

DEVELOPMENT AND PERFORMANCE OF HIGH ENERGY HIGH PERFORMANCE CO-LAYERED ETPE GUN PROPELLANT FOR FUTURE LARGE CALIBER SYSTEM

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ABSTRACT

The co-layered propellant configuration, when properly designed, is conducive to higher performance at lower gun chamber pressure. The energetic thermoplastic elastomer (ETPE) was utilized to produce co-layered propellant in the radial strip configuration. The manufacturing process was developed, and the propellants were fully characterized before the test firing using 60 mm subscale gun. The test firing of 15 shots at hot, ambient, and cold temperatures showed mixed results.

1. INTRODUCTION

The objectives of this project were to demonstrate the manufacturing of co-layered ETPE propellants for a ballistic test and to develop co-layered ETPE propellant that has improved performance than the current propellant. For the improved propellant performance some of the requirements were: impetus greater than or equal to 1250 J/g for a “fast” burning formulation and 1075 J/g for a “slow” burning formulation, a flame temperature less than or equal to 3450K, vulnerability and sensitivity characteristics the same as or better than those for JA2, and acceptable mechanical properties from -32°C to 63°C (Manning et al., 2005). This paper will address the development and characterization of the manufacturing process as well as the ballistic firing results.

Co-layered propellants are composed of three layers. The fast burning inner layer is sandwiched by the two slow burning outer layers as shown in Figure 1. The advantage of utilizing co-layered propellant is its progressive burning relative to pressure generation. Well designed and fabricated co-layered propellants can impart a “double hump” in the ballistic pressure-travel plot, consequently increasing the muzzle velocity without significantly increasing the maximum pressure in the

chamber. As the slow burning layer burns first the pressure in the chamber rises slowly and moves the projectile forward. The increasing volume in the chamber due to moving projectile decreases the pressure in the gun. However, when the slow layers are burnt out the fast burning inner layer begins to burn more quickly.

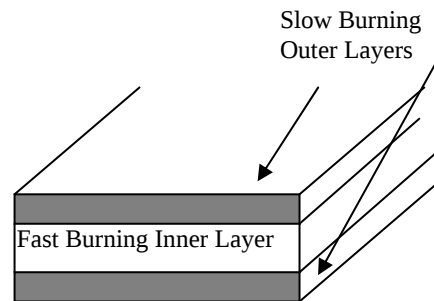


Figure 1. Colayered Propellant

Therefore, the pressure in the gun can be built for the second time transferring more kinetic energy to the projectile (Braithwaite et al., 1998). The area under the Pressure-travel curve translates to the velocity of the projectile. So, by inducing the second hump, the area under curve can be increased (Cline et al., 2004). The shaded region in Figure 2 depicts that added area, which can in turn increase the projectile velocity.

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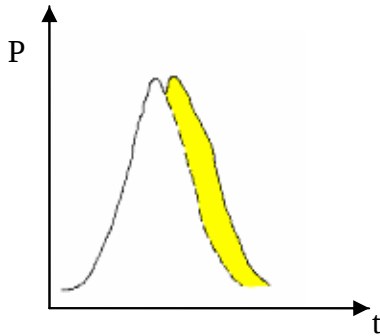


Figure 2. Double Hump in the Ballistic Pressure-time Plot

When designing a co-layered propellant, several parameters must be considered such as the burn rate ratio of fast to slow burning layers, thickness of individual layers, the configurations, and the manufacturability of the propellants. Usually the increasing burn rate ratio will yield better gun performance, and the ratio of 3:1 is desired and sought (Oberle et al., 1997). The burn rate ratio and configuration dictate the thickness of individual layers. In this program, the burn rate ratio of 1.7:1 was achieved.

The thicknesses of individual layers can have such a great influence on the ballistics that even the slightest deviations in the individual layer thickness can easily skew the shape of the curve (Isle et al., 1998). The configuration of co-layered propellants is another important design parameter. Several configurations such as disc, cord, scroll, concentric wrap, and radial strip have been studied (Robbins et al., 1992). For this effort the radial strip configuration was selected, and the details of which are to be explained in the later sections of this report. Finally, the ease of manufacturability is another important parameter. It is heavily influenced by all of the preceding parameters and also by the propellant formulation and ingredients. The ETPE binder system was chosen for this effort because it has many desirable characteristics when compared to the conventional NC binder system. The ETPE propellant: 1) minimizes plasticizer migration, 2) is recyclable, 3) is processed without solvent, 4) is not hygroscopic, thus is not subject to shape deformation in change of humidity, and 5) is plastic when heated (Harris et al., 1998 and Aprea et al., 1997). However, the major unattractive characteristics of ETPE are that: 1) the ETPEs are still experimental and available in limit quantities, 2) there is no production base, and 3) the synthesis is complex resulting in high cost.

2. APPROACH AND RESULTS

To successfully develop high energy, high performance, co-layered ETPE propellant, the following approaches were taken: the design of charge,

manufacturing process development, and propellant characterization.

2.1 Charge Design

The Propulsion Research and Engineering Branch of U.S. Army Armament Research, Development and Engineering Center (ARDEC), located in New Jersey, had contracted Aerojet Corp. (Contract number DAAE30-01-0-0800) to manufacture BN7 (an ETPE). The propellant ingredients were further processed at ARDEC to fabricate co-layered ETPE propellants in the radial strip configuration. Upon the complete fabrication of ETPE propellants, the rounds were assembled and fired by BAE Systems (formerly United Defense, L.P.), MN in May of 2005.

From several candidates of slow and fast burning propellant formulations, PAP 8194 and PAP 8288 were down selected because of their superior manufacturability, mechanical properties, and burn rate ratio compared to others evaluated. Their compositions are shown in Table 1.

Table 1. Ingredients of Slow and Fast Burning ETPE Formulations

Slow Burning PAP 8288	Fast Burning PAP 8194
BN7	BN7
RDX (size A)	RDX (size A)
RDX (size B)	NQ
BDNPA/F	BDNPA/F

The BN7, serving as a binder system, is an ETPE composed of two different polymers: poly-BAMO (bis-azidomethyl oxetane) and poly-NMMO (3-nitratomethyl-3-methyloxetane). Aerojet synthesized the BN7 with RDX and NQ to form a molding powder. The molding powder was supplied to ARDEC where it was further processed into co-layered ETPE strips. The concept of radial strip configuration was first conceived by BAE Systems (formerly United Defense, L.P.), Minneapolis, MN., and was designed for the 60 mm electrothermo chemical (ETC) igniter gun. The radial strip geometry has the advantages of having better flame-spreads over disk geometry (Isle et al., 1998).

A total of 24 sets of strips comprised of 4 different sizes and shapes would fill a single 60mm cartridge as shown in Figure 3. A total of 1440 colayered radial strips were fabricated. These propellants were assembled into 15 rounds for ballistic testing.

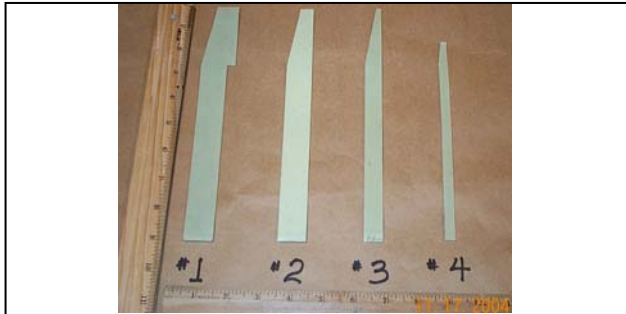


Figure 3a. Various Shapes of Radial Strips

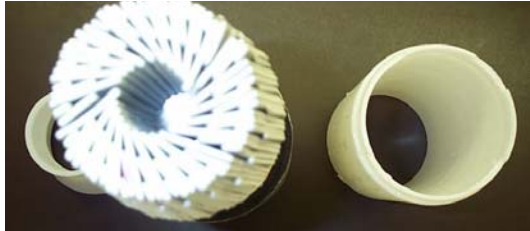


Figure 3b. Inert Strips in a Cartridge

Figure 3. Radial Strip Design

2.2 Manufacturing Process Development

The basic concept of this program was derived from the previous manufacturing processes of fabricating co-layered ETPE propellants in disk configurations. However, this program modified the process so that the process control and product quality were greatly increased to meet the program requirements. There were four major steps through which the ETPE propellants were processed into co-layered strips: 1) mixing and extrusion, 2) rolling, 3) sorting and trimming, and 4) lamination. Attempting to manufacture 1440 radial strips of co-layered ETPE and simultaneously developing the manufacturing process, while not sacrificing the quality, schedule, and cost, was a difficult task. Overall, the manufacturing methods were very labor intensive, time-consuming, and somewhat crude for mass production (Park et al., 2005). The operating procedures for each process were developed and fine-tuned over the course of the project.

2.2 Propellant Characterization

Several candidates for both fast and slow burning propellants were characterized for downselection. These candidates were tested for mechanical properties, burning rate, and manufacturability. Once the formulations were selected, the formulations were processed into co-layered ETPE propellant strips. The co-layered propellants were further tested to obtain burning rate, mechanical strength, lamination strength data at hot (63 °C), ambient (21 °C), and cold temperatures (-32 °C). Also, rheology data were acquired for reworked lots.

The mechanical properties data of downselected PAP 8194 (fast burning formulation) and PAP 8288 (slow burning formulation) were compared to those of JA2. The effect of strain rate (%) on the stress (MPa) were plotted for three temperatures (63 °C, 21 °C, and -32 °C) as seen in Figures 4, 5, and 6. The remains of propellant samples can be seen in Figure 7.

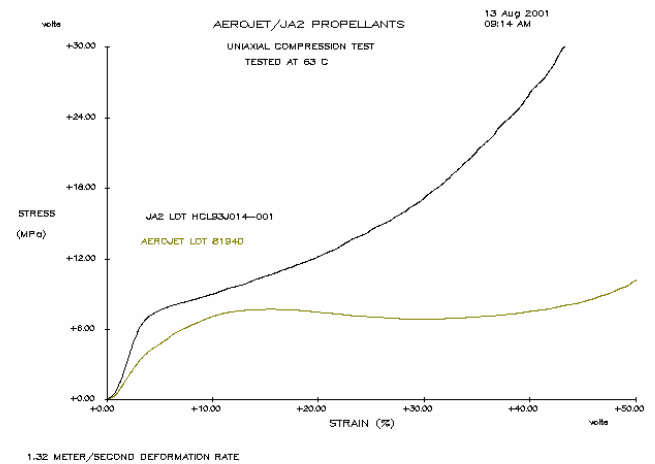


Figure 4. Stress vs. Strain of Plot JA2 and PAP 8194BB at 63 °C

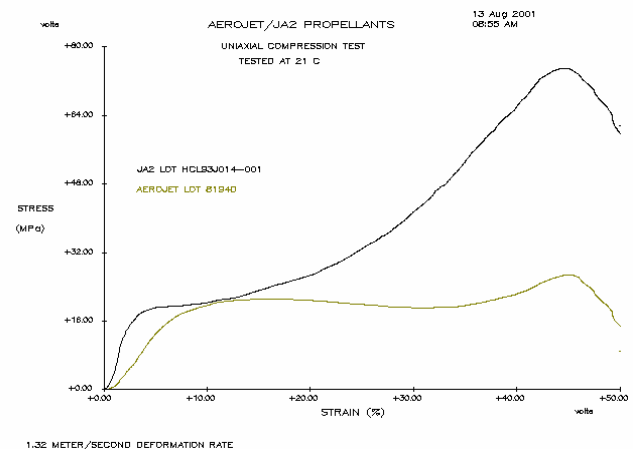


Figure 5. Stress vs. Strain of Plot JA2 and PAP 8194BB at 21 °C

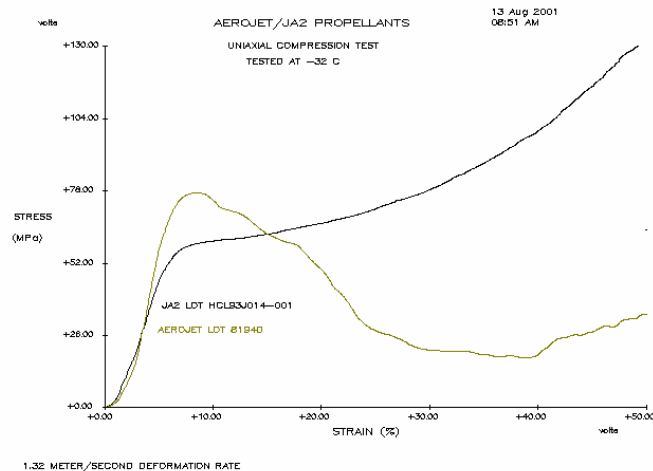


Figure 6. Stress vs. Strain Plot of JA2 and PAP 8194BB at -32 °C

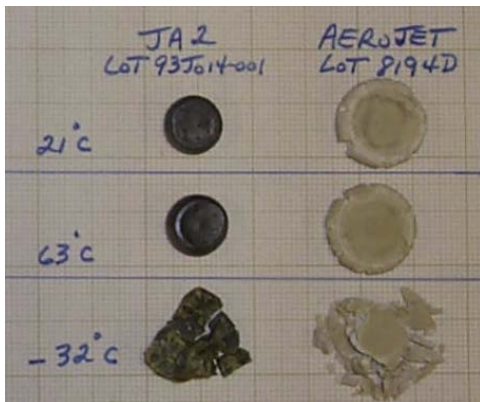


Figure 7. Remains of PAP 8194 and JA2 tested at 21 °C, 63 °C, and -32 °C.

The basic concept of this program was derived from the previous manufacturing processes of fabricating co-layered ETPE propellants in disk configurations. However, this program modified the process so that the process control and product quality were greatly increased to meet the program requirements. There were four major steps through which the ETPE propellants were processed into co-layered strips: 1) mixing and extrusion, 2) rolling, 3) sorting and trimming, and 4) lamination.

In order to determine the strength of a bond at the slow and fast burning propellant interface, the pull test was conducted. The two-layer samples were prepared and were attached to steel bars. The bars were slowly pulled by the machines in the same way as the tensile strength test. The samples were tested at three temperatures: 63 °C, 21 °C, and -32 °C (see Figure 8). All of the samples broke off at places other than the slow-fast propellant interface. This showed that the technique by which the layers of propellant are laminated is adequate and the laminated strips would not be likely to delaminate in the ballistic cycle. The SEM images also confirmed

that the two layers of propellant are tightly bonded at the interface as seen in Figure 9.

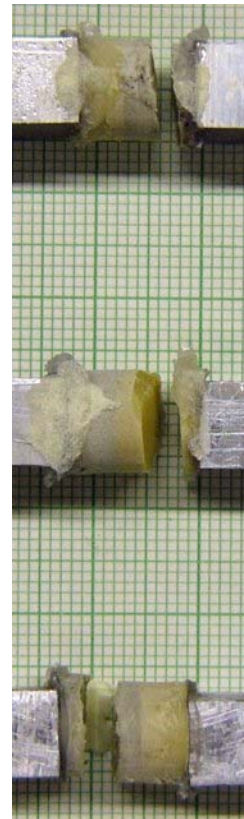


Figure 8. Tested Specimens of Co-Layered Material at -32 °C

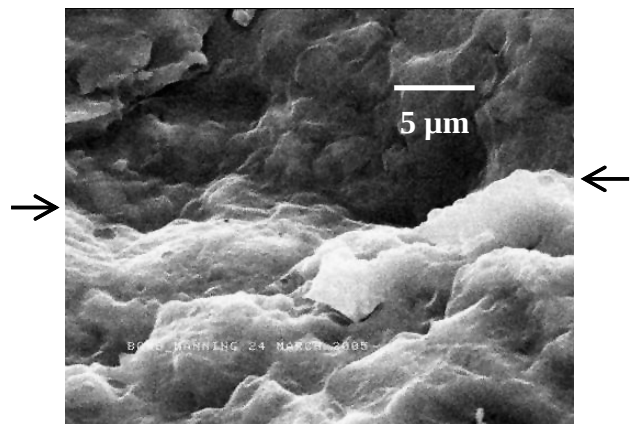


Figure 9. SEM Image of Tightly Bonded Slow-Fast Burning Layer Interface

2.3 Ballistic Test Firing

Enough co-layered ETPE propellant strips were manufactured to be assembled in 15 rounds. Each round was designed to contain 4 different grain configurations (shapes), and each configuration was comprised of 24 propellant strips thus totaling 96 strips per round.

Before the actual live rounds were loaded in the gun for test firing, an interior ballistic code (IBHVG2) was utilized to model and simulate the gun firing. The burn rates of co-layered ETPE propellants were acquired from closed bomb test (see Table 2).

Table 2. Burn Rates for Co-Layered ETPE Propellants (all three layers: Lots 8288-8194-8288)

Pressure (Kpsi)	Burn Rates (in/s) @ 63°C	Burn Rates (in/s) @ 21°C	Burn Rates (in/s) @ -32°C
20 (137MPa)	2.96	2.77	2.72
40 (275MPa)	8.63	8.15	7.75
60 (414MPa)	11.95	11.45	10.98

In addition, vivacity curves were plotted for all three temperatures to see if any sign of propellant break-up occurred (see Figure 10). The curves looked consistent across all three temperatures. As expected, the curves resembled a ‘step’ due to an abrupt change in gas generation rate at the interface of slow and fast burning layers.

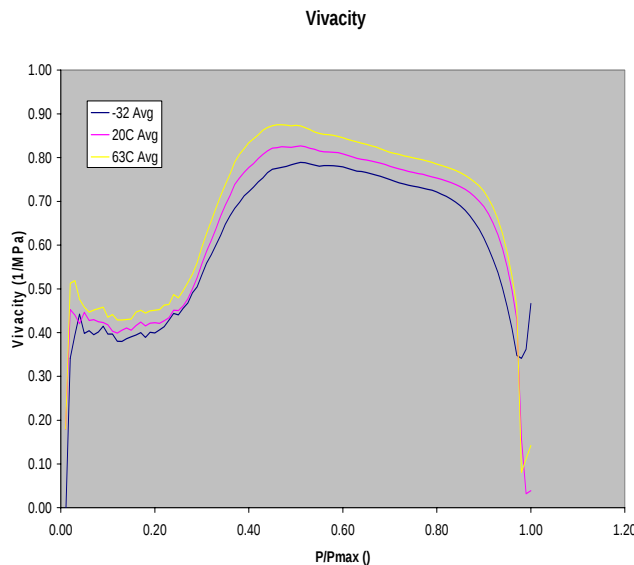


Figure 10. Vivacity Curves for Co-layered Radial Strips at 63 °C, 21 °C and -32 °C

Once the burning rates were obtained from closed bomb test, the rates were inputted in the interior ballistic code to predict the velocity of projectile. The curve with two peaks (first peak is more pronounced) in Figure 11 is the Pressure-travel curve. The first peak is unintentionally more pronounced, because the thickness of outer slow burning layer was higher than the target thickness due to processing limitations. The other curve in Figure 11 indicates the predicted velocity of projectile traveling down the gun tube. The maximum pressure of

the pressure-travel curve is 590 MPa which is below the maximum allowable pressure (675 MPa) in the 60 mm ETC gun test fixture. The muzzle velocity was predicted to be 762 meters per second. It was determined after various characterization studies that the co-layered propellants were safe to fire in the 60 mm ETC gun test fixture.

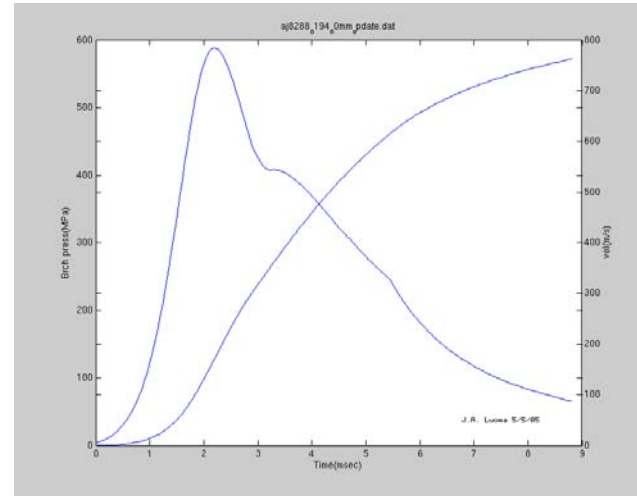


Figure 11. Theoretical P-t Curve and Projectile Velocity

The propellants were carefully loaded and fired in the systematically designed sequence. The first 3 rounds were loaded to the charge weight of 0.9, 1.0, and 1.14 kg. The charge weight of 1.14 kg was established which was used in the subsequent firing. The next 3 rounds were fired at 21 °C, and the 7th, 8th and 9th rounds were fired at 63 °C. Then the temperature at which the rounds were fired were incrementally lowered to -32 °C, and the last 3 rounds were test fired at -32 °C. The firing sequence is tabulated in Table 3.

Table 3. Ballistic Firing Sequence

Rounds	Purpose	Temperature
1-3	Charge Establishment	21 °C
4-6	Ambient	21 °C
7-9	Hot	63 °C
10-12	Cold Walk-down	0, -10, -20 °C
13-15	Cold	-32 °C

The ballistic firing results were mixed. The shapes of P-t curve did not quite resemble the predicted shape. Instead, the second peak was slightly higher than the first peak, and the height difference was less pronounced than the prediction. The maximum pressure was lower than the prediction while the muzzle velocity was comparable to the predicted values. However, at cold firings, the evidence of a minor propellant breakage and/or

delamination could be seen. Both the maximum pressure and muzzle velocity were higher in cold firings.

CONCLUSIONS

The energetic thermoplastic elastomer (ETPE) has many desirable characteristics as a gun propellant ingredient. It minimizes plasticizer migration, is recyclable, requires no solvent, is not hygroscopic, and is plastic when heated. However, it is very expensive, and the quantity is limited. The co-layered propellants in the radial strip configuration, when correctly designed, impart high muzzle velocity at lower maximum pressure. After initial characterization and downselection, PAP 8288 was chosen as the slow burning formulations and PAP 8194 was chosen as the fast burning formulation. The manufacturing process of ETPE co-layered propellants was developed at ARDEC and enough radial strips to cover 15 rounds were manufactured. The co-layered propellants were further characterized to verify whether it is safe to test them in the 60 mm ETC gun. The ballistic gun firing results were partially successful. At ambient and hot temperatures the pressure was low while achieving relatively high muzzle velocity. However, at cold temperature, the data showed the evidences of propellant break up and/or delamination.

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