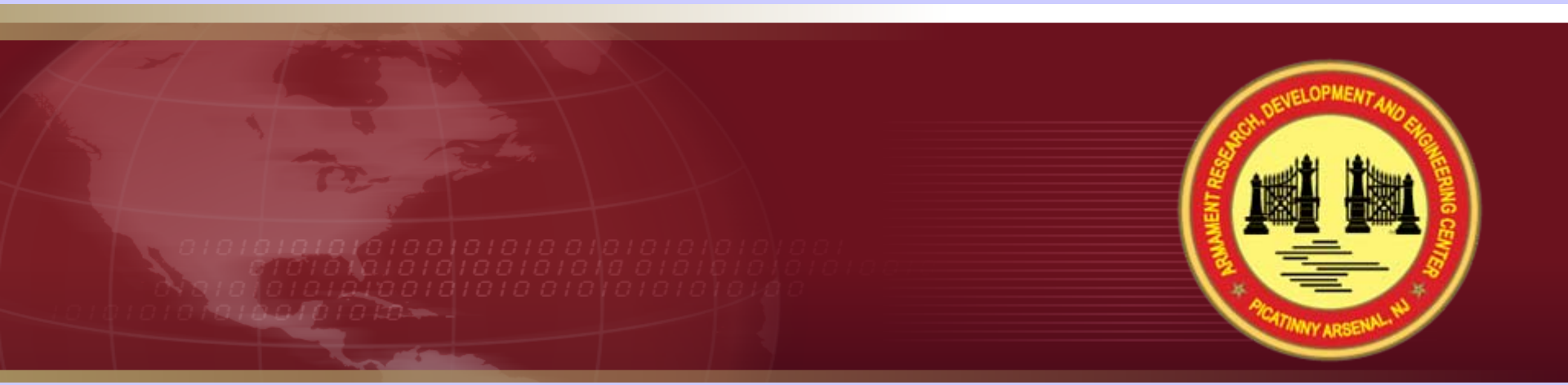


TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

ENVIRONMENTALLY FRIENDLY 'GREEN' PROPELLANT FOR THE MEDIUM CALIBER TRAINING ROUNDS

NDIA 2007 Insensitive Munitions & Energetic Materials Technology Symposium
Miami, Florida
Oct 15-18, 2007

ATK

AUTHORS

T.G. Manning, C.P. Adam and M. Ellis
U.S. Army RDECOM-ARDEC

R. Lieb, M. Leadore, J. Colburn, and B.E. Homan
US Army Research Laboratory

W.J. Worrell, K.B. Moran, and S.J. Ritchie
ATK / Alliant Ammunition and Powder Co. / Radford Army Ammunition Plant

Outline

- **Introduction**
- **Technical Objectives**
  - Program Description
  - Manufacturing Process
- **Technical Approach**
  - DOE
  - Demonstration Site
  - Characterization
  - Performance Test
- **Conclusion**
- **Future Work**

INTRODUCTION
TECHNICAL OBJECTIVES

- **Demonstrate and validate new green Legacy propellants to replace medium caliber propellants containing environmentally objectionable plasticizers, stabilizers, and oxidizers.**
  - Design and demonstrate a solventless propellant formulation that exhibits improved insensitive munitions (IM) properties as well as be environmentally friendly ("Green") both during processing and to the soldier, while maintaining or exceeding current ballistic requirements.
  - *25mm M793, LW30mm M788 TP and M910 training ammo that is:*

- *- "GREEN"*
  - *i.e.. no Di-Nitrotoluene (DNT), Barium Nitrate ($BaNO_3$), Di-butyl phathalate (DBP)*

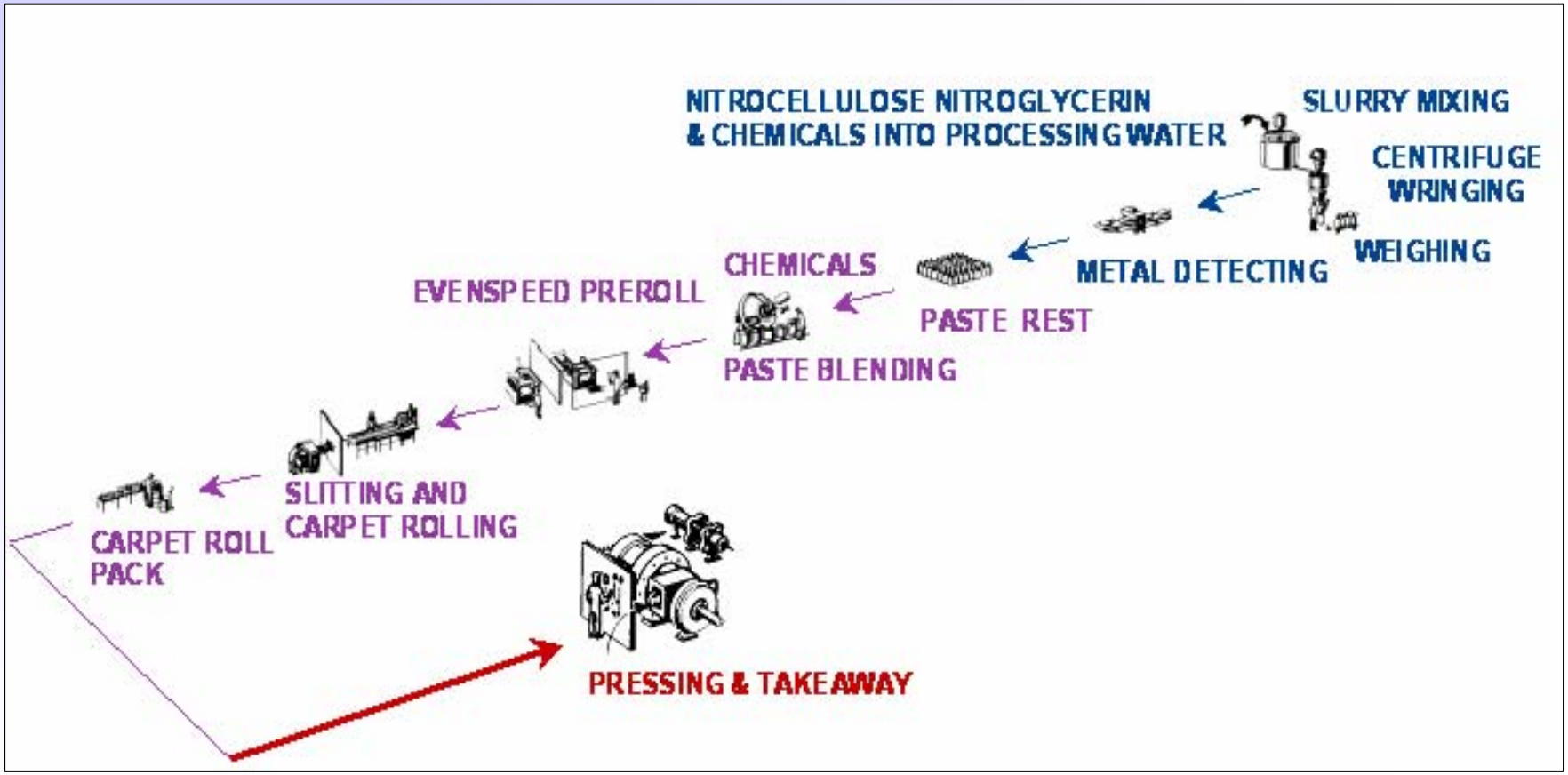
  and Di-phenyl Amine (DPA)

Three Year Project

Projected 3 year contract award via ESTCP

- Year 1 - Complete
  - Ballistic modeling – integration of formulation to establish single perf geometry
  - Solventless extrusion capability study
  - Deterrent coating trials
  - Analysis of propellant – chemical, physical and ballistic evaluations
- Year 2 – Ongoing – Ballistic Testing Scheduled for Sept 2007
  - Ballistic modeling – integration of formulation to establish 7 perf geometry
  - Re-design of single perf die tooling based on lessons learned from Year 1
  - Extrusion capability study of both seven perf and new single perf die designs
  - Deterrent Coating trials
  - Analysis of propellant – chemical, physical and ballistic
- Year 3 Projected Emphasis
  - Manufacturability study – production throughput, cost analysis
  - Detailed Environmental and Insensitive Munitions (IM) testing
  - Performance Test

A Solventless Propellant Is the Best Solution To The Requirements



Solventless propellant manufacturing process at the Radford Army Ammunition Plant

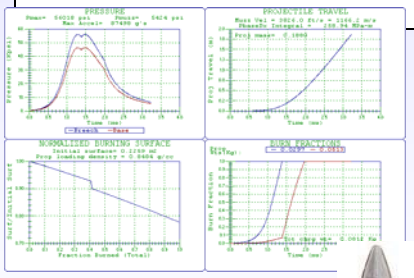
TECHNICAL APPROACH

1.) **Optimize NITROCELLULOSE based propellants**
- Design of Experiment (DOE)
- Thermochemical/Ballistic properties
- Characterization: Closed Bomb, Mechanical properties, RDX particle size, Grain geometry, Sensitivity

2.) **Manufacture propellant quantity** for gun firing incorporating modifications.

3.) **25 mm gun firing at ARDEC ATF Facility**
- Hot, cold, ambient
- 25mm M793

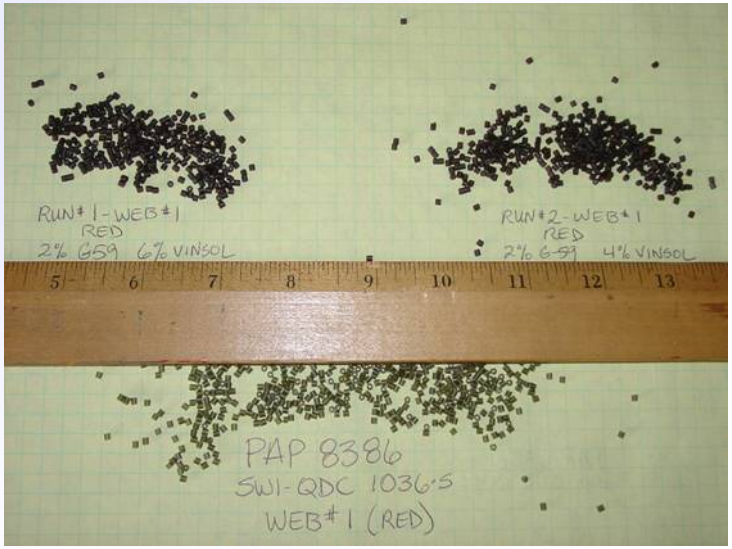
4.) **PVAT data analysis** from 25 mm testing.



To Improve Burn Rate Temperature Sensitivity and Pressure Exponent

- **DOE PARAMETERS**
  - NC TYPE
  - PLASTICIZER TYPE
  - PLASTICIZER LEVEL
  - FILLER TYPE
  - FILLER LEVEL
  - DETERRENT TYPE AND LEVEL

Small Scale Coating Facility Integral Part of Medium Caliber Development



- **Highly plasticized PAP-8386 needs a deterrent that will not migrate throughout grain**
- **Coating optimized by combining a high molecular weight polyester with an inhibitive outer deterrent**

PAP-8386 for 25mm M793

Deterrent Coating

- Combination of deterrents were used
- Two coating levels for each web size
- Water, alcohol and acetone used for solvent deliver system
- Results favorable

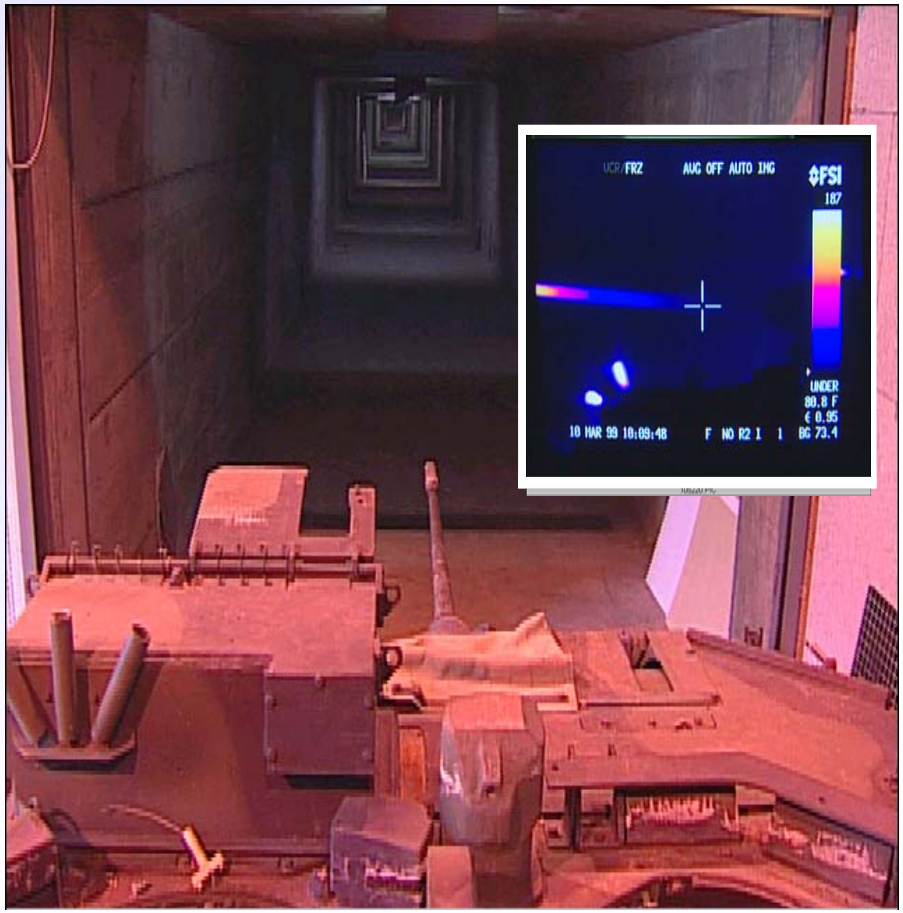
Demonstration Site

ARDEC Armament Technology Facility (ATF) Bldg 7

Armamment Technology Facility

- *The Armamment Technology Facility (ATF) has unique indoor firing ranges, including 4 watertraps, 100m, and 300m range (capable of accommodating the M2 BFV and the M1 Abrams MBT).*

- *Capabilities include state-of-the-art instrumentation such as*
  - *Doppler RADAR, High Speed Video (color and B/W), Forward Looking Infrared Radar (FLIR) and Digital cameras and videos, Environmental Conditioning Chambers, EPVAT, Weapon Inspection equipment, Penetration, Precision, Ricochet, etc.*



25 mm Gun Test Fixture

300 m Range

Approved fo

FIGHTER FOCUSED

Flash Test

Noise Test ARDEC

PAP-8386 for 25mm M793

Task:

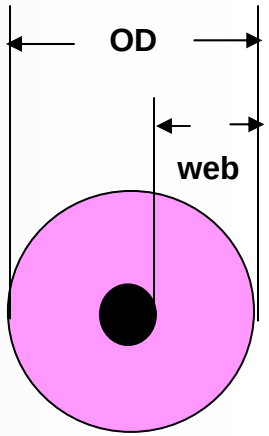
- **Initial formulation effort originated from ARDEC pilot plant**
- **ATK Alliant Ammunition & Powder Co./ Radford AAP produced quantities of PAP-8386 solventless formulation – 3 web sizes for evaluation and best effort deterrent coating**
- **Web sizes were determined by ARDEC, ATK and ARL using IBHVG2 Code prior to extrusion.**

PAP-8386 for 25mm M793

- Using IBHVG2 code, ARDEC, ARL and ATK-Radford each modeled the propellant for performance in the 25mm M793 round.
- Both locations concurred on a target web size of 0.024”
- A smaller than target web (0.020”) and larger than target web (0.0275”) were granulated

Granulation Challenges

- Based on internal ballistic computer modeling, the predicted web size (burn rate determinating factor) target was established as 0.024 inches
- Prior to this effort, the smallest granulation produced at Radford was in support of Term-KE. Granulation was a single perf propellant with an Outer Diameter of 0.095” and a web of 0.039”
- Three geometries were manufactured targeting 0.024” web as the mean.
- The smallest granulation was 0.020” web with an outer diameter of 0.077”
- The median granulation was 0.024” web with an outer diameter of 0.078”
- The largest granulations was 0.0275” web with an other diameter of 0.078”



PAP-8386 for 25mm M793

ATK

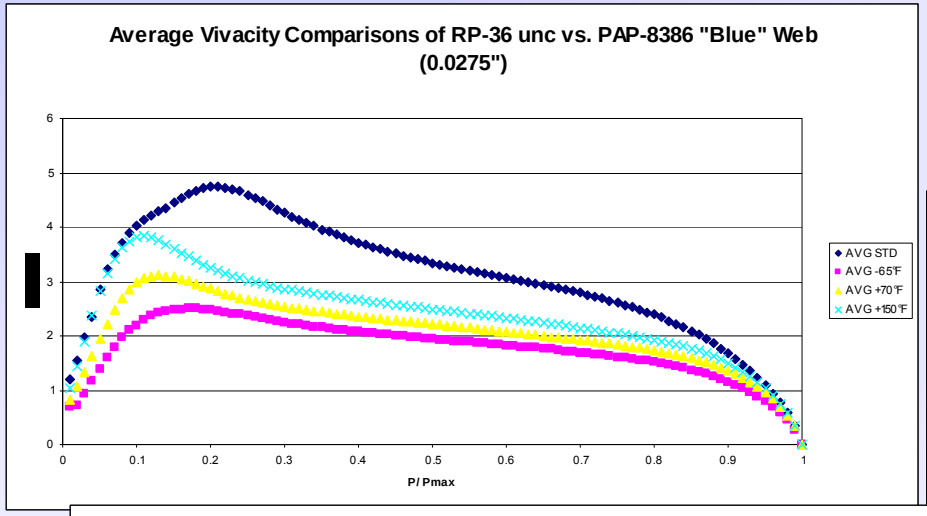
Chemical Analysis= all ingredients were within acceptable limits

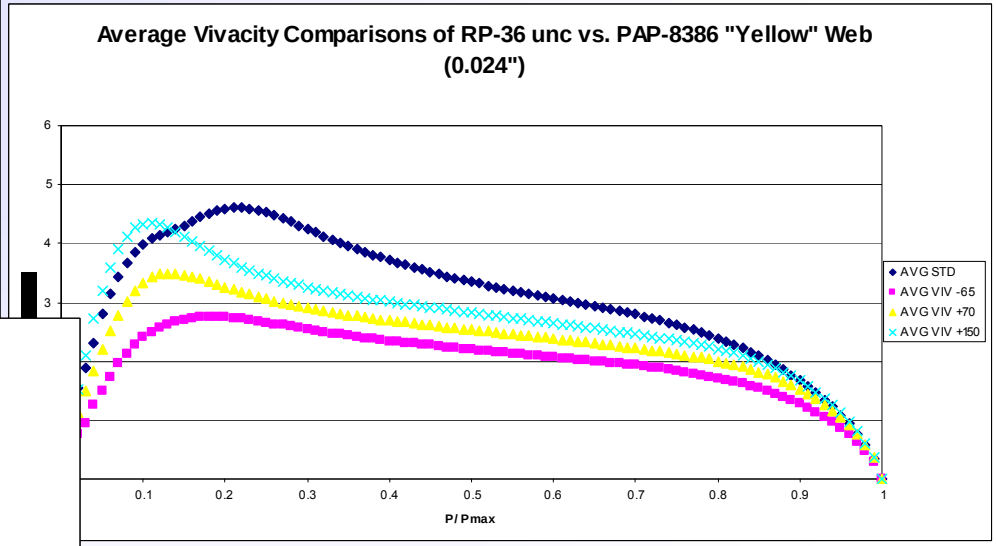
PHYSICAL MEASUREMENTS						
Sample	LENGTH, inches	OD, inches	WEB, inches	PERF, inches	LENGTH/ DIAMETER RATIO (L/D)	DIAMETER/ PERF RATIO (D/D)
Web Target = 0.0275 BLUE	0.074	0.0776	0.0266	0.0246	0.954	3.154
Web Target = 0.024 YELLOW	0.0754	0.0778	0.0244	0.0292	0.969	2.664
Web Target = 0.020 RED	0.0749	0.0771	0.0192	0.0388	0.971	1.987

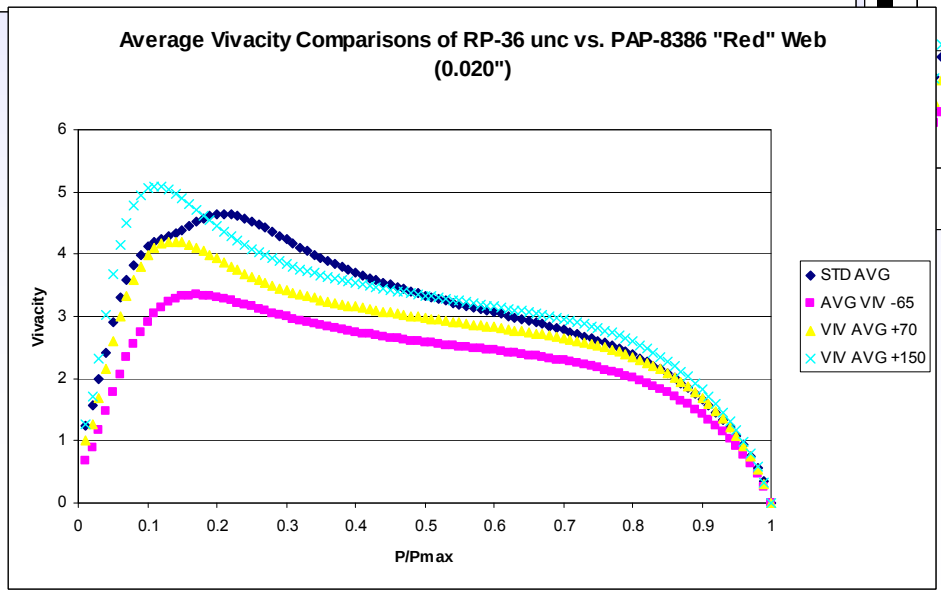
Closed Bomb & Density Analysis

Sample	+70°F		+150°F		-65°F		
	RQ	RF	RQ	RF	RQ	RF	AD
Web Target = 0.0275 BLUE	67.84	104.13	77.33	105.18	57.76	101.64	1.60
Web Target = 0.024 YELLOW	77.98	104.26	88.82	105.83	66.25	102.50	1.60
Web Target = 0.020 RED	92.55	104.48	105.55	105.90	78.08	102.17	1.57

PAP-8386 for 25mm M793

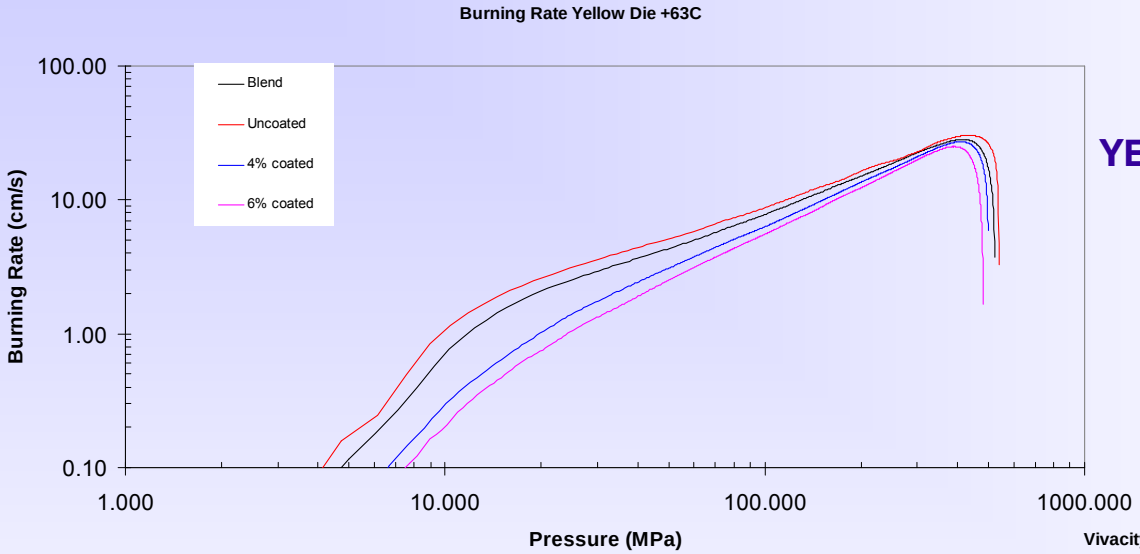




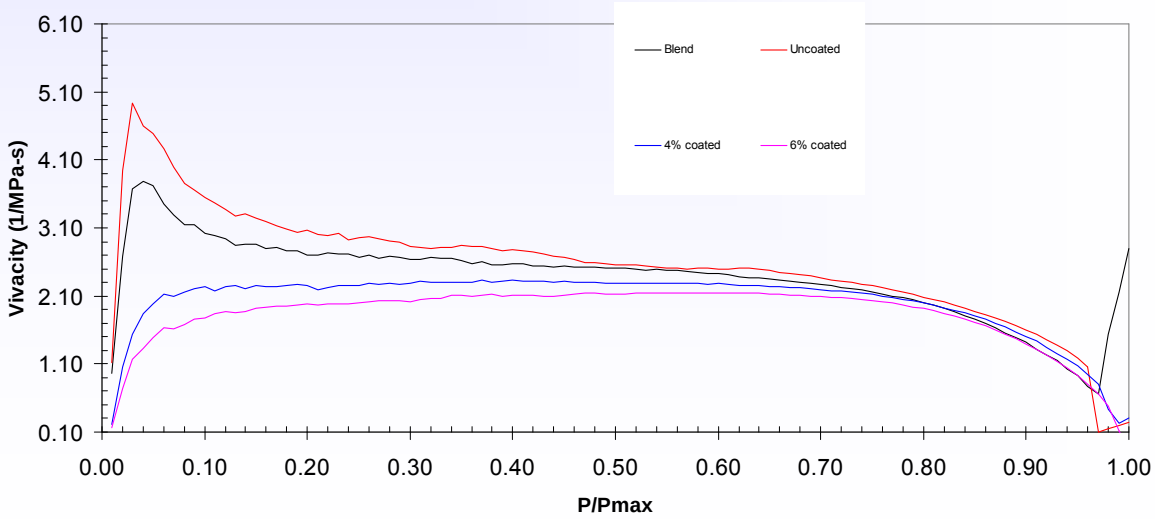


PAP-8386 for 25mm M793

Burn rates and Vivacity Curve@+63C

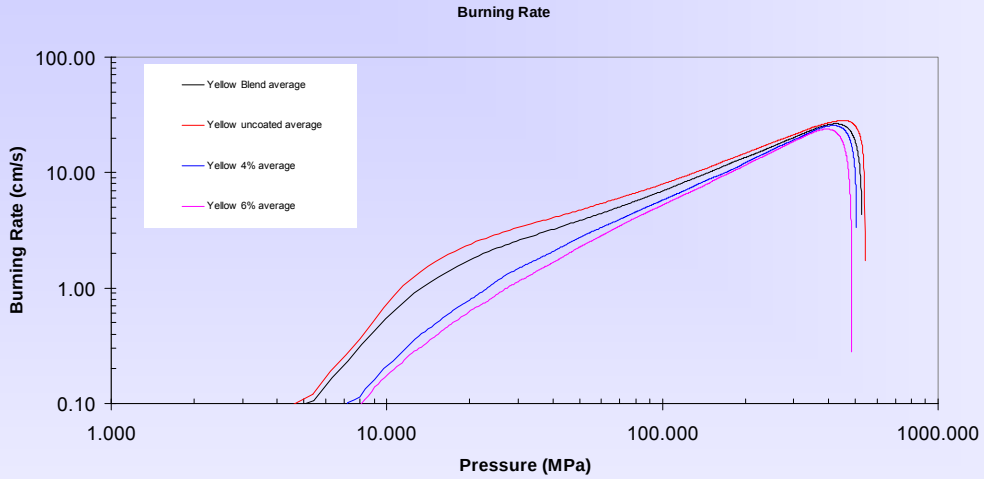


YELLOW DIE= 0.024" web

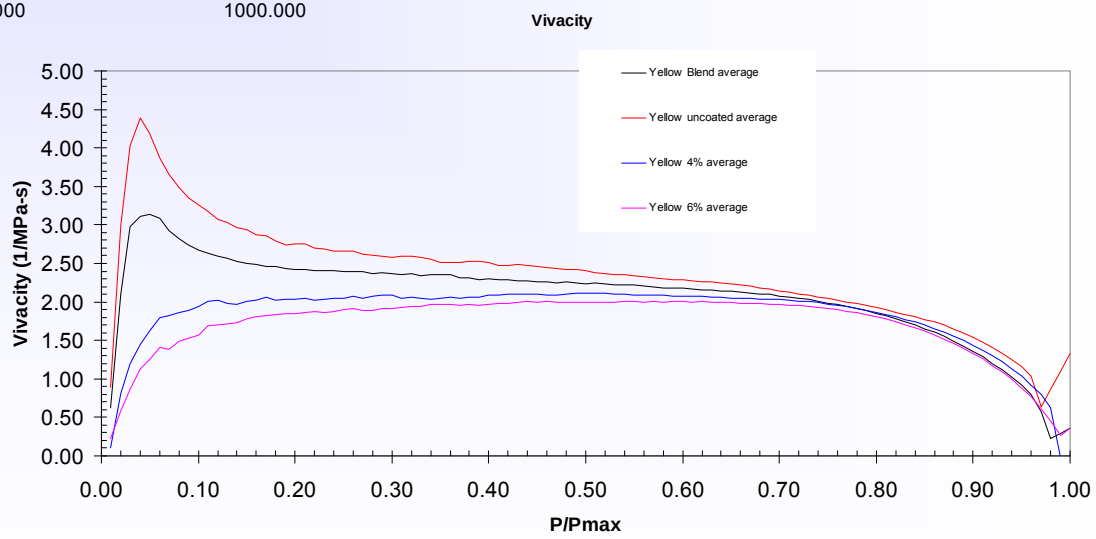


PAP-8386 for 25mm M793

Burn rates and Vivacity Curve@+21C

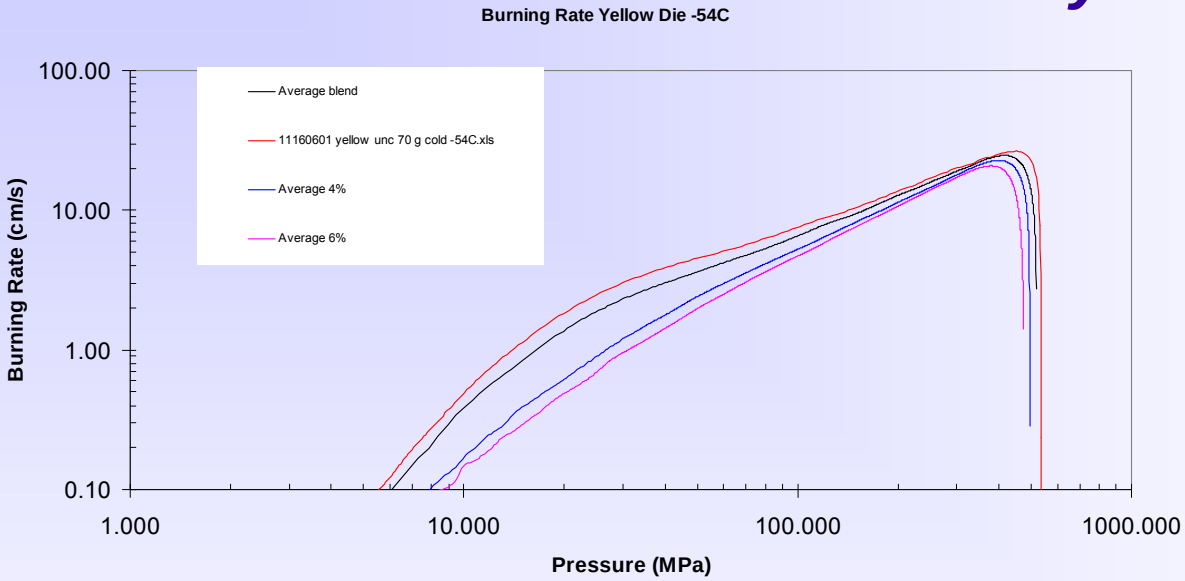


YELLOW DIE= 0.024" web

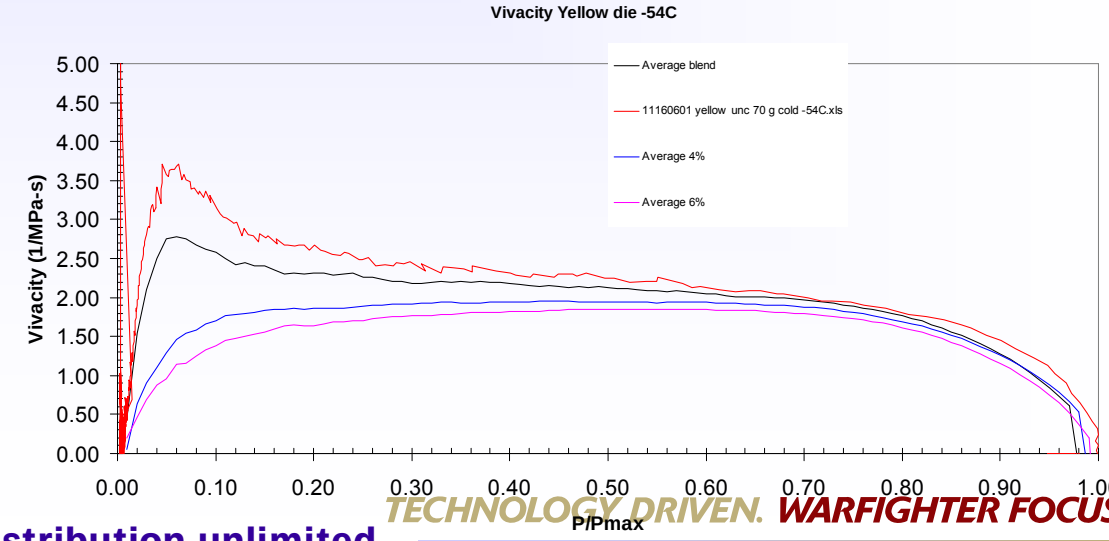


PAP-8386 for 25mm M793

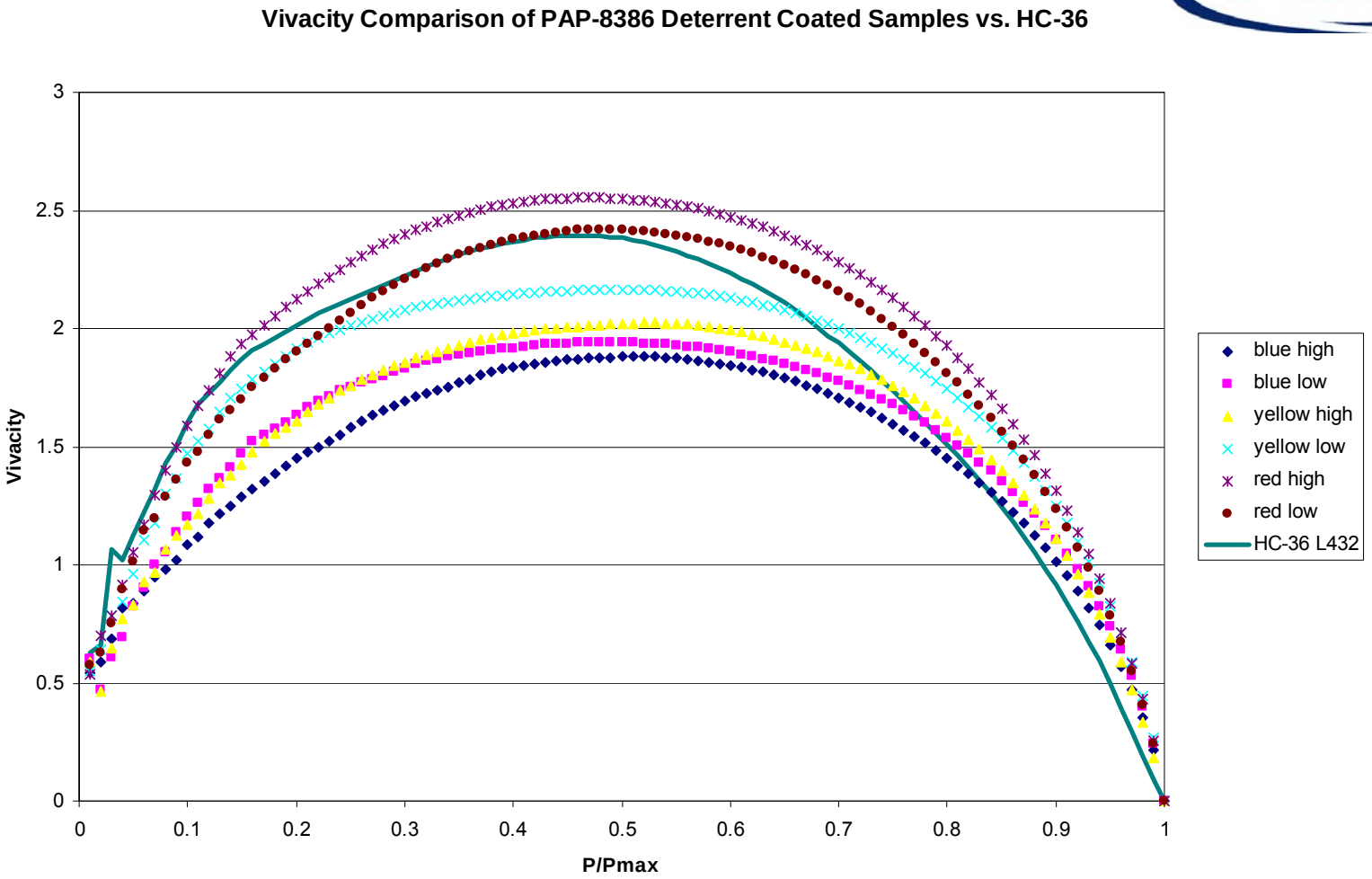
Burn rates and Vivacity Curve@ -54C



YELLOW DIE= 0.024" web



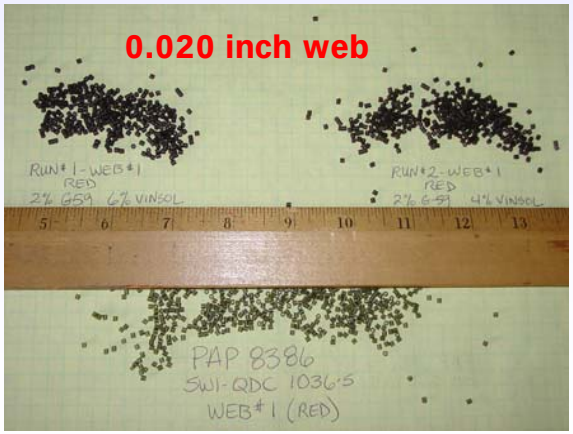
PAP-8386 for 25mm M793

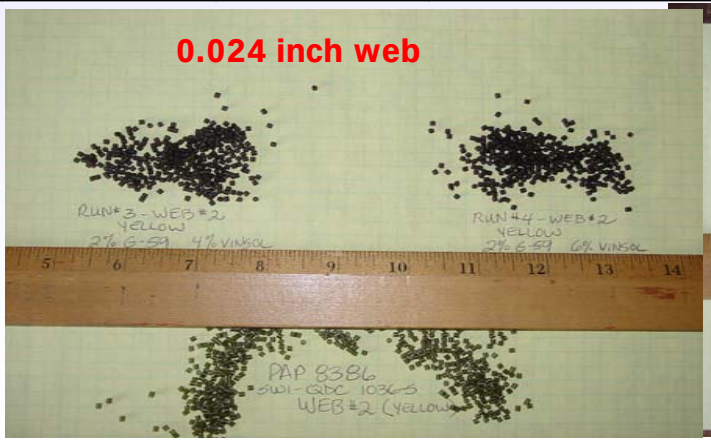


Example for legend blue high refers to blue web, high coating level, etc.

25 mm M793 Charge Design and Interior Ballistics Prediction

Pin diam, in	Web, in	Vel, m/s	ChWt, g	Pmaxamb, MPa	Pmaxhot, MPa
0.04	0.02	1100	72.6	439.9	486.5
0.034	0.023	1105	77.1	427.7	473.6
0.032	0.024	1117	79.4	440.1	487.4
0.025	0.0275	1101	83.9	431.6	478.6
0.02	0.03	1109	88.4	456.6	506.6





Uncoated Propellant

Gun Test Results of the PAP-8386

Sample	Chg Wt	Velocity	Pressure	AT
Blue Die - MFC-8	72	1029.2	381.6	3.024
Blue Die - MFC-5	75	1053.3	433	2.932
Blue Die - MFC-2	78	1095.3	461.9	2.805
Blue Die - MFC	80	1120.5	501.2	2.724
Yellow Die - MFC-8	67	1022.2	384.8	3.125
Yellow Die - MFC-5	70	1054.2	413.5	3.059
Yellow Die - MFC-2	73	1084.9	448.9	2.976
Yellow Die - MFC	75	1108.5	472.6	2.911
Red Die - MFC-8	59	991.8	354.9	3.192
Red Die - MFC-5	62	1020	374.2	3.093
Red Die - MFC-2	65	1048.4	417.8	3.086

Note: MFC = Max Full Case. i.e, MFC-8 = Max Full Case minus 8 grams of propellant.

Firing results of a blend of coated and uncoated PAP-8386.

Sample	Chg Wt (g)	Velocity(m/s)	Pressure (MPa)	AT (ms)
Low Deterrent Coat				
Blue Die 50/50	75	903	237	6.2
Blue Die 50/50	78	921	254	5.5
Blue Die 50/50	80	934	261	5.5
Blue Die 70/30	75	868	218	7.1
Blue Die 70/30	78	895	233	6.5
Blue Die 70/30	80	907	245	5.8
Blue Die 70/30	82	932	258	5.7
High Deterrent Coat				
Blue Die 30/70	75	937	272	4.5
Blue Die 30/70	78	980	310	4.0
Blue Die 30/70	80	1010	339	4.1
Blue Die 20/80	75	958	289	4.1
Blue Die 20/80	78	1004	327	4.0
Blue Die 20/80	80	1022	347	4.0

Note: Coated Reference Refers to coated/uncoated percentages

Ballistics Results of Final Blend

Ballistic Results of PAP8386 Blue Web (0.0275”) at 21 C

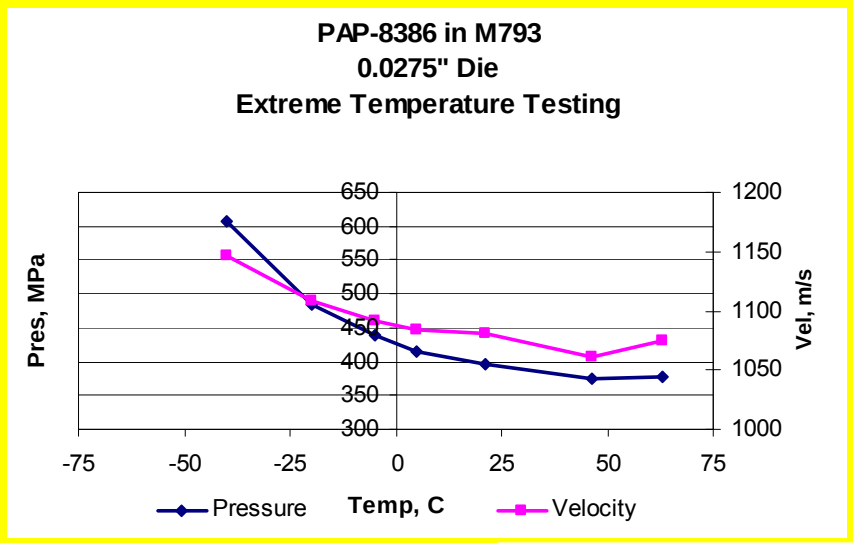
Round #	Charge Weight [g]	Muzzle Velocity [m/s]	Pressure [MPa]	Action Time [msec]
1	85.5	1070	389.5	3.365
2	85.5	1090	409.2	3.364
3	85.5	1082	389.4	3.422
Average	**85.5**	**1081**	**396**	**3.384**

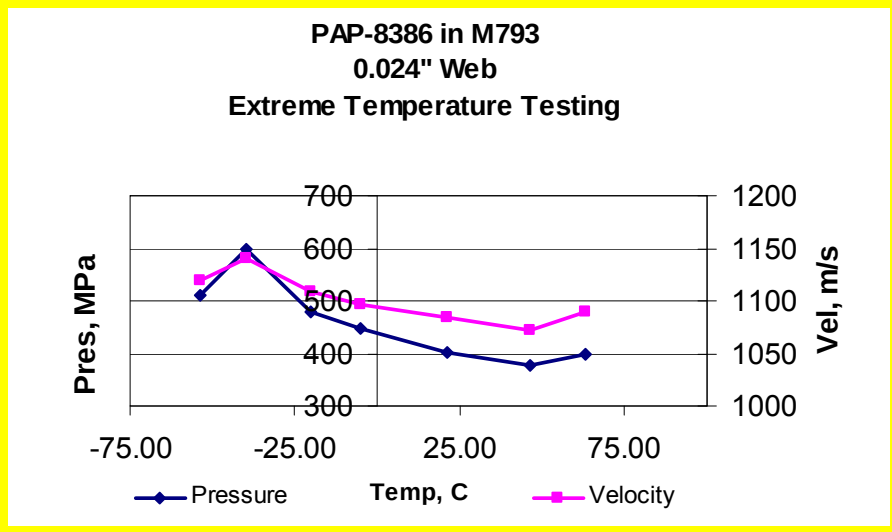
Ballistic Results of PAP8386 Yellow Web (0.024”) at 21 C

Round #	Charge Weight [g]	Muzzle Velocity [m/s]	Pressure [MPa]	Action Time [msec]
1	83.0	1079	404.7	3.752
2	83.0	1085	395.9	3.799
3	83.0	1090	401.7	3.806
Average	**83.0**	**1085**	**400.73**	**3.786**

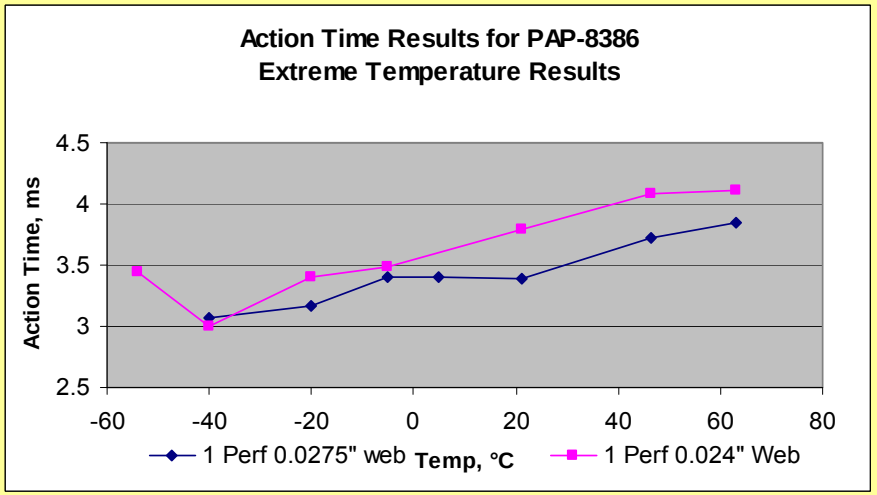
Year 1: First Iteration PAP8386

Meets M793 Requirements at Ambient





Muzzle velocity falls within M793 requirements. Pressure high at cold due to non-optimized geometry.

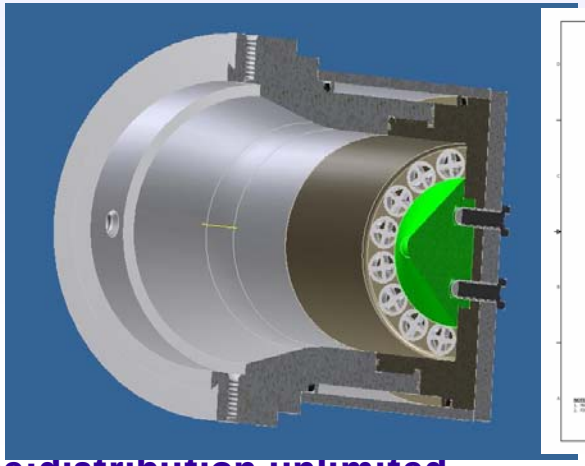


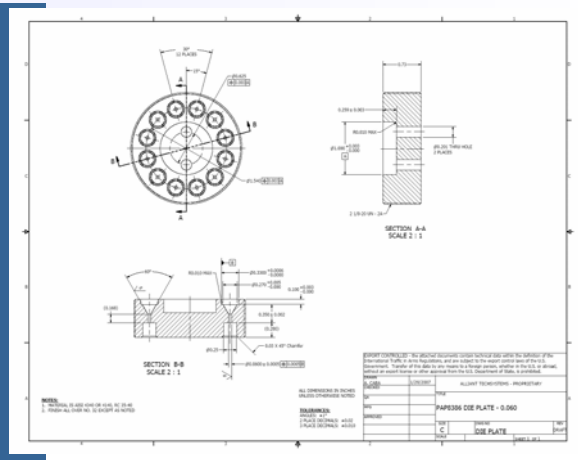
Three single perf web sizes extruded as part of design investigation

Granulation Challenges

- The extrusion system encountered processing problems related to the small granulation size of the propellant. Because of the small flow area, the pressure difference across the extrusion ram was in excess of safety limits observed; therefore, extrusion was limited by ram rate.

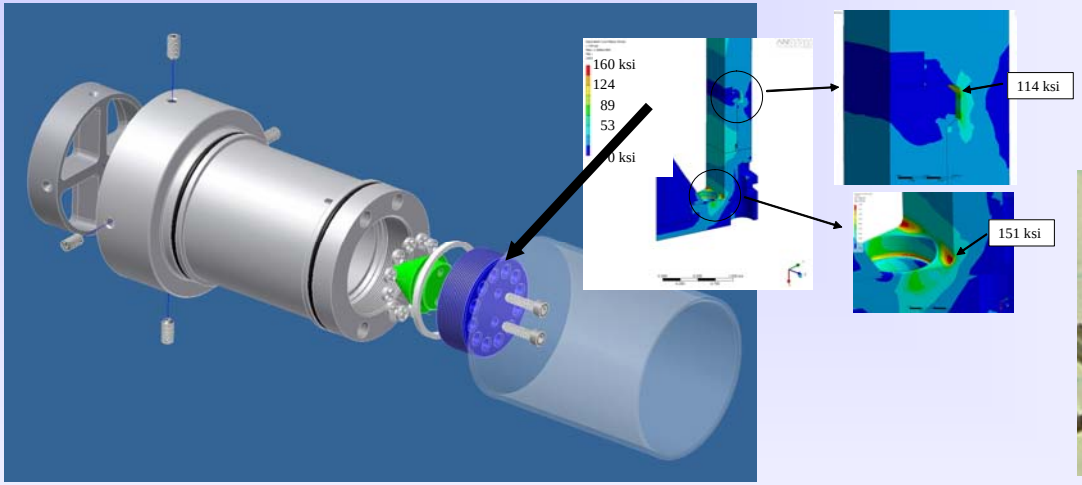
- Currently during Year 2 of this project, ATK has redesigned the extrusion tooling to reduce the pressure drop across the dies, with an emphasis on increasing the extrusion rate.

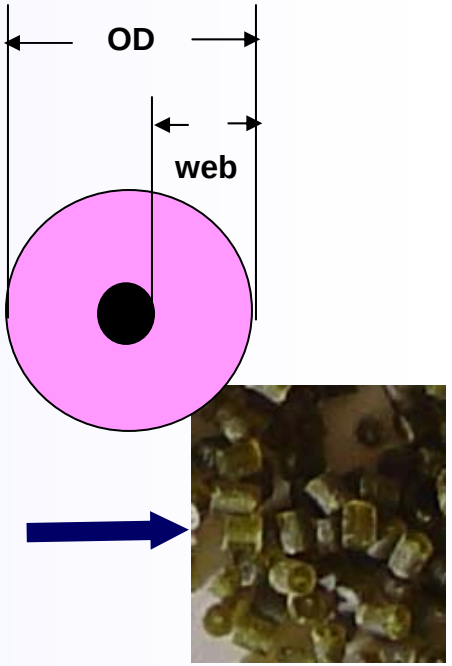




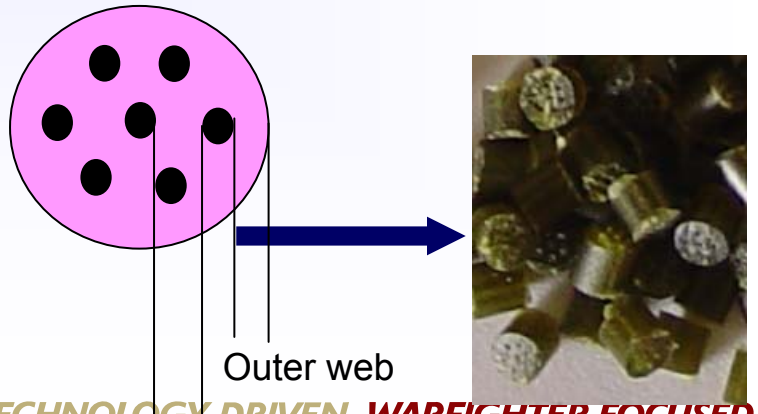
Year 2: Concentration on Extrusion

Rheological modeling used to improve extrusion process of single perf material

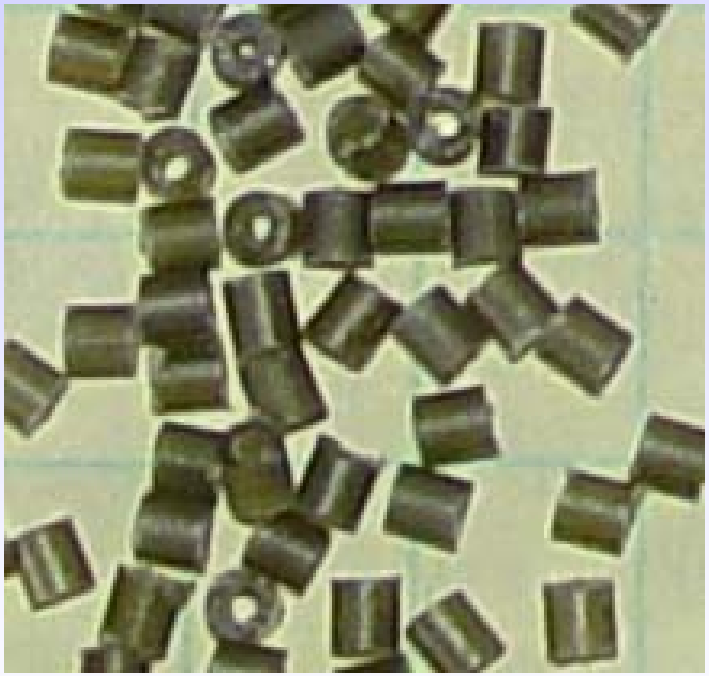




Seven perf propellant configuration offers progressivity over single perf version



PAP8386 – ARDEC Formulation Is An Excellent Candidate



- Solventless formulation – Completely eliminates solvent during granulation
- Material Properties similar to JA2 – Improved impact sensitivity
- Environmentally-friendly formulation – VOC's, DNT, DPA and DBP eliminated
- Same Ingredients as JA2 and RPD380 –
  - Compatible with existing systems
  - 1.3c Hazard Classification
  - Similar storage life
- Flame Temperature < 3000 K – Low barrel erosion

Thermochemical Parameter	Value
Flame Temperature, [K]	2948
Impetus, [J/g]	1063.6
Gas Molecular Weight, [g/gmol]	23.049
Covolume, [cc/g]	1.042
Frozen Gamma	1.244

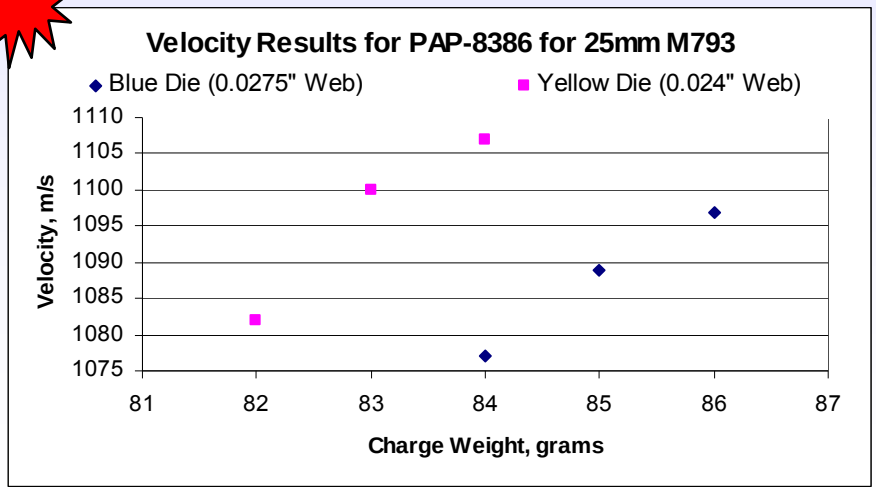
PAP8386 Is A Strong Replacement Candidate For M793 25mm Training Ammunition

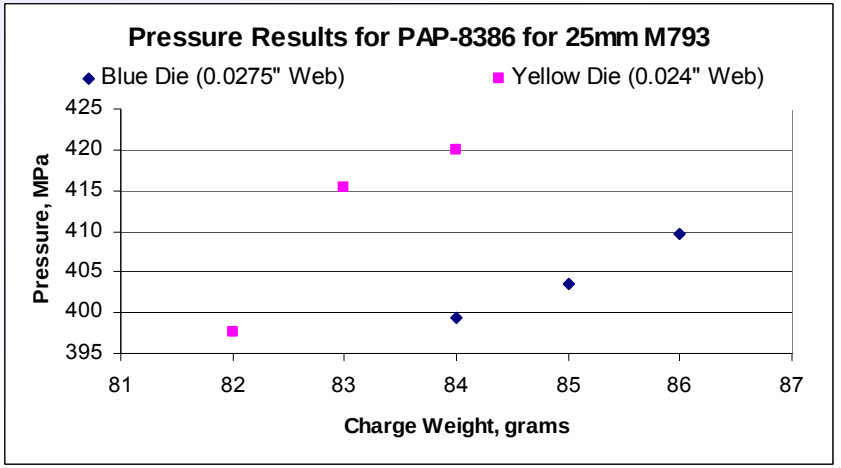
- Eliminates solvents from processing and final propellant
- Meets M793 ballistic requirements above -21 C. Additional work needed to improve low temperature ballistics .
- IM Improvement – demonstrated improvement in impact response.
- Affordable solution– economy of scale will make PAP8386 affordable.
- Environmentally friendly - solventless process removes VOC's, DNT, DBP and DPA.
- Manufacturing capacity – existing U.S. Army solventless facilities at RFAAP sufficient for near term requirements.
- Propellant is compatible with existing cartridge materials.
- Propellant shall not negatively impact gun barrel life – low flame temperature.
- Propellant storage life of 30 years and hazard classification 1.3c meet existing requirements.

Performance Requirements
25mm M793

Parameter	Requirement	Desired	NC based Propellant Predicted
Muzzle Velocity			
+21^0 C	1100 + 25 m/s, σ < 13 m/s	As close to 1100 m/s as possible. Higher is better.	1101-1117 m/s
+63^0 C	No requirement		
-54^0 C	No requirement		
Chamber Pressure			
+21^0 C	Avg + 0.72σ < 402 MPa Avg + 5σ < 496 MPa	In the 390 MPa range, σ < 5 MPa In the low 400 MPa range, σ < 5 Mpa	431.6-440 MPa
+63^0 C	Avg + 5σ < 496 MPa	In the low 400 MPa range, σ < 5 Mpa	478.6-487.4 MPa
-54^0 C			-

PAP-8386 PROPELLANT GUN FIRING RESULTS MEET THE VELOCITY AND PRESSURE REQUIREMENTS





Demonstration Plan

Characteristic	Requirement	Inspection method
Ave. Peak Chamber Pressure 18° to 24° C -54° to 62° C	Pressure plus 0.72 std dev ≤ 402 MPa Pressure plus 5 std dev ≤ 496 MPa	Measure / record
Velocity 18° to 24° C	1100 ± 25 mps std dev not to exceed 13mps	Measure / record
Action time -54° to 62° C	6.0 milliseconds	Measure / record
Metal parts security	Fragments < 0.10 gram	Measure / record
Impulse noise	Information	Visual
Muzzle flash	Information	Visual

If the propellant group fails to meet either or both velocity requirements, a second sample of the group may be fired. If the second sample fails to meet the velocity requirements, the propellant group shall be rejected.

If the propellant group fails to meet the pressure requirement, a second sample of the group may be fired. If the second sample fails to meet the pressure requirement, the propellant group shall be rejected.

If any sample cartridge fails to meet the requirement for action time, the propellant group shall be rejected.

Separation or breakup of metal parts as evidenced by recovering the parts or fragments or holes in the fragmentation screen, shall be classified as a defect. The propellant group shall not be penalized for evidence of any individual fragment with a weight of less than 0.10 grams.

TECHNOLOGY TRANSFER

ATK

- **Training Rounds**
  - 25 mm M793 training rounds
    - Most customer- Army, Navy and Marines
    - 1.4-1.5 M rounds per year
  - 30 mm LW30 M788 training rounds
    - Customer is Army
    - 1.1M rounds per year
  - 25 mm M910 TPDS-T
    - Customer- Army and Marines
    - 900,000-1M rounds per year
- **Full IM Test per Mil-Std-2105C**
  - Slow Cook-Off
  - Fast Cook-Off
  - Fragment Impact
  - Bullet Impact
  - Shape Charge Jet Impact
  - Sympathetic Detonation

PAP-8386 for 25mm M793

Environmental Impact Comparison

Table 5-1: Examples of Types of Costs By Category							
Direct Environmental Activity Process Costs				**Indirect Environmental Activity Costs**		**Other Costs**	
Start Up		**Operation & Maintenance**					
Activity	**$**	**Activity**	**$**	**Activity**	**$**	**Activity**	**$**
Equipment Purchases	=	Labor to Operate Equipment	↑	Compliance audits	=	Overhead assoc. with process	↓
Equipment Design	=	Labor to manage hazardous waste	=	Document maintenance	=	Productivity/Cycle time	=
Mobilization	=	Utilities	=	Envr. Mgmt. Plan development and maintenance	=	Worker injury claims & health costs	=
Site preparation	=	Mgmt/Treatment of by-products	↓	Reporting requirements	=		
Permitting	=	Hazardous waste disposal fees	↓	Test/analyze waste steams	=		
Installation	=	Raw Materials	↑	Medical exams	=		
Training of Operators	=	Process chemicals, nutrient	↓	Waste transportation	↓		
		Consumables and supplies	↓	OSHA/EHS training	=		
		Equipment maintenance	=				
		Training of operators	=				

Small Scale Slow Cookoff Test

Test Results

	M14		PAP-8386	
Confinement Sleeve thickness	Reaction Type	Reaction Temp ^{0}F	Reaction Type	Reaction Temp ^{0}F
0.015”			BURN	280
0.030”			BURN	285
0.045”	BURN	285	BURN	280
0.060”	DEFLAGRATION	290	BURN	295
0.075”	DEFLAGRATION	290	PRESSURE RUPTURE	285
0.090”	DEFLAGRATION	285	PRESSURE RUPTURE	285

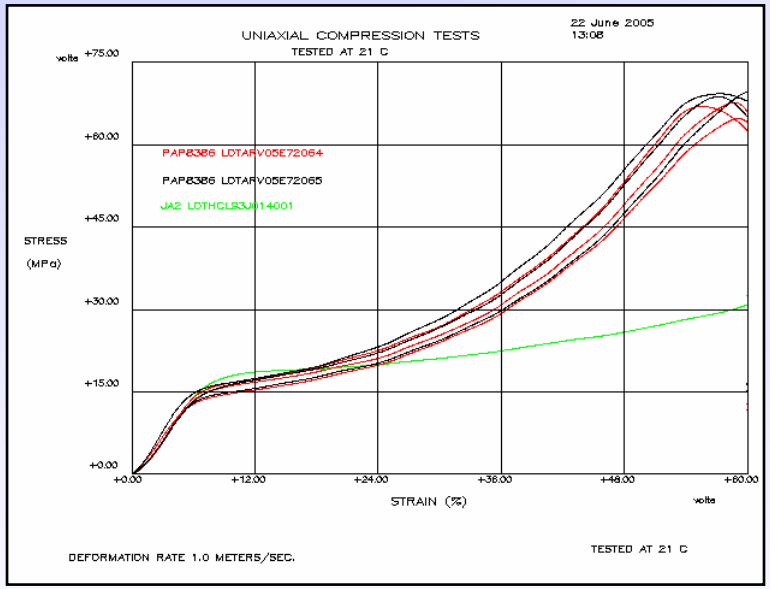
PAP-8386 SMALL SCALE SLOW COOK-OFF TEST BETTER THAN M14 PROPELLANT

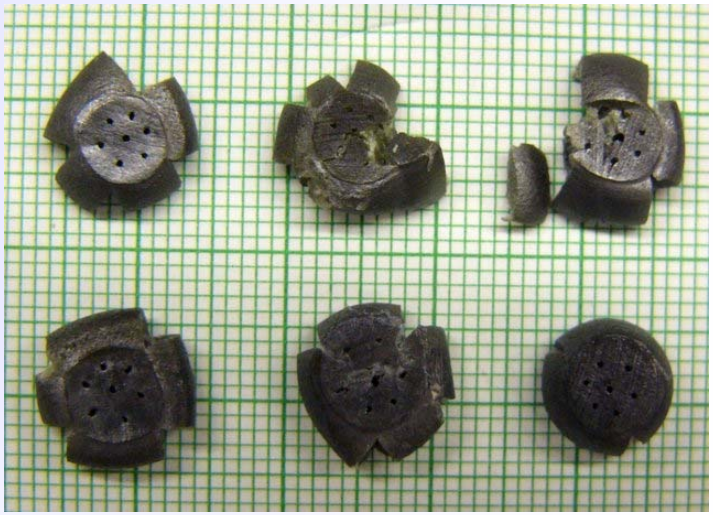
SMALL SCALE SENSITIVITY SCREENING TEST

Propellant	ERL Type 12 Impact 50% point (cm)	Electrostatic Discharge Test (ESD) NR (NO REACTION)	BAM Friction (N) N (NEWTON)
RDX Lot # 21-18	24.8± 1.2 25.1± 1.7	-	212N reacted 188N 10/10 no go
RPD380 Lot # ARV01A002001	27.1± 2.1	NR 20 trials @ 0.25 Joules	192N reacted 168N 10/10 no go
L1M Lot # NC-00J2890	27.6± 1.5	NR 20 trials @ 0.25 Joules	212N reacted 188N 10/10 no go
JA2 Lot # PD-065-5	32.0± 1.4	NR 20 trials @ 0.25 Joules	212N reacted 188N 10/10 no go
M14	48.4±1.3	NR 20 trials @ 0.25 Joules	252N reacted 240N 10/10 no go
PAP-8386 (RPD-469)	75.4± 1.2	NR 20 trials @0.25 Joules	252N reacted 240N 10/10 no go

PAP-8386 is less sensitive to impact, ESD and friction.

Superior Properties In High Rate Mechanical Response Testing

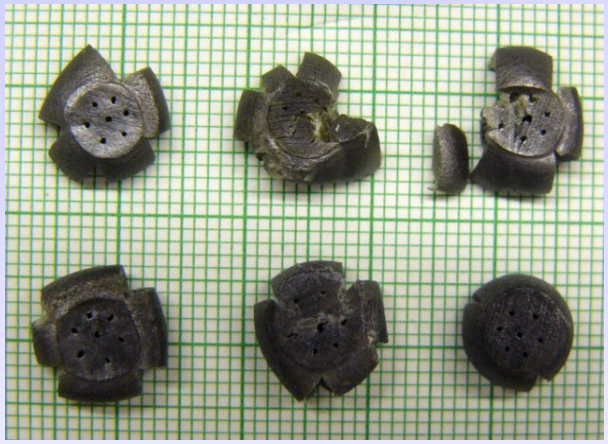




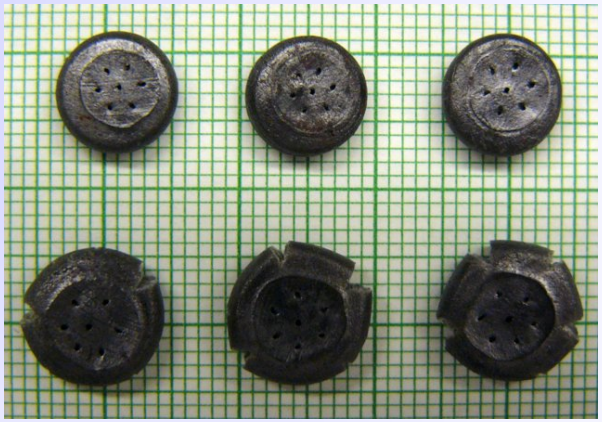
Ambient Results for PAP8386 compared to JA2

"Overall, the PAP8386 mechanical response was very good. In particular, the -32ºC and -46ºC responses were most impressive. The minimal amount of fracture observed at these temperatures is atypical of the single-, double-, triple-base, and composite gun propellants that have been mechanically tested by the Army Research Laboratory."

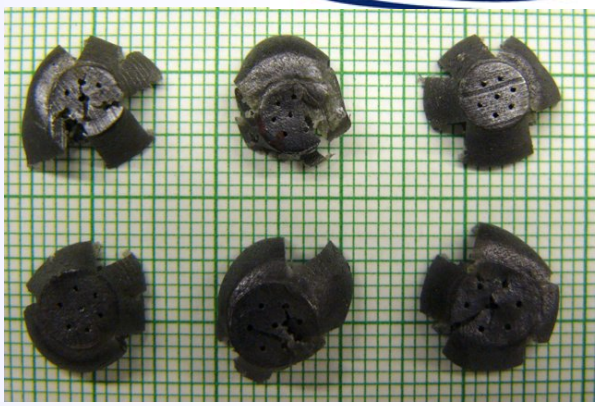
Mechanical Properties of PAP-8386 and JA2 Lots @ 21°C, 63°C, and -46°C



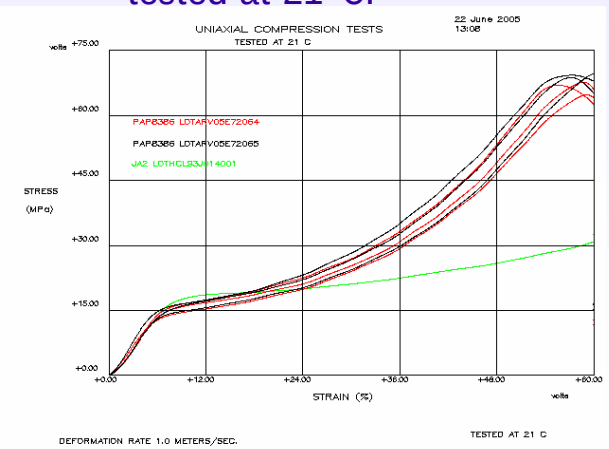
PAP8386 Specimens that were tested at 21°C.



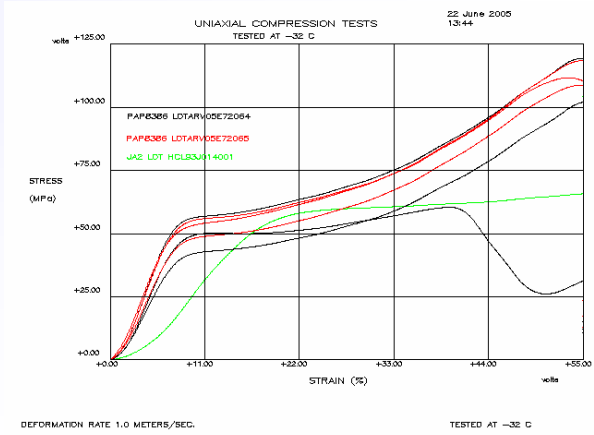
PAP8386 Specimens that were tested at 63° C



PAP8386 Specimens that were tested at -32° C



JA2 7-Perforated Specimens Tested at 21° C, 63° C, and -32° C.



PAP-8386 is better than JA2 in mechanical properties which is better than M14 propellants

Conclusion

- A new double base propellant, PAP-8386, manufactured using a solventless process shows great promise as a propellant for medium caliber applications such as the M793. The solventless process eliminates the use of VOC's during manufacture and allows for a formulation that does not contain several environmentally hazardous ingredients.
- Small-scale mechanical testing indicates superior response features relative to JA2, one of the most effective propellants in the Army's inventory. IM response of this propellant to impact stimuli is expected to be very good.
- During ballistic firing, gunners commented that no odors were noticeable during the firing sequence.

FUTURE WORK

- Additional work has been funded by ARDEC to investigate optimized physical characteristics of the propellant. New tooling will be fabricated to improve the structural integrity of the granulation.
- In addition, a seven perforated propellant configuration is being investigated.
- Conduct PVAT, IM , Vulnerability, Aging and Producibility Study.