

INSENSITIVE MUNITIONS ALUMINIZED PROPELLANT FOR TACTICAL BOOSTERS *

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ABSTRACT

Nitrate ester plasticized polyether propellants are being investigated in an attempt to reduce rocket motor response to insensitive munitions (IM) stimuli. Emphasis has been placed on the use of commercially available, sustainable materials and on the minimization of processing requirements. Earlier work, which included testing of full-scale motors, has suggested that the approach has merit. Recent improvements have resulted in promising propellant mechanical and bondline properties. Demonstration of IM capability in 8-inch-diameter motors has been completed.

INTRODUCTION

Reducing the degree of violence of rocket motor response to insensitive munitions (IM) stimuli, while maintaining performance and producibility, is a significant challenge. For the highest-performance applications, propellants have typically been formulated with hydroxyl-terminated polybutadiene (HTPB) polymer, along with high levels of oxidizer and/or nitramine. The excellent elastomeric properties achieved with HTPB and its low viscosity make such high-solids loadings possible and meet the mechanical property requirements for storage and firing throughout the temperature range of the tactical missile environment. The high performance of HTPB-based propellants, along with their relatively low cost, has made HTPB-based propellants quite prolific. Unfortunately, high-solids HTPB propellants, especially those containing nitramines, generally produce violent slow cookoff responses up to and including detonation. Reduced reaction violence with the use of composite case technology has been observed, but this alternative is not always an option.¹

Propellants incorporating nitrate ester plasticizers (NEPE propellants) have generally performed better than HTPB propellants with respect to slow cookoff, a characteristic that has made them attractive with respect to IM.²⁻⁶ With the NEPE propellants, a significant fraction of the propellant's energy is contained in the energetic binder, which decomposes at a temperature lower than that of the energetic solids. As a consequence, propellant ignition occurs before these solid ingredients have reached their decomposition temperatures, a situation that results in the absence of the self-heating and porosity/swelling that are associated with HTPB propellants and, subsequently, a milder reaction occurs. While the NEPE propellant can provide better outcomes with respect to slow cookoff, the detonability of some of these propellants precludes their use as IM propellants because of their tendency to detonate during impact or shock events.

To take advantage of the superior cookoff response of NEPE propellants and to minimize the response to impact and shock, IM propellant formulators have been using the less-energetic nitrate ester plasticizers with polyether polymers, along with low levels of nitramine. To achieve performance comparable to that of the HTPB propellants, ammonium perchlorate (AP) levels have to be higher than typically used in NEPE propellants, but the

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solids levels are still lower than those found in HTPB propellants. Compared to HTPB propellants of comparable energy and burn rate, the “modified” NEPE propellants result in improved slow cookoff response and keep detonability low. Incorporating this technology with that of an IM case and possibly of a bore mitigant through a systems approach increases the potential for passing the IM tests outlined in MIL-STD-2105B.⁷

APPROACH

The approach Thiokol and NAWCWD personnel have taken for IM propellant development has been to use moderate-energy NEPE binders for reduced cookoff violence, along with low levels of nitramine to improve high performance but minimize detonability. Emphasis has been placed on the use of ingredients that are commercially available, are sustainable, and do not require special handling techniques.

RESULTS

The results of some early slow cookoff screening tests with an HTPB propellant and a modified NEPE propellant are shown in Figure 1. Both propellants were aluminized, contained nitramine and AP, and exhibited similar performance and burn rates. The small cookoff bombs (SCBs), essentially closed pipes, each held about 1 lb of propellant. Each SCB was instrumented with two thermocouples, one placed near the case wall and one in the center of the propellant. A vent hole was used to simulate a nozzle and sized to accommodate normal propellant burning at room temperature at a pressure consistent with the rocket motor of interest.



**Modified NEPE
Propellant**



**HTPB
Propellant**

FIGURE 1. Results of Small Cookoff Bomb Testing of Modified NEPE and HTPB Propellants.

The difference in reaction violence between the two test articles is clear. The modified NEPE propellant simply burned, while the HTPB propellant exploded, which caused the cylindrical case to rupture and leave dents (about 8 mm deep) in the 13-mm-thick mild steel plates bolted to the ends of the case. The SCBs were slowly heated at 3°C per hour, and reaction occurred at 152°C for the modified NEPE propellant and 203°C for the HTPB propellant. Internal self-heating was not observed for either sample.

Slow cookoff testing of the two propellants was repeated with 120-lb steel-cased rocket motors. Even at the larger scale, the reduced reaction violence of the modified NEPE propellant was noticeable, particularly for pieces heavier than 5 lb, as seen in Figure 2. For the remaining pieces, the average distance thrown was about one-third to one-half shorter for the modified NEPE propellant than that observed for the HTPB propellant. Slow cookoff testing was also done in full-scale dual-grain motors. The contribution of the modified NEPE propellant to the reduced reaction violence was somewhat nebulous, however, because the full-scale motors used a hybrid steel composite case and a second IM propellant.²

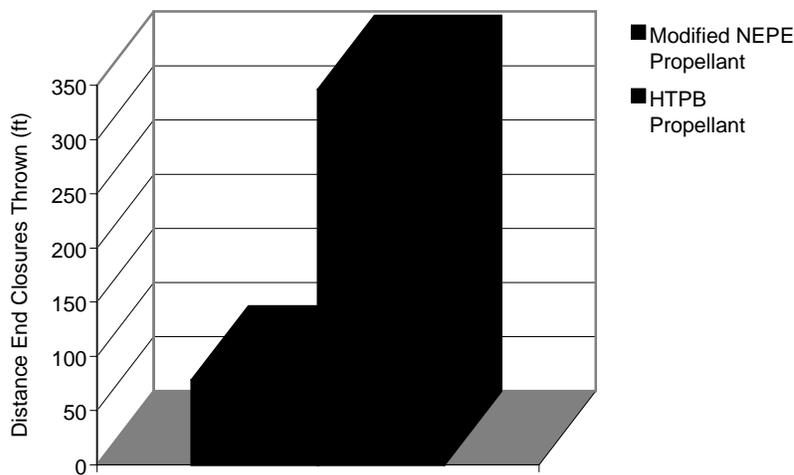


FIGURE 2. Results of Slow Cookoff Testing of 8-inch-diameter, 120-lb Steel-cased Rocket Motors Containing Modified NEPE and HTPB Propellants.

MIXED POLYETHER PROPELLANT DEVELOPMENT

The first modified NEPE propellants showed that improved IM response without loss of performance could be realized. Recent work has focused on improving their mechanical properties and aging characteristics and on improving the propellant–liner bond. While early work was done using polymers that were difficult to process because of their high melting points, polymers identified recently have pour points well below room temperature and are low-cost, commercially available materials. The best overall properties have been obtained with a formulation that uses mixed polyether polymers. The polymer change has not affected the propellant’s thermal decomposition temperature. Consequently, retention of the improved response to slow cookoff (with respect to HTPB propellant) is expected.

As seen in Table I, the elastomeric properties of this mixed polyether (MPE) propellant are excellent. Strain capability generally improves as temperature is reduced and strain rate is increased, a characteristic observed under both ambient and pressurized conditions. Testing at high temperature and low rate is done to simulate long-term storage. The results obtained at 145°F indicate that the MPE propellant’s strain endurance is high, possibly even greater than that of HTPB propellants, a characteristic that suggests that the MPE propellant could be suitable

for similar applications and designs. Five 5-gallon mixes of the MPE propellant were made for fabrication of one 40-lb static test motor and four IM motors. Variability was relatively low as the standard deviation of the propellant's tangent modulus was 40 psi (75°F, 2 inches per minute) for the five mixes. For the corrected stress, the standard deviation was only 4 psi.

TABLE I. MPE Propellant 5-gallon Mix Mechanical Properties.

	-20°F, 20 inches per minute	75°F, 2 inches per minute	145°F, 0.02 inch per minute	45°F, 200 inches per minute, 1000 psi
$E^{2.6}$, psi	2635	383	182	811
ϵ_m^t , %	89	62	33	86
$\epsilon_m^{t,c}$, %	94	62	33	101
ϵ_f^t , %	96	63	33	108
σ_m , psi	367	107	42	449
σ_m^c , psi	701	173	56	870
Shore A		52		

$E^{2.6}$ = tangent modulus, ϵ_m^t = true strain at maximum stress, $\epsilon_m^{t,c}$ = true strain at maximum corrected stress, ϵ_f^t = true strain at failure, σ_m = maximum stress, σ_m^c = maximum corrected stress.

Before the motors could be fabricated, a suitable liner needed to be identified and bondline properties needed to be characterized. The solubility of the nitrate ester plasticizer in the liner that was chosen is relatively low, a factor that weighed heavily in the selection process. Good bondline results were obtained as tensile specimen failure was consistently in the propellant. Tensile strength was similar to that of the propellant at comparable temperatures and rates. The hardness profile revealed a neutral to slightly hard propellant layer adjacent to the liner.

The viability of the propellant and the bond system for low-temperature transportation and storage was verified using 5-inch-diameter analog motors (See Figure 3). Four motors were fabricated with 3/4-inch-diameter bores and 8-inch-long propellant grains. Each motor was insulated and lined. A 1/2-inch-long insulation flap was used at the end of the propellant grain to eliminate edge effects. After pretest X-ray, the motors were temperature cycled between -20 and 0°F for 1 month. The number of cycles ranged from one, for Motor No. 4, to ten, for Motor No. 1.

From the bore diameter measured at -20°F, a maximum bore strain of 14% was calculated. After 4 weeks, no propellant cracks were observed, nor did the motor bore size measurements indicate that the propellant–liner bond had failed.

In an attempt to determine the maximum strain capability of the motors after temperature cycling, the temperature was lowered to -30°F for 4 days. No cracks were observed in the motor bores even though the measurements indicated that the bore strain increased to 17%. When an attempt was made to decrease the temperature to -35°F, the conditioning box failed. Post-test X-rays indicated no defects in any of the four motors.



FIGURE 3. Analog Motors Used for Verification of Low-temperature Storage Capability.

MIXED POLYETHER PROPELLANT IM TESTING

All the mixed polyether propellant tests were performed at NAWCWD on live 8-inch analog motors loaded with 53 lb of boost propellant developed by Thiokol Propulsion. One of the IM motors is shown in Figure 4. The composite cases, provided by NAWCWD, were specifically designed for screening new propellants for IM and performance properties.⁸ The motor case was an epoxy-resin-impregnated carbon fiber with Kevlar® overwrap and contained no igniter. A 1.25-inch-diameter hole in the aft plate served as a dummy nozzle. The test article was 8 inches in diameter and 29 inches in length, with a total weight of 104.9 lb. These tests were not performed for score. Post-cure X-ray analysis of the loaded motors showed them to be free of propellant–liner debonds and free of propellant voids.



FIGURE 4. Eight-inch-diameter Test Bottle (IM Motor Without Dummy Nozzle) Loaded With MPE Propellant

The fast cookoff test was conducted on 13 April 2000. One 8-inch analog motor loaded with 53 lb of DL-N240 propellant was subjected to the fast cookoff environment of MIL-STD-2105B. The unit was instrumented with five thermocouples. One measured internal temperature and the other four measured flame temperature across the length of the motor. The flame temperature reached 1000°F 35 seconds after the fuel was ignited. From that time until venting of the motor was first seen and heard, the average temperature was 1748°F. Venting ceased at 3 minutes, 2 seconds. Eighty-seven percent of the non-energetic material was recovered directly under the test apparatus, with forward and aft motor pieces being shown in Figure 5. The Ordnance Hazard Evaluation Board judged this a Type V (Burn) reaction.



FIGURE 5. Material Recovered Following Fast Cookoff Testing of IM Motor.

The slow cookoff test was conducted on 11 April 2000. One 8-inch analog motor loaded with 53 lb of propellant was subjected to the slow cookoff environment of MIL-STD-2105B. The unit was instrumented with nine thermocouples. The temperature of the test article was raised at 6°F per hour from 89 to 294°F. The reaction started at 35 hours and 31 minutes into the test. A fireball, accompanied by a loud report, was seen. Burning propellant and other motor components were hurled from the center of the reaction. Burning and venting continued for approximately 4 minutes. The largest piece found was the aft end of the motor. This piece, shown along with other recovered pieces in Figure 6, weighed 38.23 lb and was found 163 feet from the center of the test area. The Ordnance Hazard Evaluation Board judged this a Type IV (Deflagration) reaction.

The bullet impact test was conducted on 7 April 2000. One 8-inch analog motor loaded with 53 lb of propellant was subjected to the bullet impact environment of MIL-STD-2105B to determine the response of the motor to multiple .50-caliber bullet impacts. Three .50-caliber rounds (2800 ±200 feet per second) were shot at the motor at intervals of 75 ms. The rounds were aimed at the center of the motor on the centerline and 1/8 inch on either side. Venting could be seen immediately after the bullet impacts. At 21 seconds, a portion of the motor fell from the test stand onto the witness plate. At 1 minute, 8 seconds, all venting ceased, but burning could be seen for several more minutes. Ninety-four percent of the non-energetic material and 18% of the energetic material were recovered, as seen in Figure 7. The Ordnance Hazard Evaluation Board judged this a Type V (Burn) reaction.



FIGURE 6. Material Recovered Following Slow Cookoff Testing of IM Motor.



FIGURE 7. Material Recovered Following Bullet Impact Testing of IM Motor.

The fragmentation impact test was conducted on 13 April 2000. One 8-inch analog motor loaded with 53 lb of propellant was subjected to the fragmentation impact environment of MIL-STD-2105B. Five fragment cubes were propelled at the motor at 8100 feet per second. A fireball was seen as the motor was impacted and the motor broke into several pieces. Venting and burning continued for 1 minute and 18 seconds. Ninety-two percent of the non-energetic material and 5% of the energetic material were recovered after the test. The aft end of the motor is shown in Figure 8. The Ordnance Hazard Evaluation Board judged this a Type V (Burn) reaction.



FIGURE 8. Material Recovered Following Fragment Impact Testing of IM Motor.

CONCLUSIONS

A low-cost, aluminized, mixed polyether propellant has been developed to reduce rocket motor response to IM stimuli. The propellant's binder incorporates a mixture of low-cost, commercially available polyether polymers with a relatively low level of nitrate ester plasticizer. The propellant is AP oxidized, with some nitramine incorporated to enhance performance. Propellant performance is relatively high, equivalent to that achievable with high-solids HTPB/AP/aluminum propellant. The Naval Ordnance Laboratory large-scale gap test is a no-go at zero cards.

The propellant has excellent mechanical properties over a broad range of conditions. High-temperature, low-rate tensile testing indicates that the propellant's strain endurance could be as high as 35%. Under firing conditions, pressurized strain approaches 100%. Good propellant–liner bond has also been demonstrated with lined panels and several motor configurations. Five-inch-diameter analog motor testing showed that the propellant/bond system had an acceptable low-temperature storage capability.

Eight-inch-diameter IM test motors were cast with 53 lb of the mixed polyether propellant and delivered to NAWCWD for IM testing. Bullet impact, fragment impact, and fast cookoff testing resulted in burn reactions. A deflagration was observed for the slow cookoff test. Though not a “pass,” this outcome is an improvement compared to HTPB propellants that explode in this configuration and is a satisfying result in light of the propellant's high performance, its moderate burn rate, and its use of low-cost ingredients with no special handling requirements.

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