“Green” Rocket Propellant Technologies Based on Energetic Thermoplastic Elastomers

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ABSTRACT

A propellant with an energetic thermoplastic elastomer-based binder was developed as a “green” rocket propellant. Characterization of the mechanical and ballistic properties and the demonstration of: 1) continuous processing, 2) recycle, recover and reuse (R^3) concepts and 3) full-scale motor tests were accomplished. Mechanical and ballistic properties are adequate for the application targeted.

INTRODUCTION

The formulation effort detailed in this paper is part of a program funded through NAVSEA Indian Head division.* The goal is to develop a rocket propellant considered “green” by supporting lower life cycle costs. These lower life cycle costs are achieved using an approach that has the following characteristics: 1) continuous material and munitions processing without solvent, 2) the ability to reprocess defective material and scraps into useful form, and 3) the ability to break down unneeded weapons into energetic materials for reuse. Traditional propellant systems based on thermoset elastomers, such as crosslinked polyurethanes, do not lend themselves to the above properties. The binder system developed, which enables all the desirable characteristics, is an energetic thermoplastic elastomer (TPE).

TPE’s combine the advantages of thermoplastics and thermoset elastomers. For example, they can be melted or dissolved in solvents like thermoplastics, but like thermoset elastomers, TPE’s exhibit elasticity below their melt temperature. This combination of properties is excellent for making rocket propellants that can be continuously processed, recycled and reused as detailed above. Thiokol currently produces energetic thermoplastic elastomers for use in rocket propellants, gun propellants and explosives.

Following development of our green rocket propellant our attention turned to the characterization of the mechanical and ballistic properties and the demonstration of: 1) continuous processing, 2) recycle, recover and reuse (R^3) concepts and 3) full-scale motor tests. All of which were successful.

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RESULTS AND DISCUSSION

Formulation: The formulation developed to demonstrate the green rocket propellant approach is shown in Table 1. Efforts to arrive at this formulation involved the study of AP and Al particle size. These efforts were detailed in a previous paper.[1]

Table 1. Typical propellant formulation.

Ingredient	Weight %
Energetic TPE	20.00
AP	63.00
Al	15.00
Ballistic Additive	2.00

Mechanical Properties: The propellant is not based on traditional thermoset elastomers, which yield excellent mechanical properties, thus we investigated the mechanical properties to confirm that they are acceptable. Some data are presented in Table 2.

Table 2. Typical Mechanical Properties.

	75°F 2ipm	20 °F 2 ipm	130 °F 0.02 ipm
$E^{2.6}$ (psi)	2990	7910	1470
ε_m^t (%)	10	9	5
$\varepsilon_m^{t,c}$ (%)	10	11	5
ε_f^t (%)	25	16	8
σ_m (psi)	159	500	44
$\sigma_m^{t,c}$ (psi)	174	549	46

The propellant exhibits about 10% strain at 75 °F 2 ipm. Although not as good as many thermoset elastomer-based propellants, this is adequate for a gun-launched cartridge-loaded grain.

Ballistic Properties: The ballistics of the formulation shown in Table 1, are illustrated in Figure 1. The burn rate vs. pressure data are similar to typical composite propellants and have shown the ability to be tailored to meet a variety of applications.

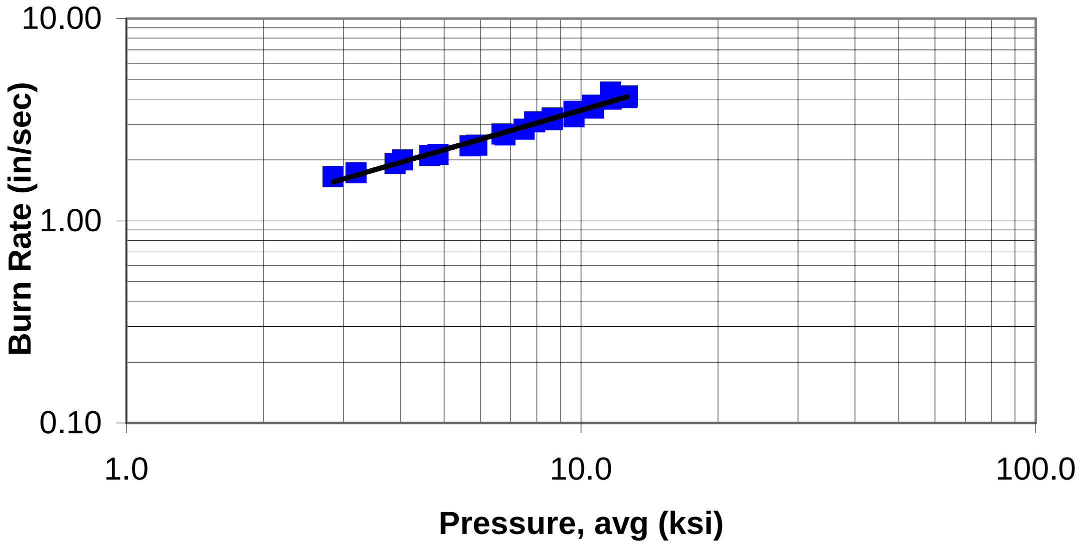

Figure 1. Typical plot of burn rate vs. Pressure

<u>Processing</u>: This formulation can be produced in a standard batch mixer up to the 1-gallon scale or with a twin-screw mixer/extruder. Both have been successfully demonstrated. Once propellant ingredients are combined, a pressing operation can form a variety of propellant grains.

<u>Recover, Recycle, Reuse (R^3) concepts</u>: Heating and reforming can easily reprocess scrap or otherwise unusable material. This has been demonstrated on several occasions. Full scale motors have been successfully tested employing reprocessed material. The recovery of energetic materials from unneeded grains has been demonstrated using a process based on solvent. This has been presented previously.[2] An R^3 process that is free of solvents is part of an ongoing investigation and will be the subject of a future paper.

<u>Full-scale motor tests</u>: To demonstrate the usefulness of this rocket propellant, a test article was constructed to fit flight designs. Conditions of the test were targeted to approximate useable design parameters. This required high pressure and 8000 psi was targeted. A schematic of the test motor is shown in figure 2. The testing performed to date is shown in Table 3 below.

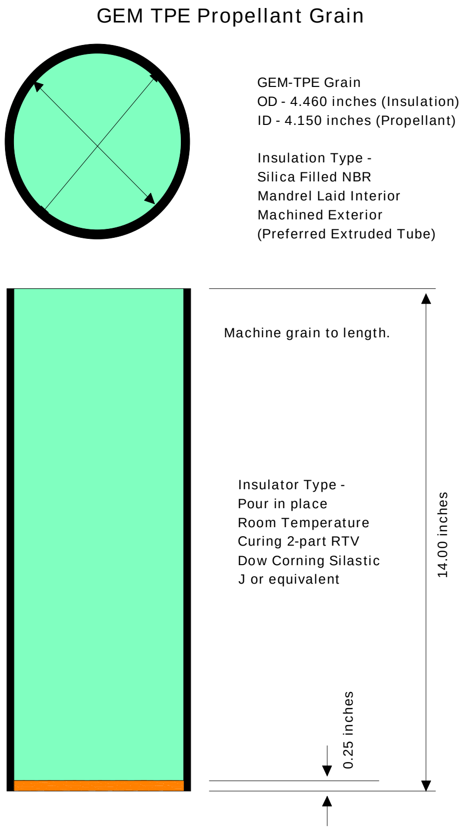

Figure 2. Demonstration grain for the Green rocket propellant

Table 3. Full-scale motor tests accomplished and planned.

Full-Scale Motor Tests					
Test number	Date	Propellant identification	Target Pressure	Average Operating Pressure	Comments
1	5 Jan. 1999	Batch	2680 psi	2645 psi	Low pressure test
2	20 Apr. 1999	Batch	8000 psi	2329 psi	Burn rate low
3	13 Oct. 1999	Batch	7209 psi	6837 psi	Pressure excursion
4	23 Nov. 1999	TSE IHDIV	8000 psi	6741 psi	Throat erosion
5	11 Oct. 2000	TSE IHDIV	8000 psi	-	Optimized process

As shown in Table 3, motor tests 3-5 targeted and achieved stable high pressure operation. Nozzle throat erosion has been observed as high as 5 mils/sec. However, the majority of tests exhibited <1 mils/sec erosion in nozzle throats. Burn rates observed in the motor tests matched the small-scale data collected prior to testing. A motor trace from one test is shown in Figure 3.

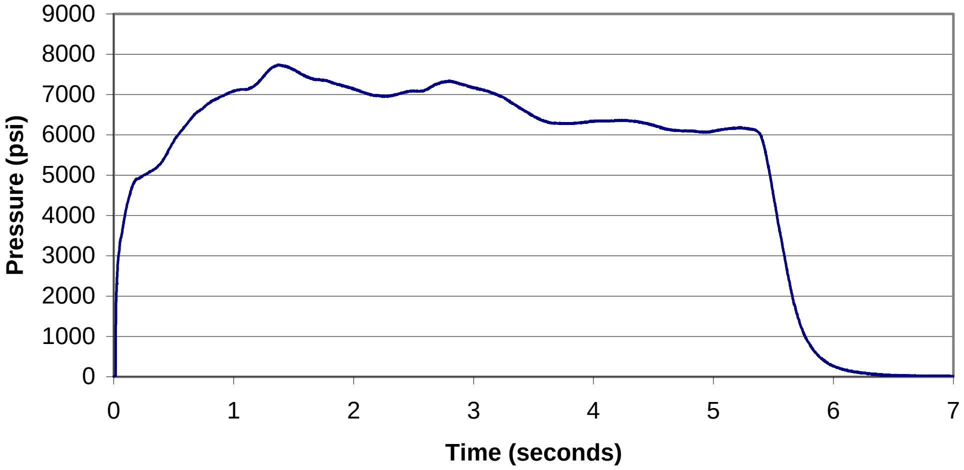

Figure 3. Example motor trace.

The motor trace exhibits some pressure excursions due to possible deformation of the grain, or a partial failure in the bond between the propellant and insulation, which both increase the burning surface area.

CONCLUSIONS

A propellant with an energetic thermoplastic elastomer-based binder was developed as a "green" rocket propellant. Characterization of the mechanical and ballistic properties and the demonstration of: 1) continuous processing, 2) recycle, recover and reuse (R^3) concepts and 3) full-scale motor tests were accomplished. Mechanical and ballistic properties are adequate for the application targeted

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1. Hamilton R.S.; Mancini V.E.; Wardle R.B.; Hughes C.D. Dovey H.N. “Ballistic Tailoring of an Oxetane Thermoplastic Elastomer Based Propellant for GEM” JANNAF Propellant Development and Characterization and Safety and Environmental Protection Subcommittee Joint Meeting; San Diego, CA; April 26-30 1999.

2. a) Hamilton R.S.; Mancini V.E.; Wardle R.B.; Hughes C.D.; Dovey H.N. “Scale up of Oxetane Thermoplastic Elastomer Based Propellant for GEM” JANNAF Propellant Development and Characterization and Safety and Environmental Protection Subcommittee Joint Meeting; San Diego, CA; April 26-30 1999. b) Hamilton R.S.; Mancini V.E.; Wardle R.B.; Hughes C.D.; Dewey M.A. A “Fully Recyclable Oxetane TPE Rocket Propellant” ICT Energetic Materials Meeting; Karlsruhe GERMANY; 1999.