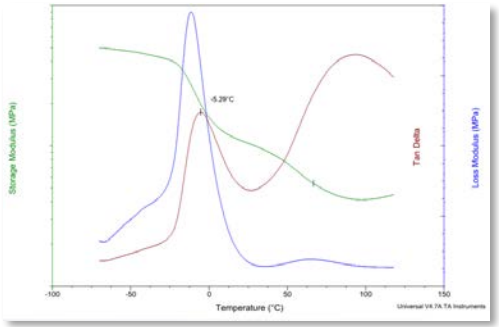
- Dynamic Mechanical Analysis (DMA) used to assess stiffness modulus across temperature
- Thermomechanical Analysis (TMA) used to assess thermal expansion across temperature (CTE)
- Glass Transition temperature identifiable by each



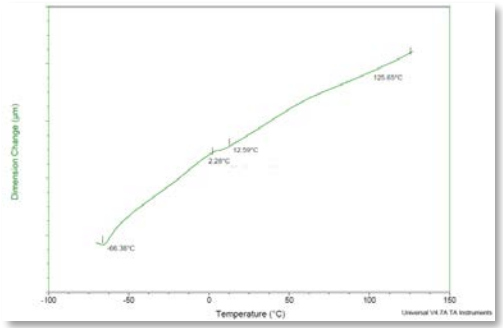
Example DMA Test Configuration



Example TMA Test Configuration



PBXN-5 DMA Results



PBXN-5 TMA Results

Planned Test Matrix

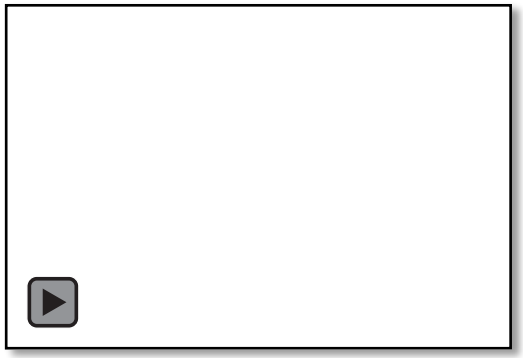
- **Some data points replicate previous data**
- **First known tests for tensile properties and confined compression**

Equipment	Rate	Temperature					
		~-50°C	~-20°C	~0°C	~25°C	~50°C	71°C
Unconfined Compression							
Load Frame	0.001	XO			O	X	O
	0.01						
	0.1	O			O		O
	1	X			X	X	
	100						
Hopkinson Bar	~500	O			O		O
	~1,000	O			O		O
	3,000	XO	X	X	XO	X	O
Tension / Brazil							
Load Frame	0.001	O			O		O
	0.1	O			O		O
Confined Compression							
Load Frame	0.001	O			O		O
	0.1	O			O		O

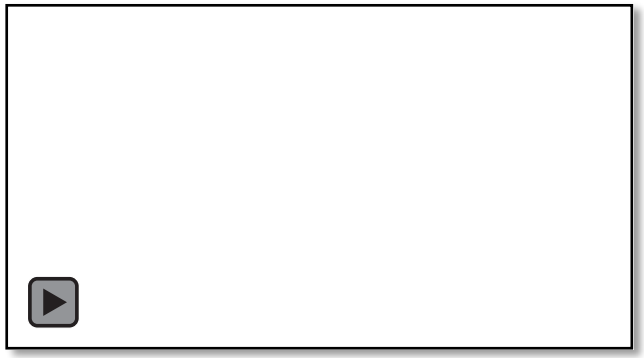
O	L3 DES tests
X	Data available from literature

DIC Test Setup

- Digital Image Correlation used for additional strain measurement
- Verifies LVDT measurement

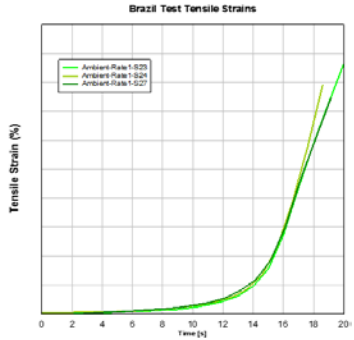


Axial Strain



Brazil Test Horizontal Strain

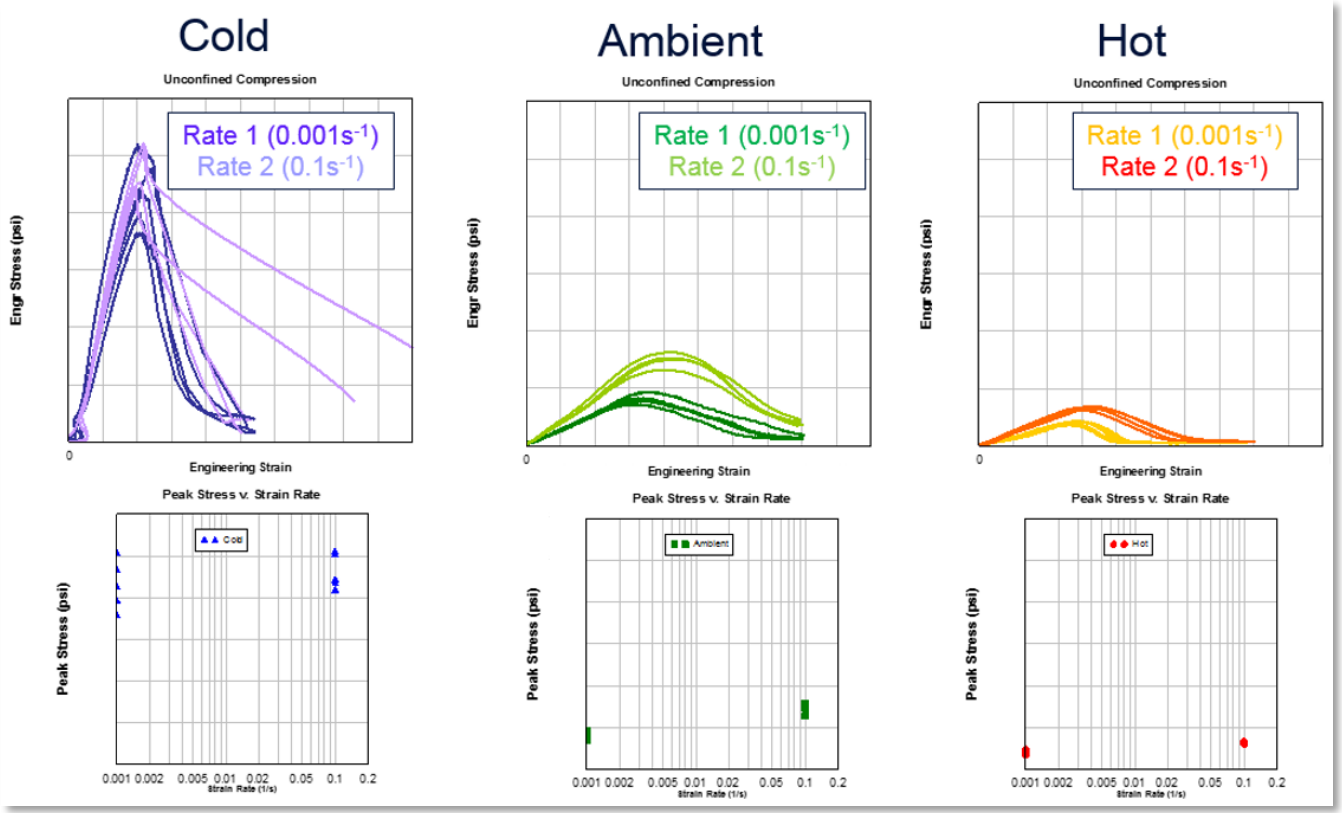
Horizontal Strain



Measured Tensile Strain

Quasistatic Unconfined Compression Results

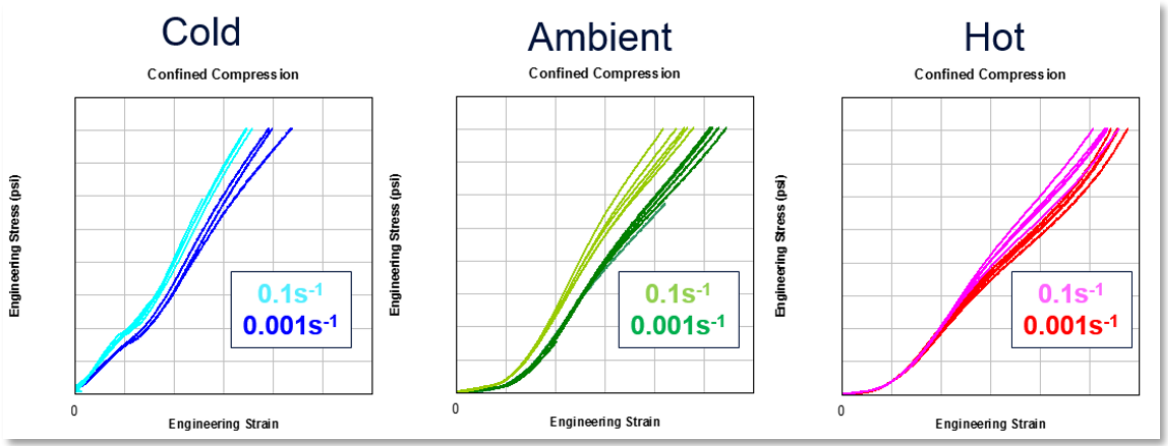
- **Clear strain rate dependence at Hot and Ambient, but not at Cold**



Confined Compression

- **Confined compression results are repeatable**
  - **Binder response is heavily influenced by temperature**

Confined Compression Fixture

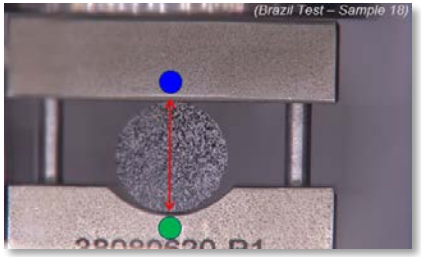


Brazil Tests

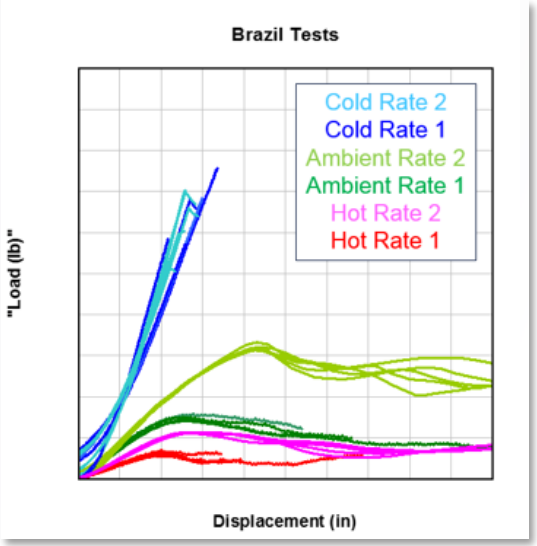
- **Splitting tensile strength calculated from ASTM D3967**

$$\sigma_t = \frac{1.272P}{\pi LD}$$

- **Splitting tensile strengths very repeatable at hot and ambient, more variability at cold**

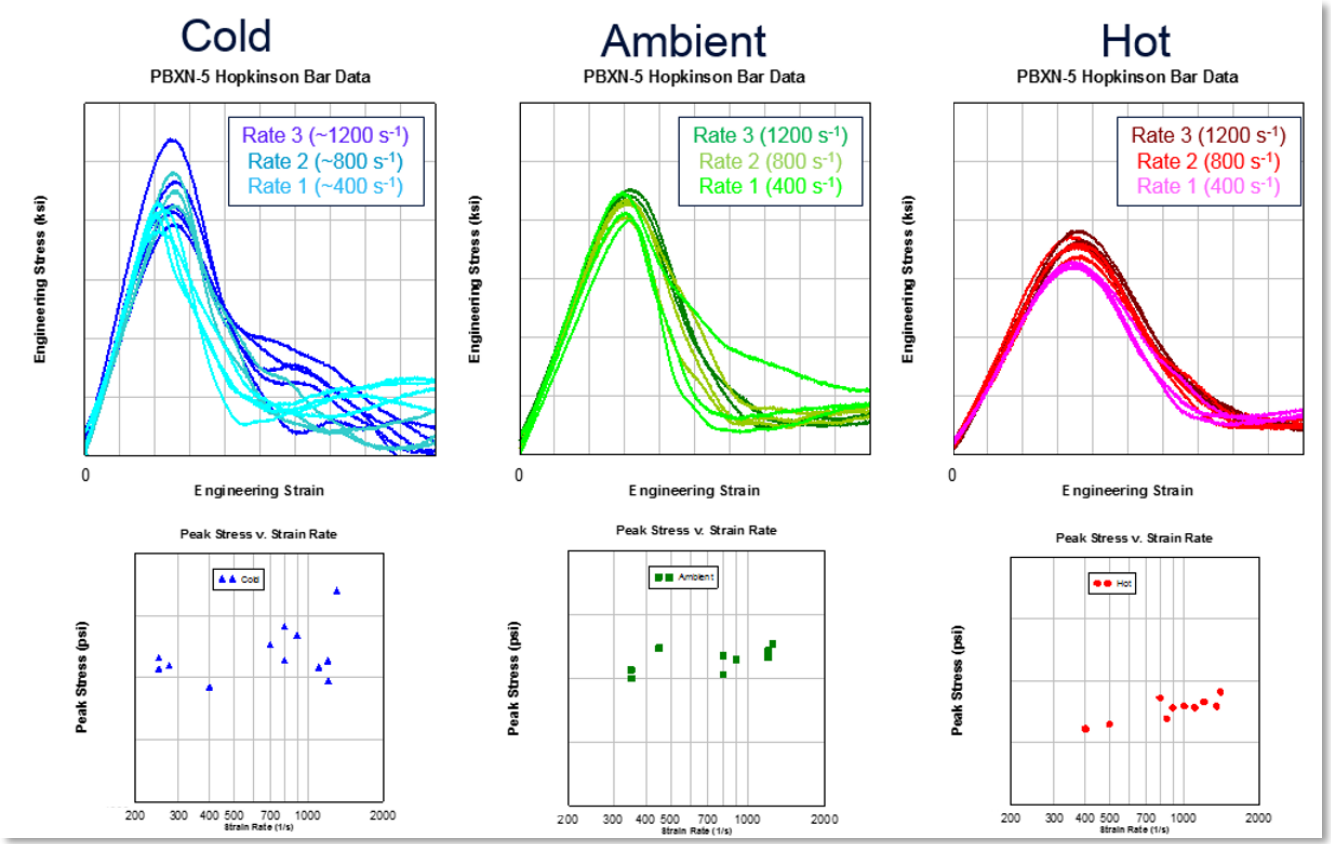


Brazil (Indirect Tension) Test



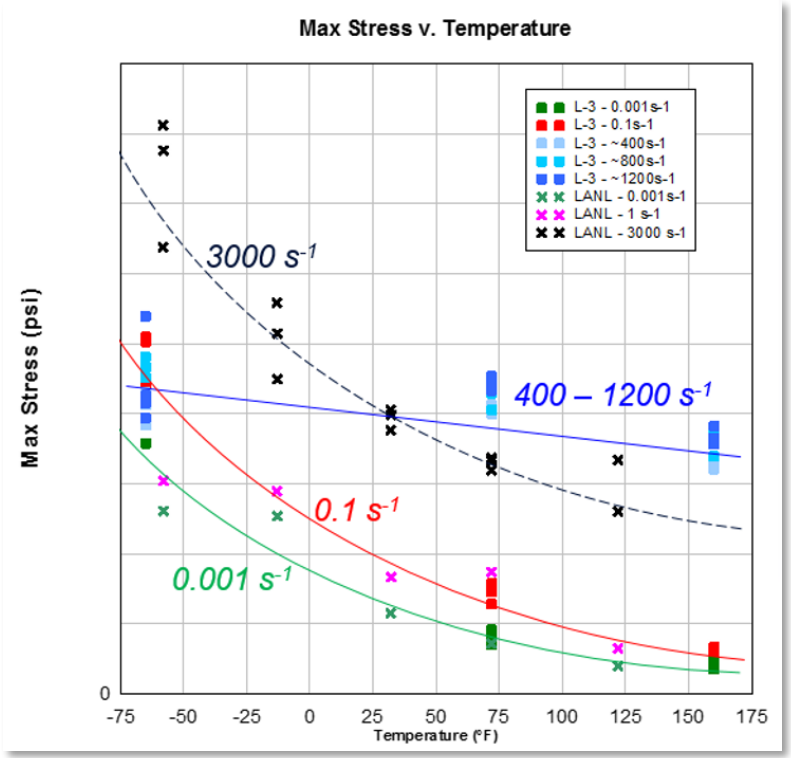
Hopkinson Bar

- **Clear temperature dependence**



Comparison to Literature

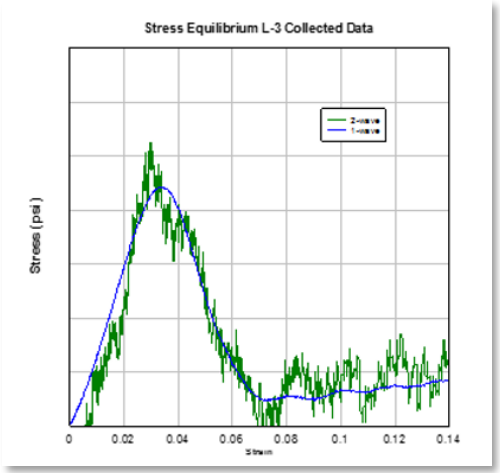
- Low rate data collected during the DOTC effort matches the low rate data collected by LANL*
- LANL temperature dependence seems to match the temperature dependence at lower strain rates
  - Magnitudes of the peak values may be suspect
- L3/ARA high rate data does not show the same temperature dependency at cold temperature
  - ARA estimated LANL peak data based on Rae*
  - (1-wave stress)

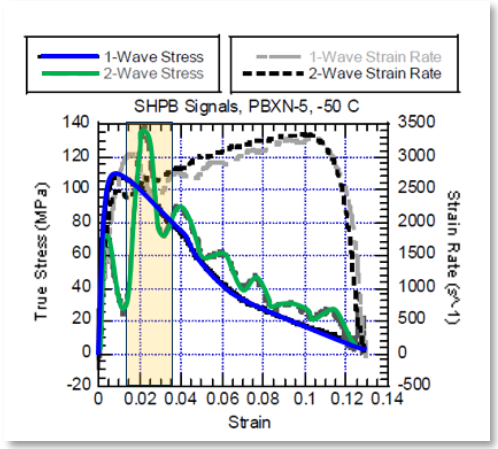


*Rae, P.J. "Compression Studies of PBXN-5 and Comp B as a function of strain-rate and temperature"
*Brown, G.W., Tencate, J.A., DeLuca, R., Rae, P.J., and Todd, S.N., "Dynamic and Quasi-static Measurements of PBXN-5 and Comp-B Explosives", Proceedings of the SEM Annual Conference, June 1-4 2009, Albuquerque, NM

Stress Equilibrium

- **Achieving stress equilibrium during testing of brittle materials becomes harder as the strain rates increase**
  - **During the DOTC testing effort, the ARA/ L3 team struggled to achieve stress equilibrium prior to failure at rates above 1200 s^{-1}**
- **Previously published LANL data was collected data at 3,000 s^{-1}**
  - **Did not reach stress equilibrium prior to sample failure**
  - **LANL indicated that data was valid between 1.5% and 3.5 % which is after the peak stress is reached**
  - **Peak stress values that were previously published may be questionable**



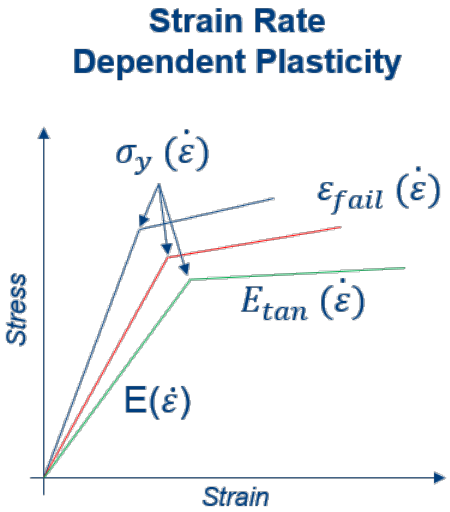


Testing Summary

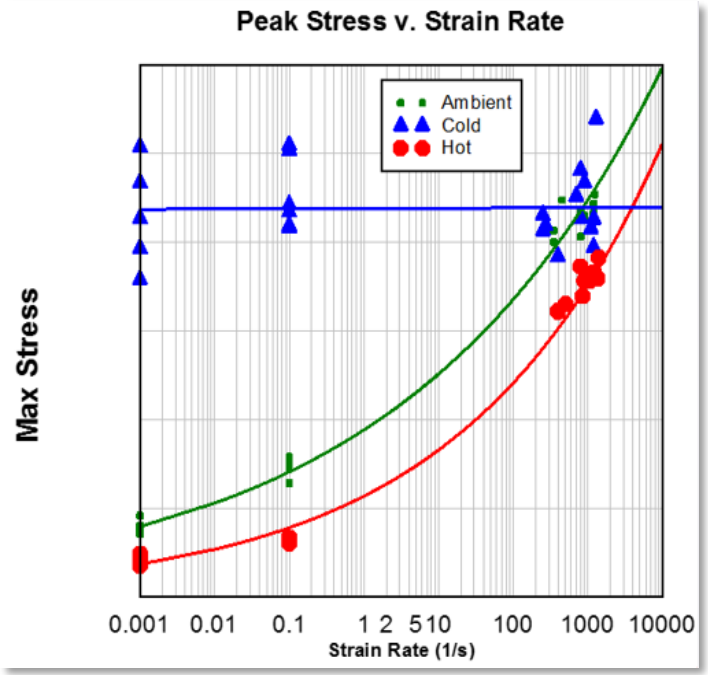
- Compression tests were conducted for 3 different temperatures (-65°F, 72°F, 160°F) over strain rates from 0.001 s^{-1} to 1200 s^{-1}
  - Low strain rate results compare well with literature
  - Less temperature dependency at high strain rate than previous results
- First known confined compression and tensile data

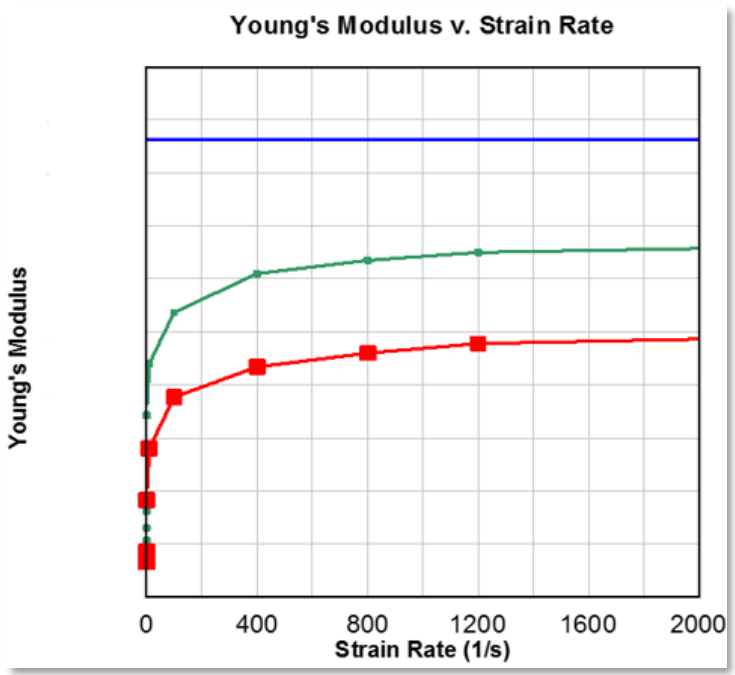
Constitutive Model Selection

- Strain Rate Dependent Plasticity Model selected
  - LS-DYNA *MAT_019
  - 1 model produced for each temperature
  - Allows rate dependent control of Elastic Modulus, Yield Stress, Tangent (Hardening) Modulus, Failure Stress
- Models capture the measured strain rate dependency of PBXN-5 elastic behavior ***prior to failure*** well
  - Simplicity makes it very stable
  - Linear (strain rate dependent) bulk modulus
  - Post-failure response not captured explicitly
  - No failure is explicitly modeled, but can be added
  - Model formulation is symmetric (same in tension / compression), does not capture the difference in elongation to failure in tension v. compression
  - Failure is best analyzed post-simulation with engineering judgement
- Model behaves well in checkout simulations
  - Responds as expected, stable in all configurations



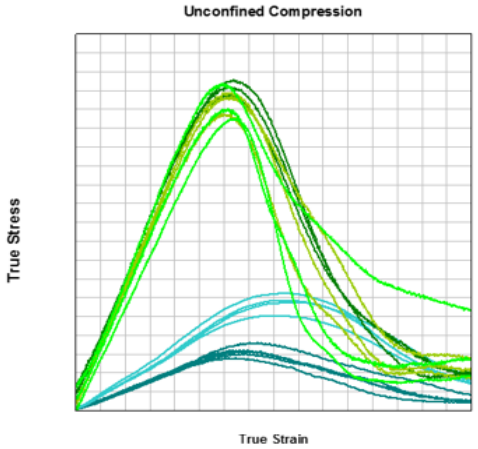
Observed Strain Rate Dependence

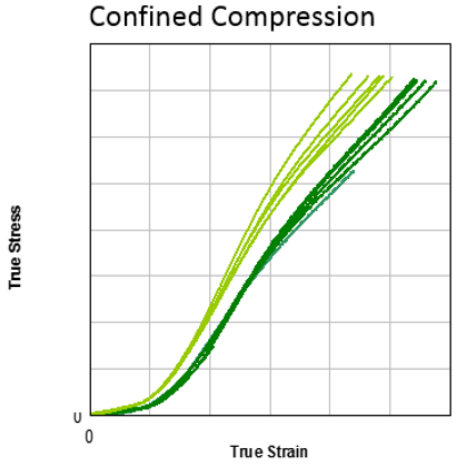




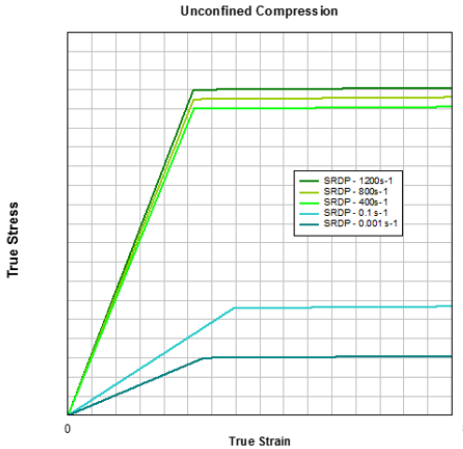
Ambient Model

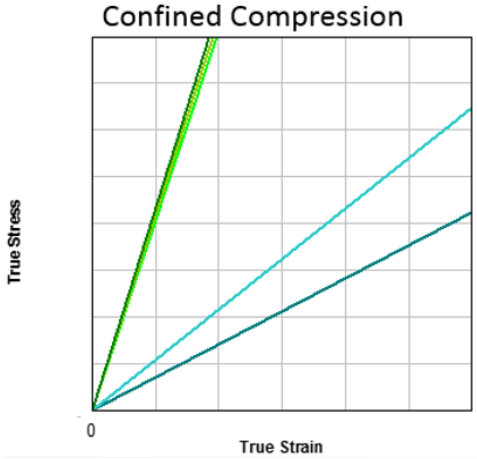
Test Data





Model Response



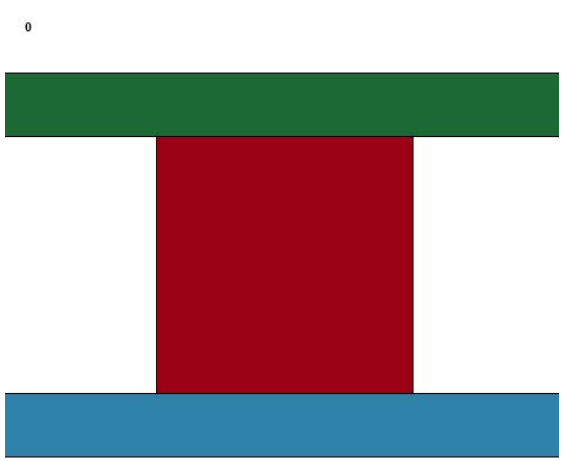


- **Strain Rate Dependent Plasticity Model captures the unconfined compression response prior to failure well.**

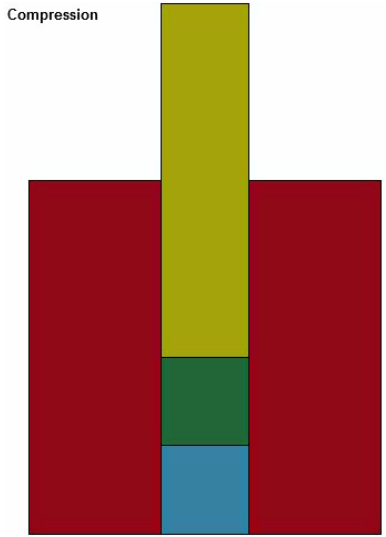
- **SRDP model bulk modulus varies**
- **At high rates it is consistent with the observed solids loading**
- **At low rates, it is consistent with the binder loading portion**

Strain Rate Dependent Plasticity Model

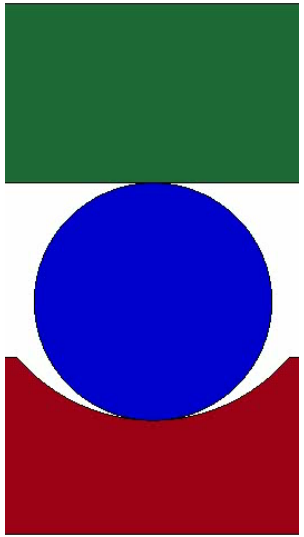
Unconfined Compression



Confined Compression



Brazilian

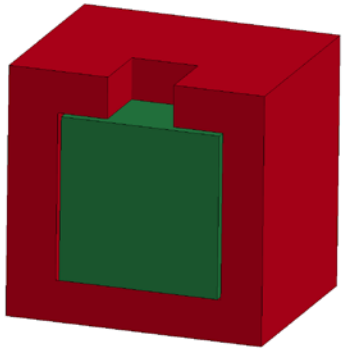


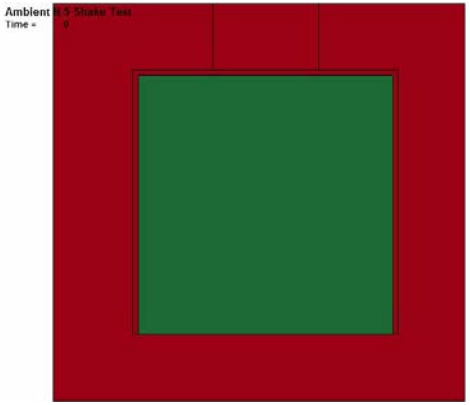
- **Tests modeled to verify behavior**
- **Model response is stable and stress strain response is as expected**
  - **Actual effective strain rate of each element varies over time resulting in some oscillation in the data at the higher rates**

Strain Rate Dependent Plasticity Model

- **To ensure that the model is stable for penetration environments, a shake test was performed with model for a realistic fuze environment**
  - **PBXN-5 Block with 0.010” gaps around the edges to allow the block to move during the simulation**
  - **Hole represents an unsupported region (i.e. firetrain)**
  - **Outer housing driven with velocity from simulation of a penetration environment**

SRDP model remains stable, good for use in penetration environments





Summary

- Suite of material data collected in house at L3 on PBXN-5 has been used to understand the strain rate dependent nature of the material and build material models
- Strain rate dependent plasticity model selected for its ability to capture the strain rate dependency of the material prior to failure
  - Model purpose is to assess risk of material failure and not to capture the response post-failure
  - Models capture the measured strain rate dependency of PBXN-5 prior to failure well
  - Simplicity makes it easy to analyze and stable in penetration environments
  - Constitutive models have been fit for 3 temperatures
  - Failure is best evaluated post-simulation
  - Models are producing results as expected

Acknowledgements

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- The authors are grateful for the support of Triet Dao, Marc Worthington and Perry Salyers of L3 DES and Frank Marso of ARA.

Abstract

- **PBXN-5 Mechanical Characterization and Proposed Constitutive Model**
  - **PBXN-5 samples have been mechanically characterized at 3 different temperatures (-65°F, 72°F, 160°F) over strain rates from 0.001 s^{-1} to 1200 s^{-1}. Quasi-static testing included unconfined compression, confined compression, and brazil tests. High rate testing was performed in an unconfined compression configuration with a Split Hopkinson Pressure Bar. The data collected in the unconfined compression testing agrees well with other quasi-static data collected by previous authors. To the author's knowledge, the confined compression and Brazilian test data is the first of its kind for PBXN-5.**
  - **The data collected under this effort was used to fit a constitutive model proposed for use in the design of hard target penetrating fuzes. The proposed model fit will be discussed and the results will be compared with the collected data.**