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ARDEC Small Caliber Barrel S&T Efforts

Presented by:
Mr. Adam L. Foltz, P.E.
US ARMY ARDEC

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U.S. ARMY ARMAMENT
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ARDEC Small Caliber Barrel S&T Efforts:

#20142 - Thermal Isolation/Barriers for Small Caliber Weapon Applications

#20143 - Development of Material Characterization Methods for Next Gen. Weapon Barrel Requirements

#20144 - Dynamic Physical Simulation of Small Caliber Barrel Steel at Elevated Temperatures

Thermal Isolation/Barriers for Small Caliber Weapon Applications (#20142)

Mr. Adam L. Foltz, P.E.
US ARMY ARDEC
RDAR-WSW-F, B2

Dr. Laurie A. Florio
US ARMY ARDEC
RDAR-WSW-F, B8

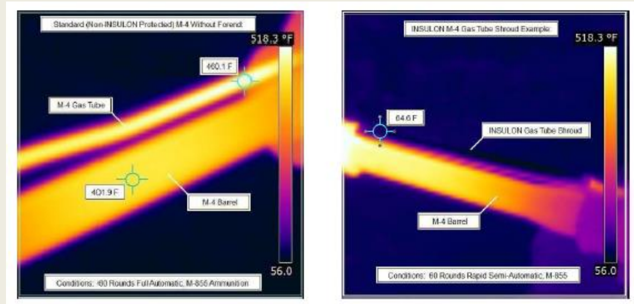
Mr. Adam M. Jacob
US ARMY ARDEC
RDAR-WSW-F, B2

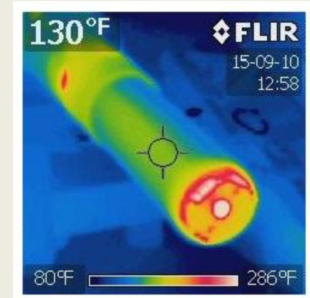
U.S. ARMY RDECOM

BACKGROUND

ARDEC

Aggressive firing rates result in extreme high temperatures in barrels and suppressors





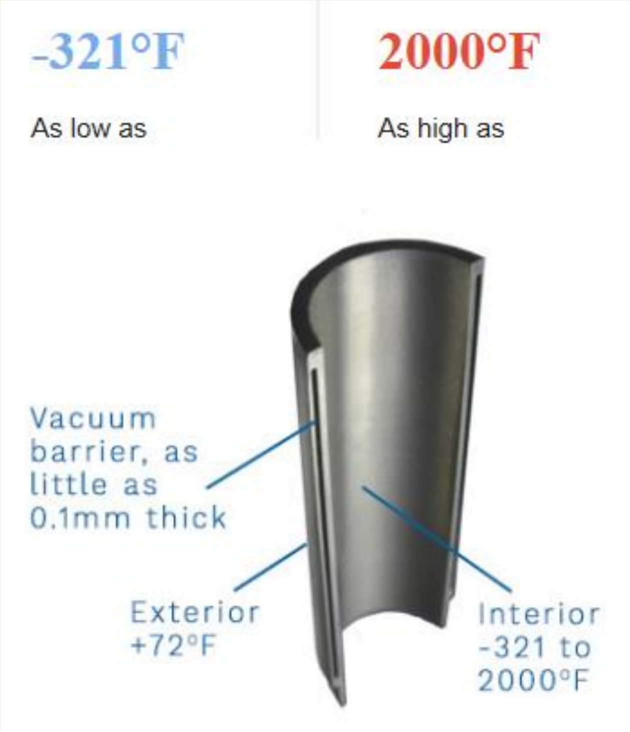
Why it matters:

http://www.flir.com/flirone/ $199

http://www.flir.com/suas/vue/ $650

Main Area of Interest:

- Vacuum insulation concepts

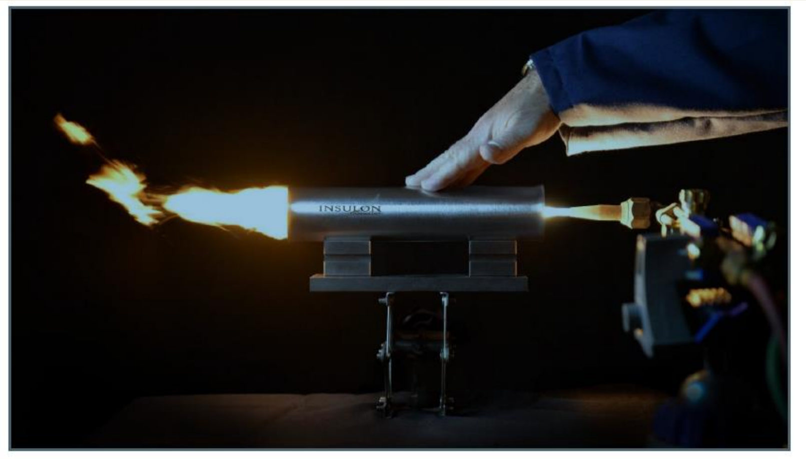


Conduction of 0.1mm Insulon:

40X more fiberglass

20X more expanded polystyrene

25X larger air gap



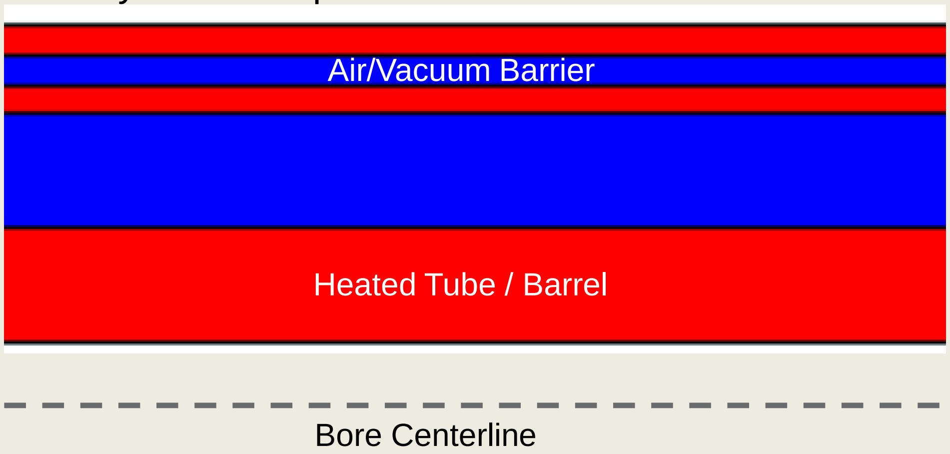
https://conceptgroupinc.com/

Technical Approach

- Modeling and Simulation

Model Setup

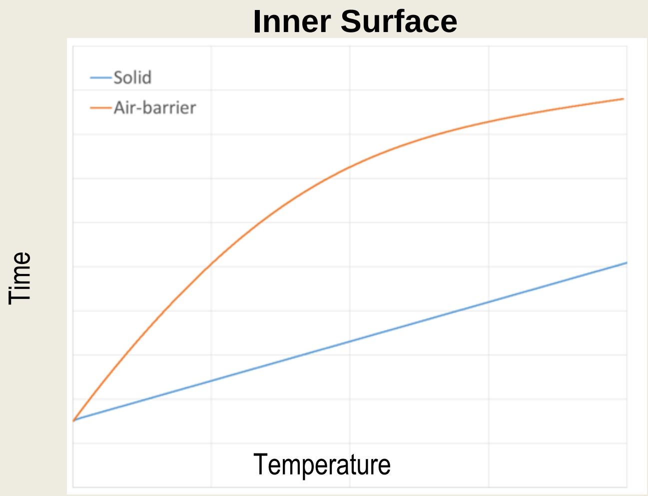
Axisymmetric representation

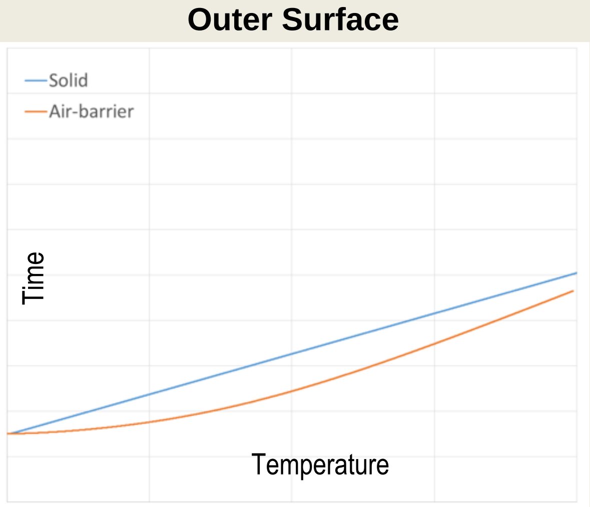


Study 1 - Constant heat flux, solid tube vs. air gap
Study 2 - Constant heat flux, emissivity influence
Study 3 - Constant heat flux, air gap vs. vacuum
Study 4 - Conditions for varied outer surface tube boundary conditions
Study 5 - Constant heat flux, forced cooling fluid between barrier/solid
Study 6 - Complex heat load to replicate live fire

Study 1 (constant heat flux, solid tube vs. air gap)

- Air gap decreases or delays the heat flow





- ➢ Inner surface of air gap layer rises faster than all solid barrel at the same radial position.
- ➢ Reduced heat flow across air barrier

- ➢ Temperature rise at outer surface delayed by air gap layer compared too all solid barrel

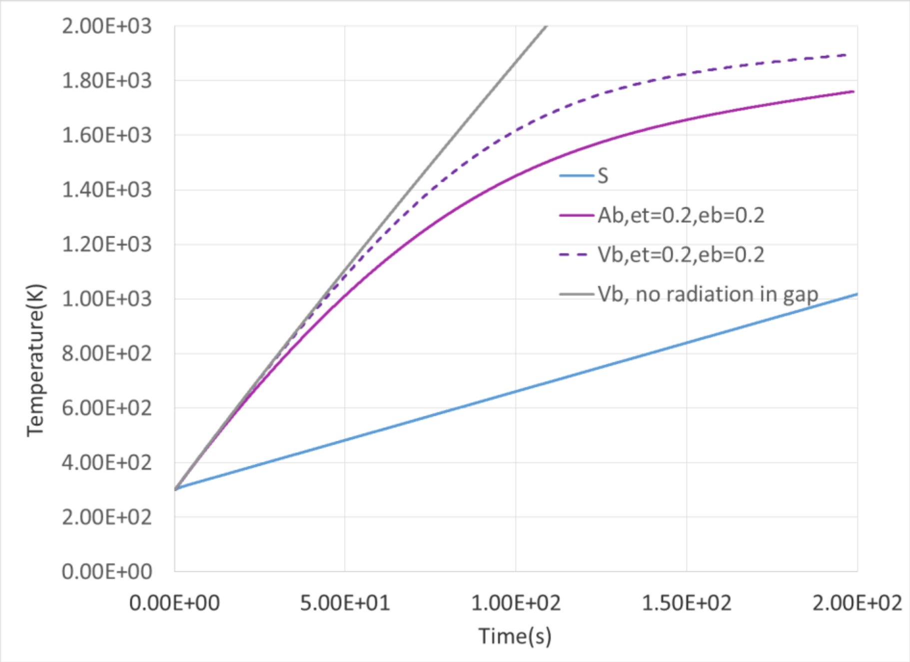
Study 2 (constant heat flux, emissivity influence)

- Emissivity – effectiveness in emitting energy as thermal radiation
- Lower reflectivity/higher emissivity results in a less effective barrier

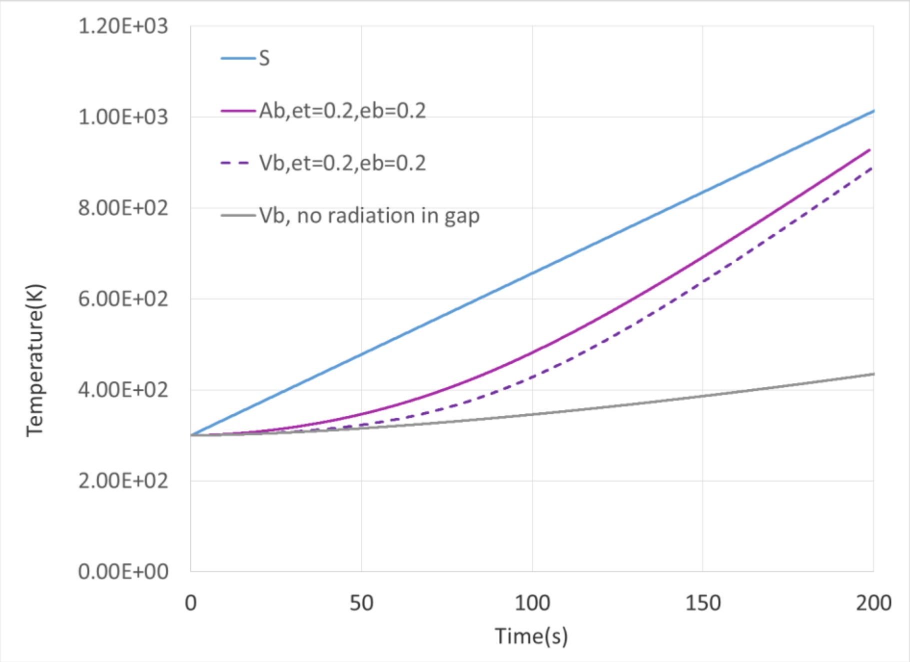
Study 3 (constant heat flux, air gap vs. vacuum)

- Vacuum barrier more effective than air gap, but higher interior temps reached (conservation of energy)

Inner Barrier Surface



Outer Barrier Surface

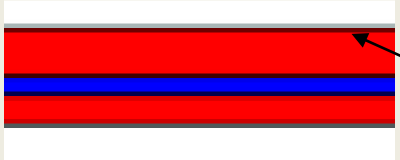


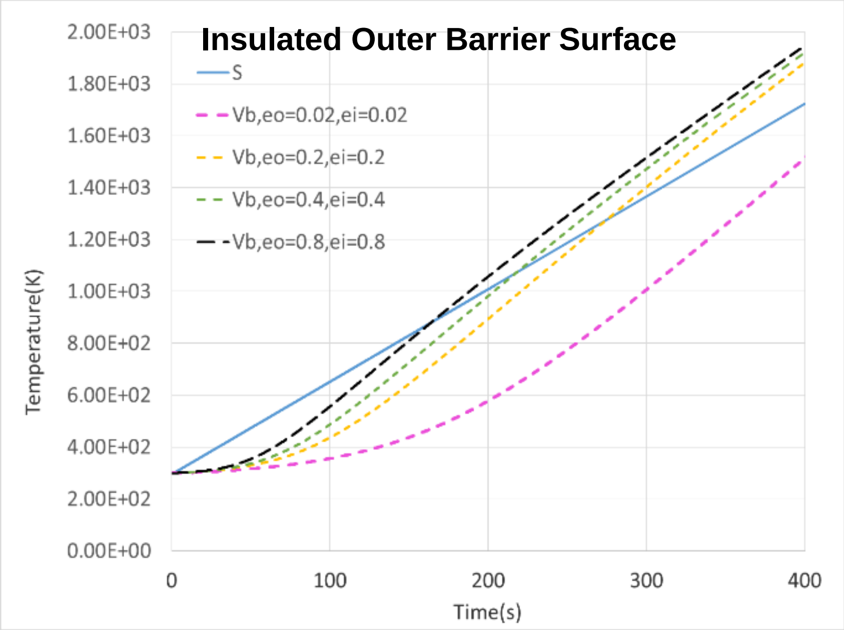
- ➢ Higher inner surface temperatures for vacuum barrier vs. air gap (resisting heat flow)
- ➢ No radiation represents upper bound of barrier performance

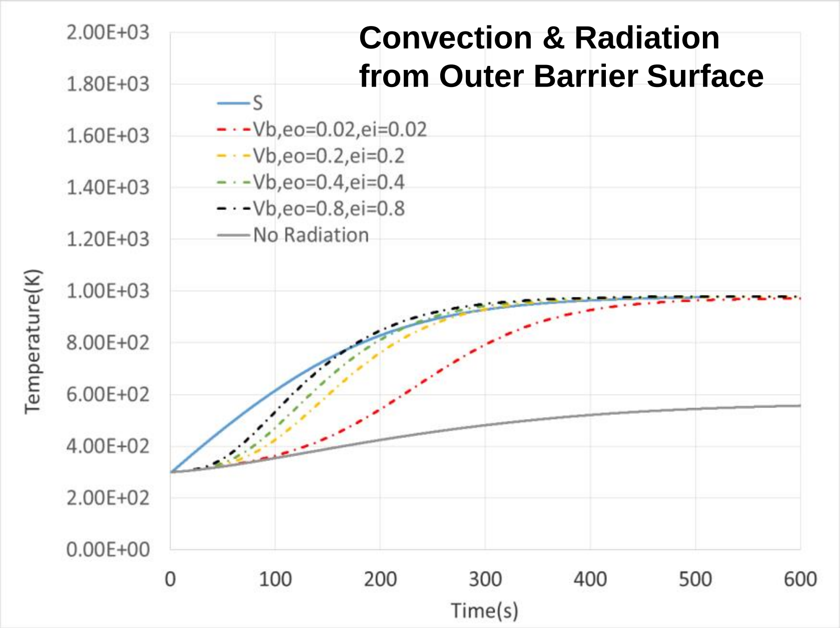
- ➢ Rate of increase in temperature for vacuum barrier eventually surpasses solid tube case (radiation)

Study 4 (varied outer surface tube boundary conditions)

- Insulated vs. convection/radiation





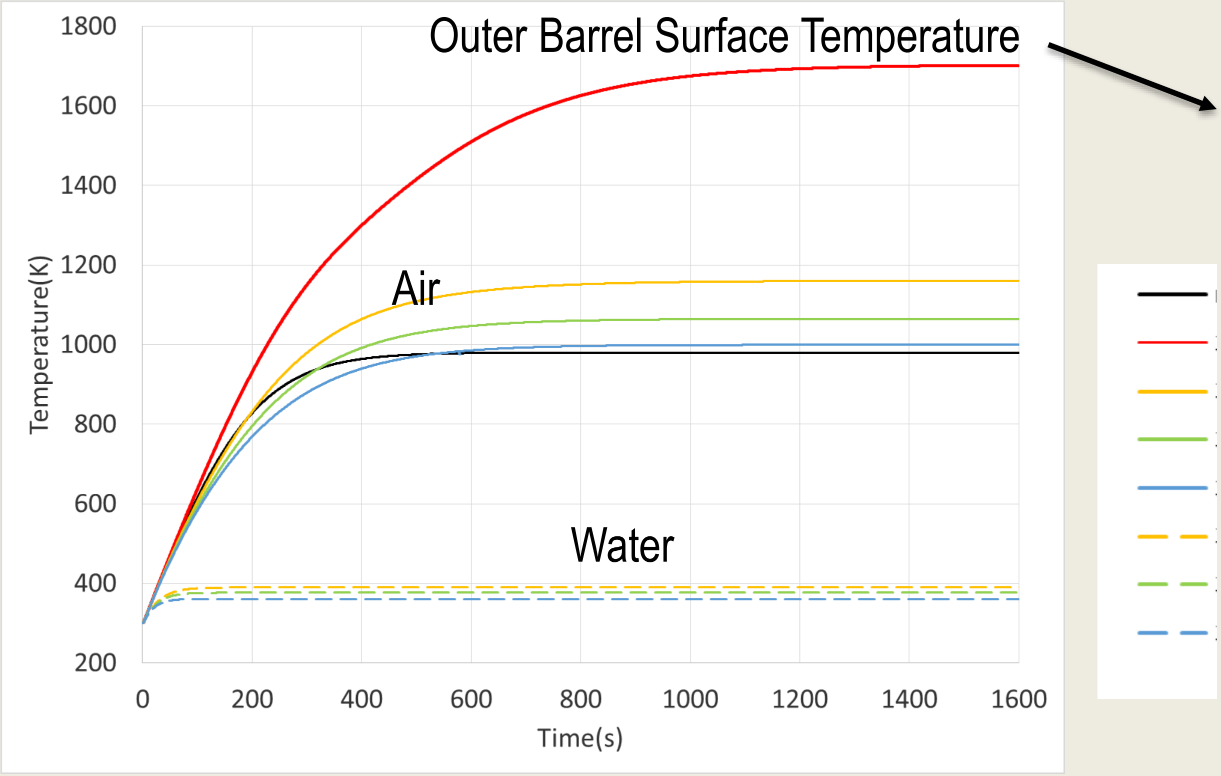


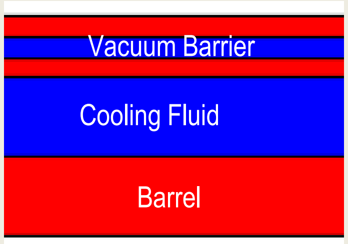
Outer boundary conditions studied represent likely extremes for heat removal

- Insulated – no heat flow, temperatures continue to rise
  - Negligible barrier benefits with long duration high heat load
- Convection/Radiation – sufficient heat removal, steady state temperatures do not vary significantly

Study 5 (constant heat flux, cooling fluid between barrier/solid)

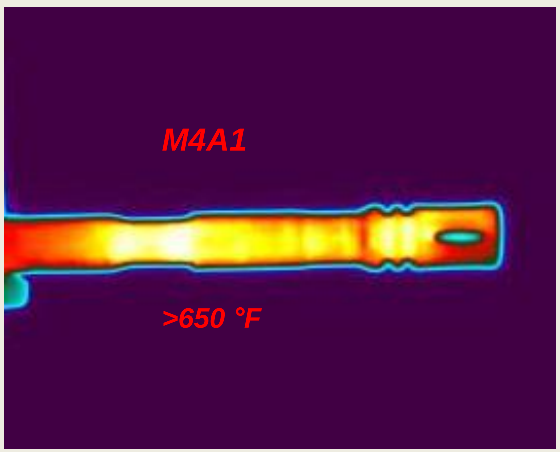
- Insufficient flow velocities/spacing increases heating
- Water more effective than air (4x heat capacity)

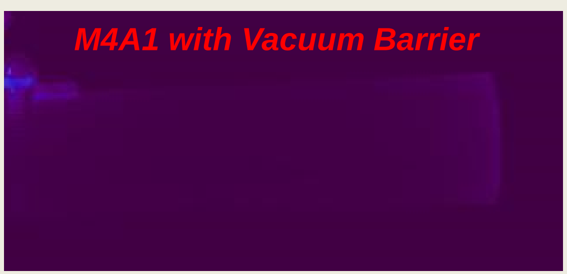


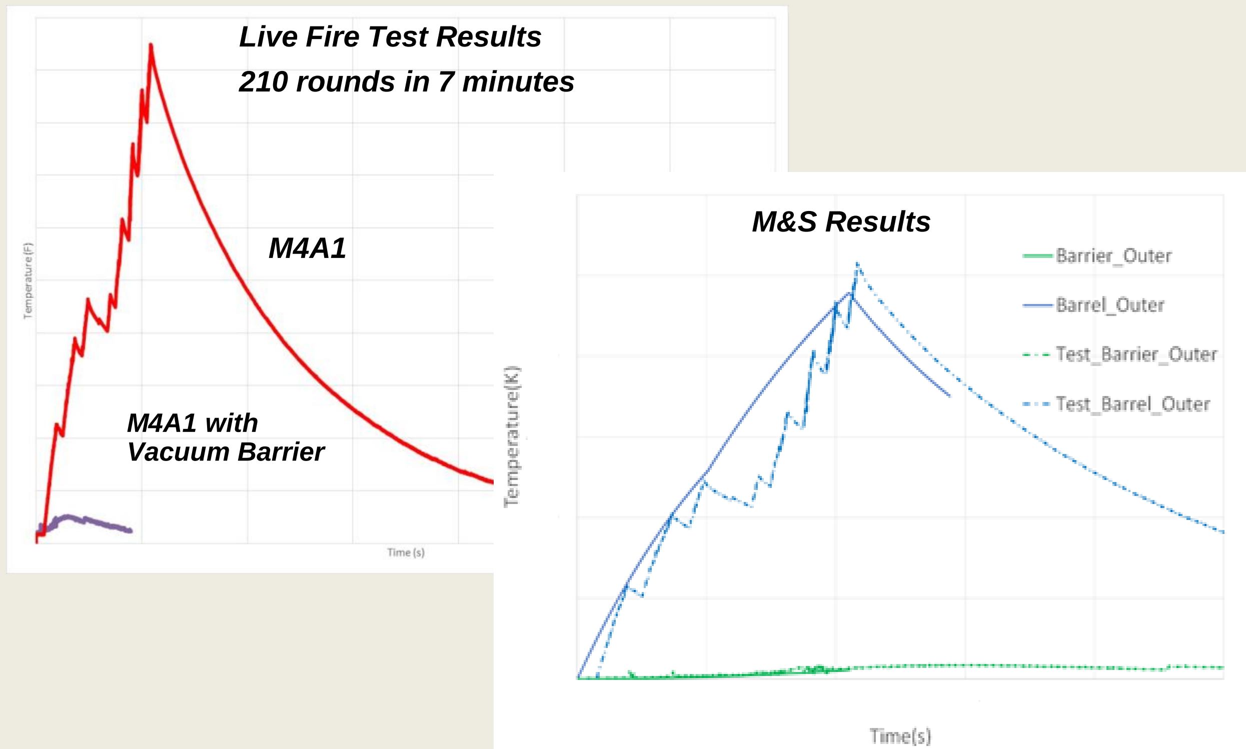


Study 6 (complex heat load, replicate live fire)

- Modeling results provide reasonable estimation of the thermal conditions that develop
  - * Good correlation between standard barrel test results and model results
  - * Good correlation between barrier test results and model results







Future Work

Possible Future Work:

- Additional live fire testing and model validation
- Active cooling optimization studies
  - Fluid type (Air / Water)
  - Flow velocity / flow spacing
  - Heat pipe concept

Results and tools developed can be directly applied toward supporting the development of next generation weapon system requirements

Development of Material Characterization Methods for Next Gen. Weapon Barrel Requirements (#20143)

Mr. Adam L. Foltz, P.E.
US ARMY ARDEC
RDAR-WSW-F, B2

Mr. Stephen B. Smith
US ARMY ARDEC
Benét Laboratories

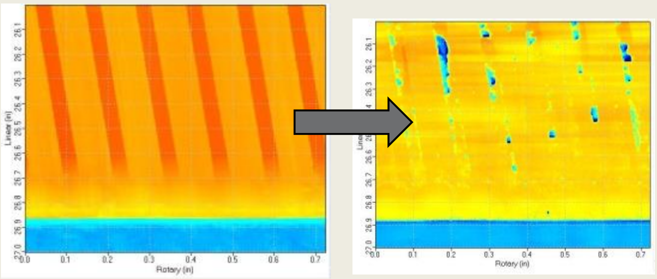
Background:

- Science and Technology (S&T) needs are repeatedly identified in the areas of increased barrel performance, including Improved Weapon Accuracy, Reduced Barrel Erosion, High Performance Alloys, Increased Barrel Life, Chrome Replacement Technologies

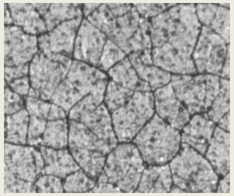
- Requirements generally related to:
  1) Mechanical strength at elevated temperatures
  2) Resistance to abrasive and adhesive wear
  3) Structural stability under thermal and chemical attack

- Vented Fixture Testing
  - Does not predict gun tube life, but does offer a low cost method for comparing the high-temperature, thermochemical erosion performance of the materials/coatings
  - To date, vented fixture testing has not been studied for small caliber barrel applications

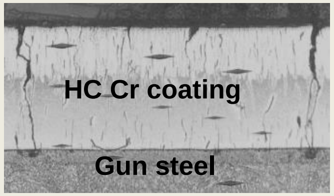
Laser Bore Mapping:



Thermal shock cracking

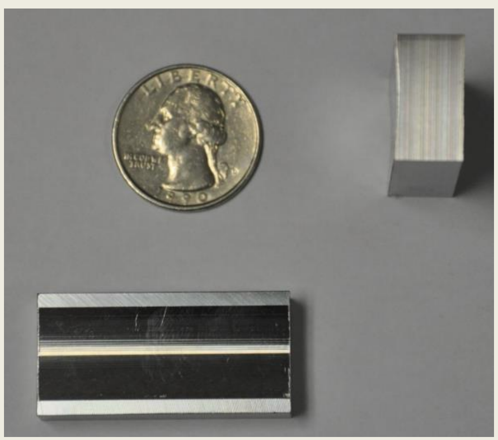


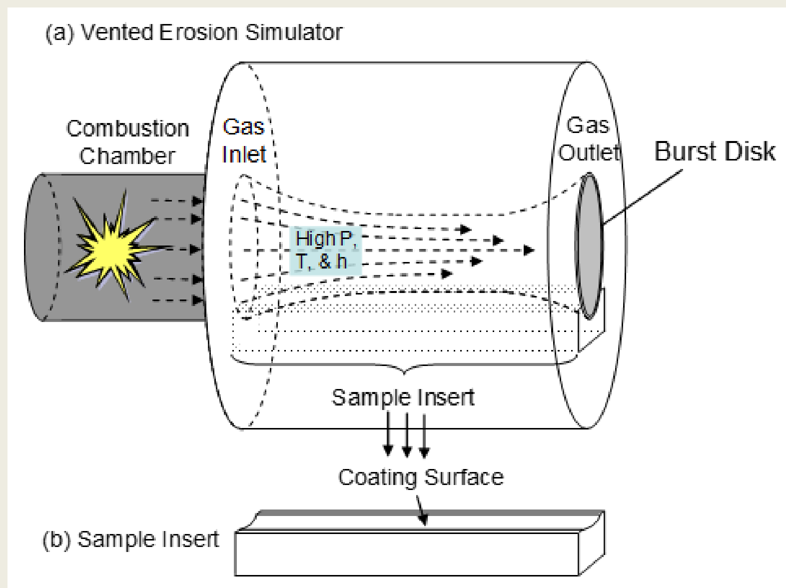
Thermo-chemical attack

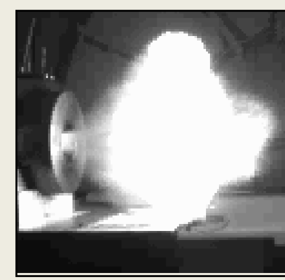


Purpose:

- Develop standardized protocols and bench scale testing procedures using a Vented Erosion Simulator (VES) to analyze barrel materials for increased barrel life
  - Develop fundamental understanding of chemical, thermal, mechanical erosion in small and medium caliber gun barrels
  - Identify and define critical material property characteristics directly associated with barrel performance
  - Investigate new steel alloys and help define the metrics and ROI necessary to justify material changes



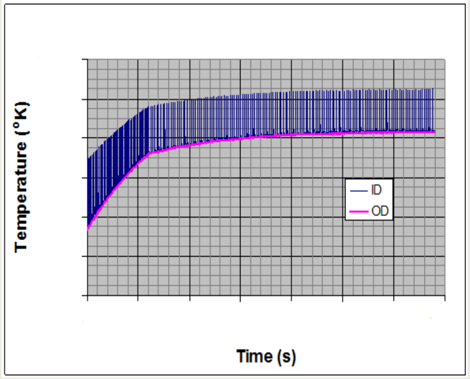




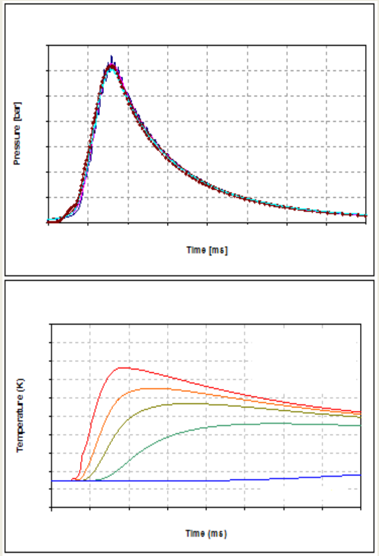
VES Process:

- Fast and cost effective screening tool
- Match thermo-mechanical and thermo-chemical barrel environment
- Modular design allows for customization of propellant load/type, burst disk, thickness/material, muzzle/sample design, etc.
- Removable sections of prototype bore materials and coatings are fitted to a converging/diverging nozzle

1. Weapon Model / Experimental Data

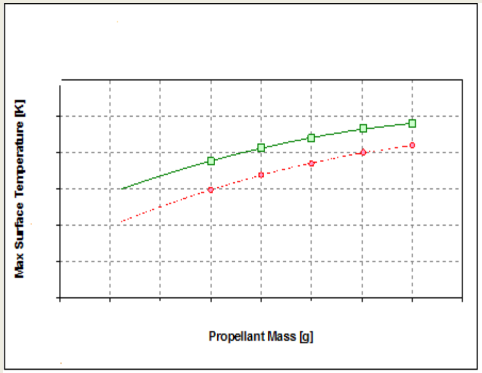


2. VES Model

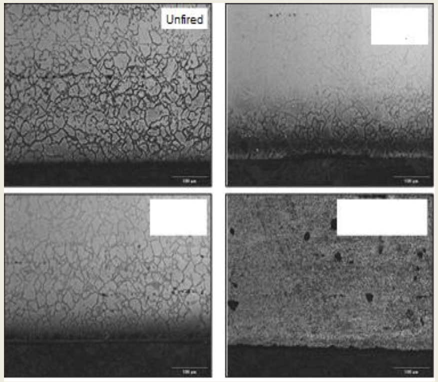


Modeling used to ensure VES can match barrel environment: load and location for pressure and temperature

3. VES Testing

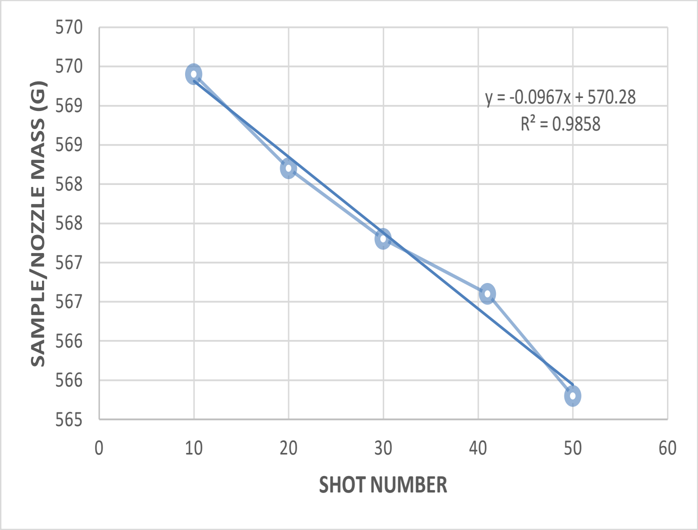


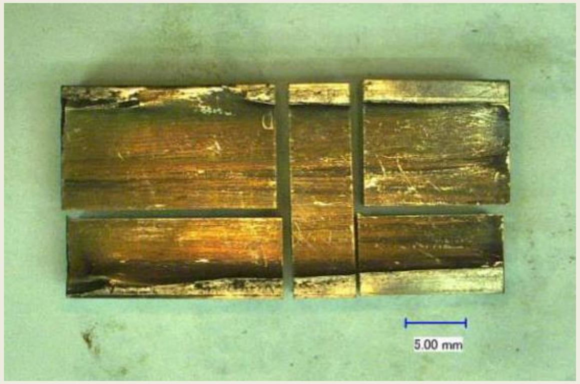
4. Material Characterization



VES Process:

- Setup validation completed one 2 samples (5 shots / 50 shots)
  - Linear regression analysis (ability to fire less shots)
  - Metallographic analysis post test



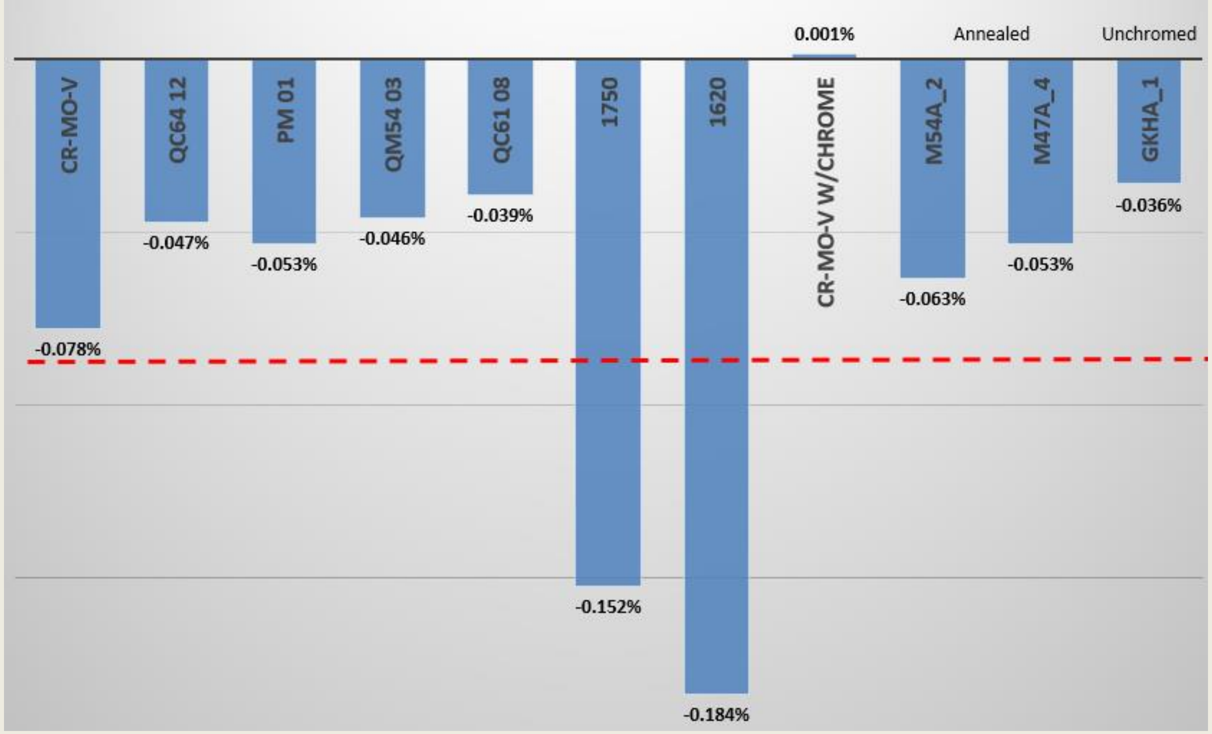


Analysis:
Micro-hardness analysis
Photographed with the light-optical microscope (LOM)
Energy dispersive spectroscopy (EDS) chemistry analysis
X-ray fluorescence (XRF) analysis

Results:

**Preliminary VES trials of selected candidate materials show improvements in material response compared to standard small caliber barrel material (Cr-Mo-V)*

Sample	Shots	Change in Mass per Shot (g)	Change in Mass per Shot (%)
Cr-Mo-V	***5***	***-0.04484***	***-0.078%***
QC64 12	5	-0.02774	-0.047%
PM 01	5	-0.0306	-0.053%
QM54 03	5	-0.02714	-0.046%
QC61 08	5	-0.0232	-0.039%
L605 1750F	5	-0.1041	-0.152%
L605 1620F	5	-0.12588	-0.184%
Cr-Mo-V *(Chromed)*	***5***	***0.0043***	***0.00086***
M54	5	-0.1888	-0.03776
M47	5	-0.1552	-0.03104
GKH	5	-0.1045	-0.0209



Additional planned materials to evaluate:

- GKH 33 CRMOV 12-10 (chromed)
- M47 (heat treated)
- M54 (heat treated)
- GKH ARMAD

Dynamic Physical Simulation of Small Caliber Barrel Steel at Elevated Temperatures (#20144)

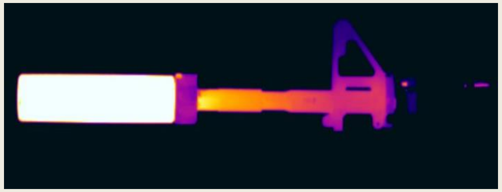
Mr. Adam L. Foltz, P.E.
US ARMY ARDEC
RDAR-WSW-F, B2

Mr. Stephen F. Bartolucci, Ph.D.
US ARMY ARDEC
Benét Laboratories

Background:

- Dynamic material responses due to impulse loading can vary greatly from static responses when considering the stresses induced by pressurization and thermal loading

- For numerous small caliber barrel applications a paradox exists relative to the strength and stress of the tube based on the extremely high temperatures experienced from repeated firing.
    - Barrels and suppressors can reach temperatures above 1500°F, where static yield strengths of the steel tubes can drop far below the allowable equivalent stress, yet catastrophic failure does not occur, demonstrating the variation in dynamic vs. static material response.



    - Gun tube thermal management is essential in determining the effects of rapid fire scenarios on the physical and mechanical properties.
        - Short breaks in the firing cadence can reduce the peak temperatures on the barrel internal bore surface, but the bulk temperature of the barrel is relatively unaffected.

- Limited data exists with very specific correlations to relevant environments for small caliber weapon applications

Approach:

- Conducted experimental research was conducted on small caliber barrel steel using both steady state test methods and physical simulation dynamic test methods in order to characterize mechanical strengths at varying strain rates to determine thermal impacts associated with aggressive firing scenarios of small caliber gun barrel applications

Gleeble System:

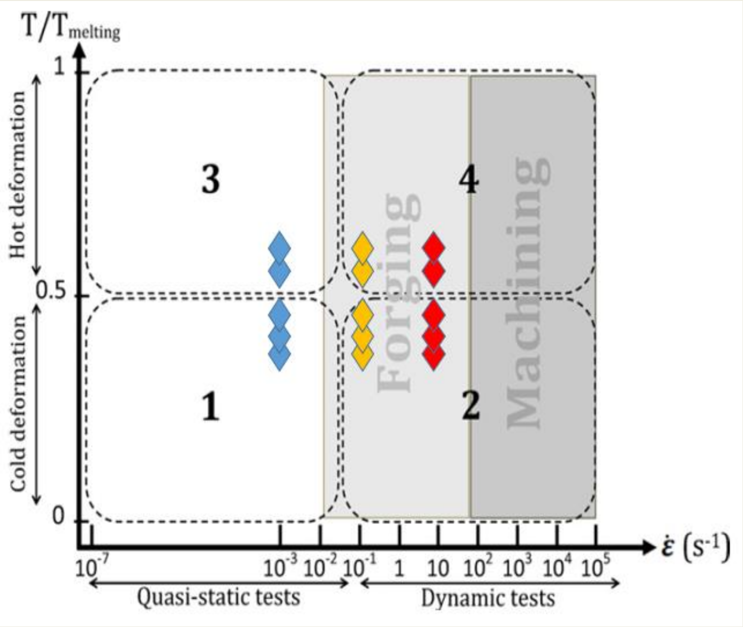
- Gleeble® system (advanced thermal-mechanical testing)
    - Provides precise control of the energy input to create the physical simulation necessary to replicate the small caliber gun barrel environment.

    - Heating rates of 10,000°C per second, stroke rates exceeding 1,000 mm per second and 22,000 lbs. of tension and compression force (Gleeble® 3500)

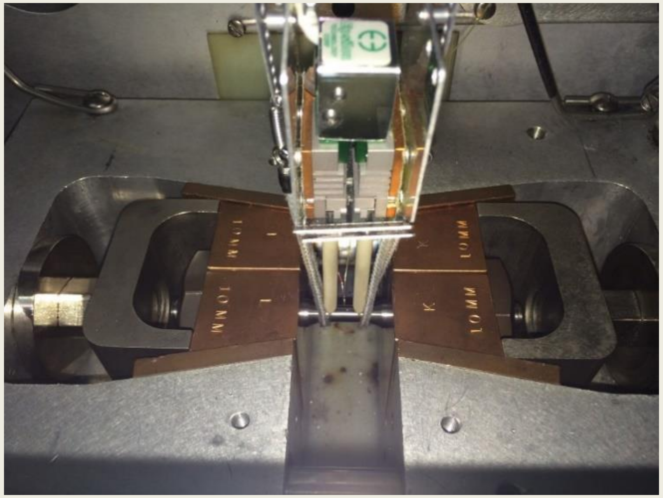
Gleeble system

Test Matrix:

- 30 minute temperature soak (static)
- 10 minute temperature soak (static)
- Non-linear heating (based on experimental live fire data)
  - Strain rates: $0.001 s^{-1}$ (quasi-static) and $0.1\ s^{-1}$(dynamic)
- Linear heating
  - Strain rates: $0.001 s^{-1}$(quasi-static), $0.1\ s^{-1}$ (dynamic) and $10 s^{-1}$(dynamic)



Quasi-static vs. Dynamic



Gleeble system

Test Results:

- Static Results (30 min soak)

Temperature (°F)	Yield (KSI)	Tensile (KSI)	% Elong
72	143	153	19
400	120	143	18
800	99	117	21
900*	81	98	
1200	28	42	55
1300	12	22	95

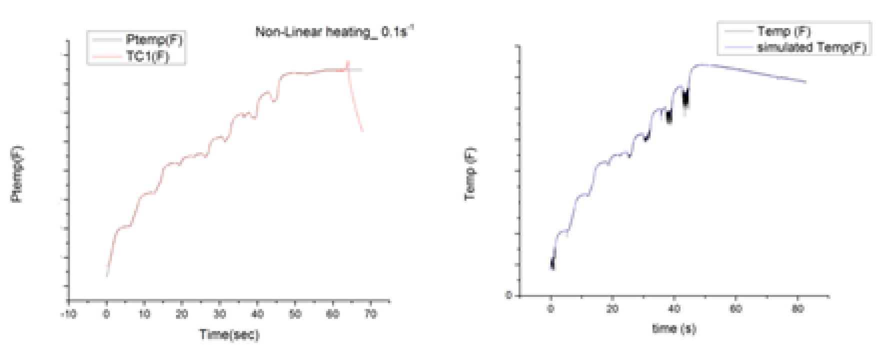
- Static Results (10 min soak)

Temperature (°F)	Yield (KSI)	Tensile (KSI)	% Elong
900	94	127	19
	98	124	21
	92	128	24
	96	125	21
Ave	95	126	21

Yield and tensile strengths as expected are only slightly higher (~10-15%) than interpolated results from the 30 minute soak at the same temperature

Test Results:

- Linear vs. Non-Linear

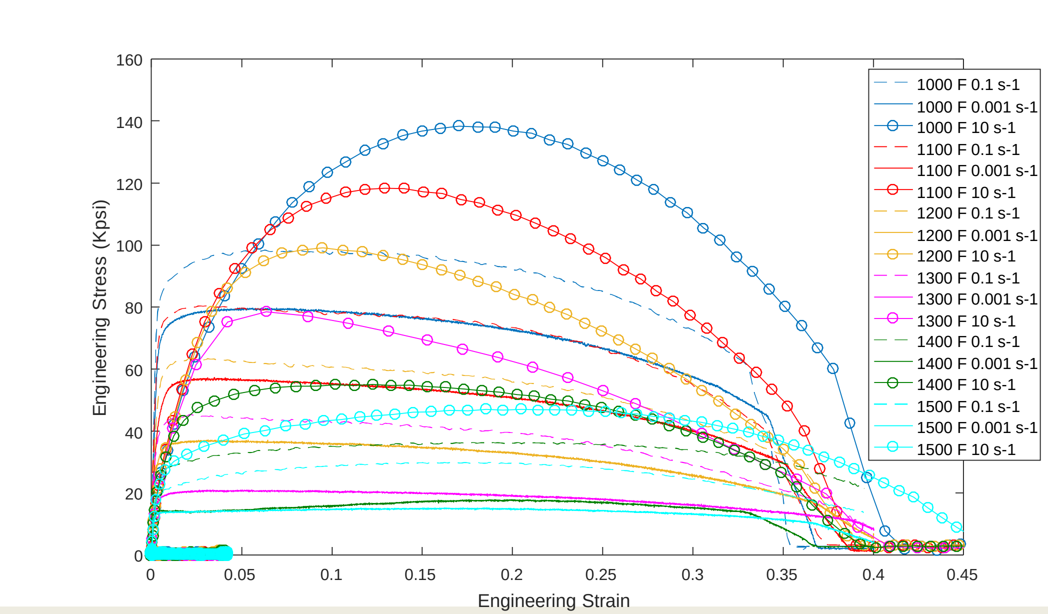


Temperature (°F)	Strain Rate (s^{-1})	Heat Rate	Yield (KSI)	Tensile (KSI)	% Elong
72	0.001	N/A	124.8	144.6	18.3
750	0.10	Non-Linear	97.0	120.4	18
	0.10	Linear (45s)	94.4	120.9	17.0
	0.001	Non-Linear	93.0	114.5	18.2
	0.001	Linear (45s)	92.9	116.1	20.1

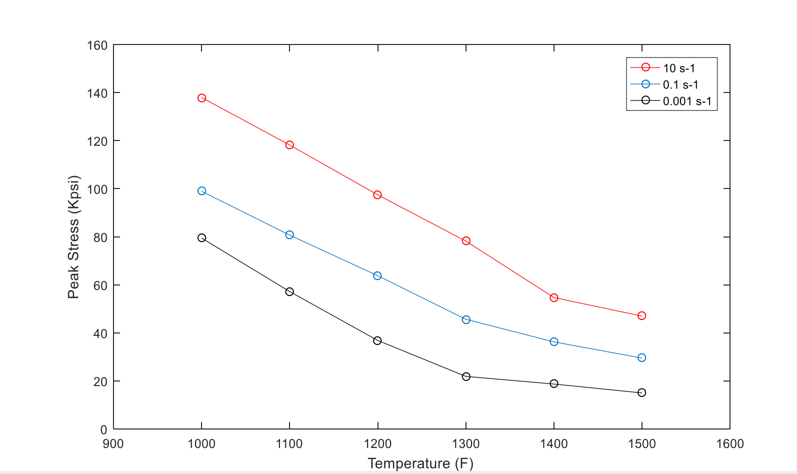
- Results show expected trends;
  - Higher strengths at room temperature
  - Higher strengths at high strain rates
  - Non-linear results nearly identical to the linear results
  - Minor differences between static and dynamic responses of the material at 750 F

Test Results:

- Dynamic
  - 0.001s^{-1}(quasi-static), 0.1 s^{-1} (dynamic), 10s^{-1}(dynamic)



Stress vs. Strain



Peak Stress vs. Temp

*Future studies planned at higher strain rates and with additional materials of interest

Point of contact:

Mr. Adam L. Foltz, P.E.
US ARMY ARDEC
RDAR-WSW-F, B2
Picatinny Arsenal, NJ 07806
Phone: 973-724-7096
Email: adam.l.foltz.civ@mail.mil