PROPELLANT DEVELOPMENT FOR INSENSITIVE MUNITIONS: IM TESTING*

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ABSTRACT

CSD has developed and IM tested two aluminized propellants. The first, UTP-33,000, is an HTPB binder propellant having a total solids loading of 86.5 wt-%. The second, UTP-32,070, is a polyether/polyester propellant having a total solids loading of 84 wt-%. Excellent mechanical and ballistic properties were obtained on both propellants. The two propellants were IM tested in 8-inch-diameter graphite composite cases. The four IM tests were BI, FI, FCO, and SCO. Both propellants performed well in the IM tests. In addition to the IM tests, both propellants underwent BVR tests. Unburned propellant was recovered from each of the BVR tests, and no detonations occurred.

INTRODUCTION

The objective of this effort was to provide a fundamental understanding of the IM response characteristics of two promising propellant systems considered as candidate technologies for Navy missile propulsion development.

The program development logic is presented in Fig. 1. This program is a collaborative effort with NAWCWD. In Phase I the Navy supplied the graphite composite motor cases and conducted the IM testing. Phase I of the program has been completed and a downselect to the polyether/polyester propellant has been made for evaluation in full-scale motor testing in Phase II .The two propellants developed on this program (HTPB and polyether/polyester) are delineated in the following sections.

EXPERIMENTAL

HTPB PROPELLANT VERIFICATION

The HTPB propellant, UTP-33,000, evaluated on this program was selected from CSD's well characterized Class 1.3 HTPB family of propellants. The UTP-33,000 propellant was derived from a CSD flight-proven booster propellant that had passed the 8-inch super card gap test. Figure 2 presents a graphical view of the HTPB propellant ingredient selection. In order to arrive at the final formulation parameters, a series of 1-gal and 5-gal mixes were made and characterized. The 25-gal mix formulation is shown in Table I.

The viscosity/potlife of the 25-gal mix is shown in Table II. Although the potlife of the propellant exceeded 6 hr, it was somewhat shorter than the 8–10 hr expected.

The mechanical properties of UTP-33,000-25/481 are given in Table III. The standard rate JANNAF properties are very good over the entire temperature range (140 to –65°F); the properties at ambient temperature (70°F) are exceptional. The high rate (200 in./min) pressurized (1000 psi) JANNAF properties are also very good. The biaxial strain was over 60%.

The HTPB propellant UTP-33,000-25/481 was tested in CSD's standard 4-lb motor configuration. A real time ballistic trace of one of the 4 lb motor tests is shown in Fig. 3 along with the pressure/rate data. This HTPB propellant has a burn rate of 0.251 in/sec at 1000 psi and a pressure exponent of 0.31; the π_k (0.12%/°F) is in the typical range. The IM testing of this propellant is described in a following IM test section.

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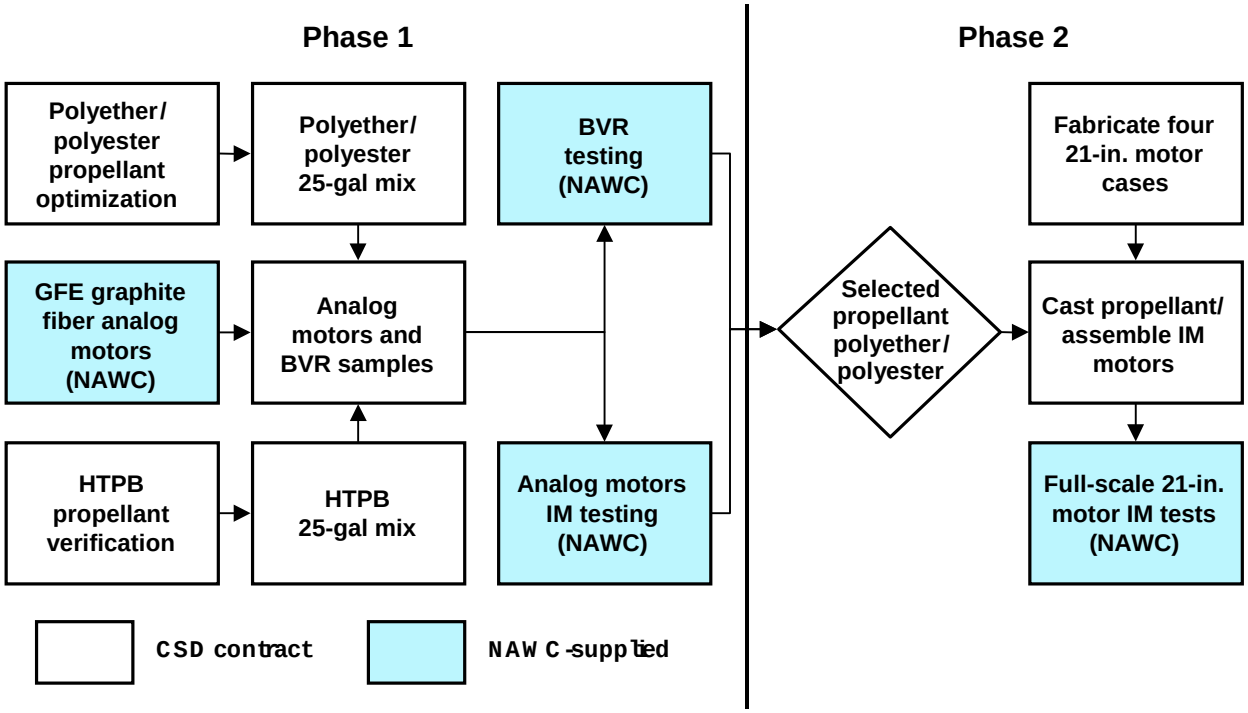

FIGURE 1. Program Logic

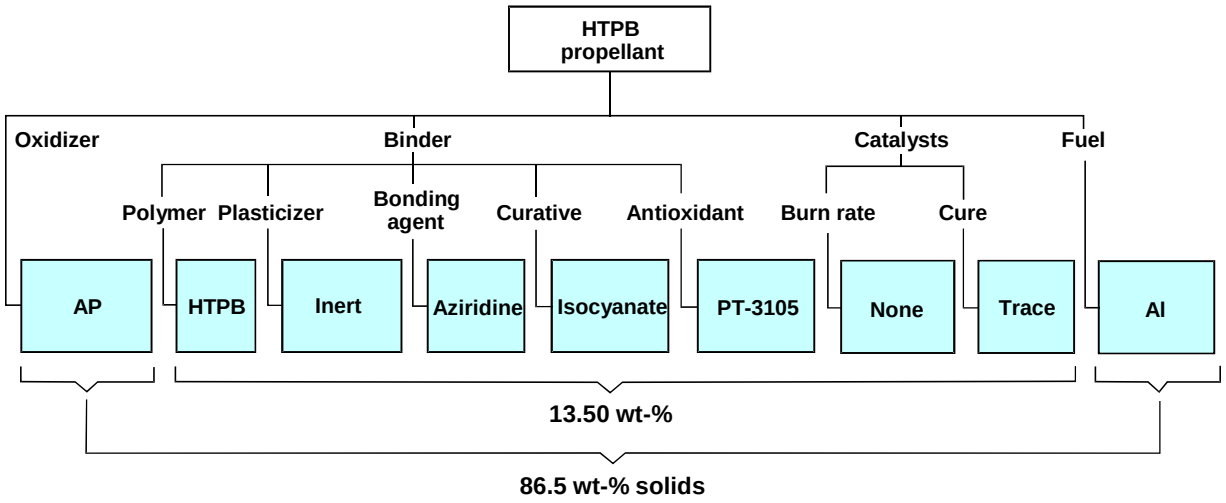

FIGURE 2. HTPB Propellant Ingredient Selection

TABLE I. UTP-33,000-25/481 Mix Formulation

Ingredient	wt-%
Polymer, HTPB Plasticizer, inert Bonding agent Antioxidant Cure catalyst	13.5
Oxidizer, AP	86.5
Fuel, Al	
Batch size 220 kg/~485 lb	

TABLE II. Viscosity Potlife UTP-33,000-25/481

Time, hr	EOM	2	4	6	8
Viscosity at 5000 dynes/cm^2, Kp	1.7	2.7	7.4	27.9	115

TABLE III. Mechanical Properties Evaluation, UTP-33,000-25/481

Batch	Temperature, °F	Rate, in./min	E_0, psi	σ_m/σ_{mc}, psi	$\varepsilon_m/\varepsilon_{mc}/\varepsilon_R$, psi
25/481	**Uniaxial JANNAF Data**				
7-day cure at 140°F	70 140	2 2	222 127	47/93 38/77	91/103/104 101/108/109
10-day cure at 140°F	70 140 –40 –65 70 70 –40 –40	2 2 2 2 200 at 14.7 psi 200 at 1K psi 200 at 14.7 psi 200 at 1K psi	405 140 5,309 12,279 1,297 1,271 9,596 13,084	55/108 38/75 246/501 580/716 95/161 218/423 533/780 1096/1434	93/102/103 93/98/99 95/121/127 12/52/60 16/110/114 81/117/135 23/53/53 30/32/32
	Biaxial JANNAF Data				
	70	2	465	45/69	29/61/62
	Relaxation Modulus, 5 years				

	70	—	21	—	—

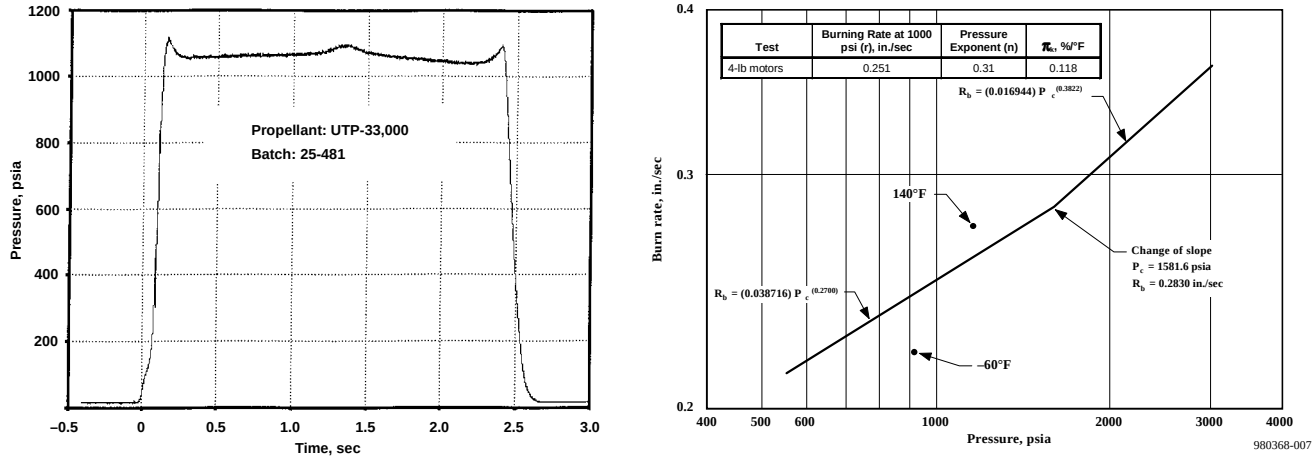

FIGURE 3. 4-lb Motor Ballistic Data, UTP-33,000-25/481

POLYETHER/POLYESTER PROPELLANT OPTIMIZATION

The polyether/polyester propellant development followed the optimization procedure outlined in Fig. 4.

Select Solids Loading
- Meet or exceed current performance parameters
  - — Oxidizer type

Process Wide Range AP Sizes
- Match burning rate of UTP-33,000, the HTPB Propellant
  - — Oxidizer size

Optimize Mechanical Properties
- Plasticizer content/type
- NCO/OH ratio and NCO type
- Cross-linker content/type
- Bonding agent content/type

FIGURE 4. Polyether/Polyester Propellant Optimization

Presented in Fig. 5 are the ingredients that were used in the subscale 1- and 5-gal mix studies.

The UTP-32,070 25-gal mix formulation details are presented in Table IV. The propellant UTP-32,070-25/486 processed very well and had an excellent end-of-mix viscosity and a potlife that exceeded 8 hr (see Table V).

The mechanical properties for UTP-32,070-25/486 are presented in Table VI. The properties are very good over the entire temperature range for both the standard rate (2 in/min.) and high rate (200 in/min) JANNAF tests. The 5-year relaxation modulus is 87 psi, which was excellent.

The 4-lb motor ballistic data is shown in Fig. 6. The propellant has a burn rate of 0.276 in/sec at 1000 psi and an excellent low pressure exponent of 0.244 all the way out to 3000 psi test pressure. IM evaluation of the UTP-32,070-25/486 propellant is presented in the following IM section.

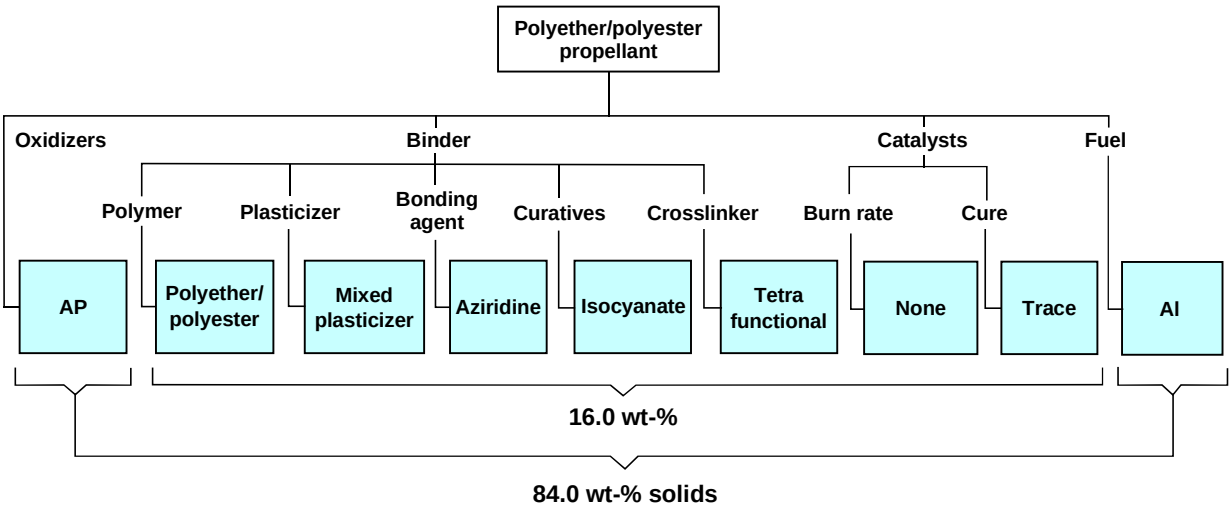

FIGURE 5. Ingredient Trade Study

TABLE IV. UTP-32,070-25/486 Mix Formulation

Ingredient	wt-%
Polymer, polyether/polyester Cross-linker Plasticizer, mixed Bonding agent Cure catalyst Isocyanate	16.0
Oxidizer, AP	84.00
Fuel, Al	
Batch size 220 kg/~485 lb	

TABLE V. Viscosity/Potlife, UTP-32,070-25/486

Time, hr	EOM	2	4	6	8
Viscosity at 5000 dynes/cm^2 Kp	0.51	0.54	0.54	0.59	0.70

TABLE VI. Mechanical Property Evaluation, UTP-32,070-25/486

Batch	Temperature, °F	Rate, in./min.	E_0, psi	σ_m/σ_{mc}, psi	$\varepsilon_m/\varepsilon_{mc}/\varepsilon_R$, psi
25/481	**Uniaxial JANNAF Data**				
7-day cure at 140°F	70 140 40 0 –40 –65 70 70 –40	2 2 2 2 2 2 200 at 14.7 psi 200 at 1K psi 200 at 1K psi	512 292 838 1837 5313 10,511 1370 1612 21,113	103/147 77/111 129/171 205/255 334/387 581/646 159/219 339/603 1300/1523	42/49/55 45/50/52 33/37/45 25/28/34 16/18/48 12/14/24 35/44/59 74/88/93 18/18/19
	Relaxation Modulus, 5 years				
	70	—	87	—	—

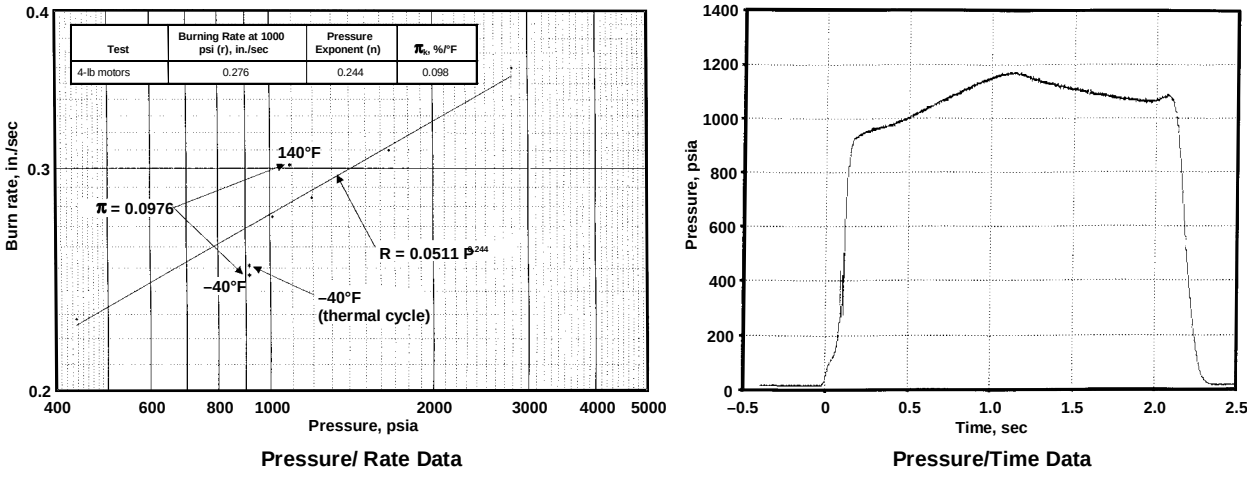

FIGURE 6. 4-lb Motor Ballistic Data, UTP-32,070-25/486

IM TESTING

The HTPB propellant, UTP-33,000-25/481, and the polyether/polyester propellant, UTP-32,070-25/486, were tested at NAWCWD for IM compliance in a NAWCWD-designed and manufactured graphite composite case motor. The configuration of this motor is shown in Fig. 7. In addition to the IM motor tests, each propellant was subjected to a series of three BVR tests (see Fig. 8). The results of the IM tests are summarized in Table VII. The IM tests were all ”passes” with the exception of the SCO test on the HTPB propellant, which had a rather violent deflagration that resulted in an overpressure of 2.8 psi. The SCO of the polyether/polyester propellant was a “pass” based on the fact that no lethal fragments went outside the test area, there was no measured overpressure and the motor case remained attached to the stand.

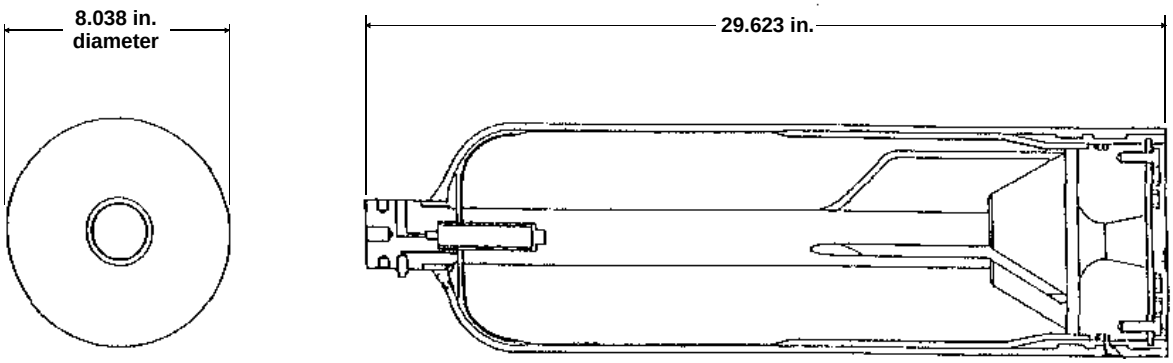

FIGURE 7. NAWCWD Standard Graphite Case Motor

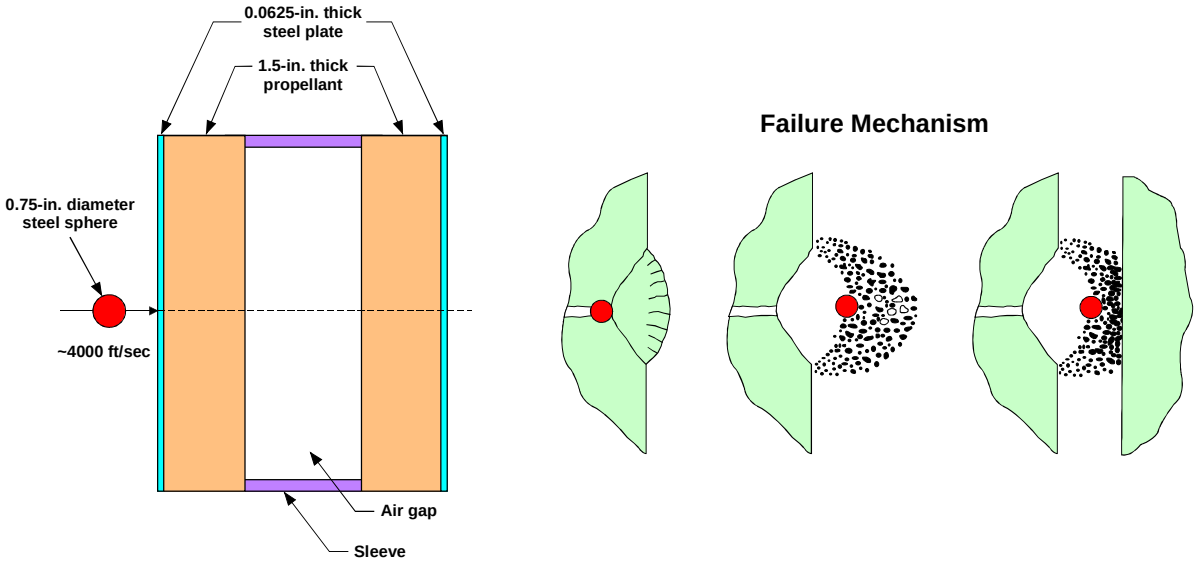

FIGURE 8. NAWCWD BVR Test

TABLE VII. Summary of IM Test Results

Propellant	IM Tests			
	BI*	**FI***	**FCO***	**SCO***
HTPB UTP-33,000	No overpressure, no lethal debris outside test area, moderate reaction PASS	No overpressure, no lethal debris outside test area, moderate reaction PASS	No overpressure, no lethal debris outside test area, burning PASS	2.8 psi overpressure, lethal debris outside test area:400°F cook off, partial detonation FAIL
Polyether/polyester UTP-32,070	Burn only, moderate initial reaction with no overpressure	Burn only, no overpressure, no lethal debris outside	Burn only, no over-pressure , no debris outside test area	Burn only no overpressure, no lethal debris outside

	PASS	test area, PASS	PASS	test area: 377^{0}F cook-off PASS
*The pass/fail results were officially determined by the review board of NAWCWD China Lake, CA .				

The BVR tests on both propellants resulted in no detonations (as measured by the low overpressure recorded on the gauges), and in all cases there was unburned propellant — in some cases from both the front and rear plates.

SUMMARY AND CONCLUSIONS

Two propellants have been formulated, processed, and characterized. The HTPB propellant, UTP-33,000, and the polyester/polyether propellant, UTP-32,070, both exhibited the following properties:

1. Good processibility (flowed into the motors to produce void-free grains)
2. Good pot lives
3. Excellent ballistic performance
4. Very good mechanical properties
5. Good IM characteristics (SCO a fail, however, for the HTPB)

A downselect to the polyether/polyester propellant has been made and will be used in Phase II of the program. A CSD-designed and –manufactured 21-in. diameter motor will be used for IM testing of the downselected propellant.

ACKNOWLEDGMENT

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ACRONYMS

BI	bullet impact IM test
BVR	burn to violent reaction test
CSD	Chemical Systems Division
FCO	fast cookoff IM test
FI	fragment impact IM test
HTPB	hydroxy-terminated polybutadiene
IM	insensitive munitions
NAWCWD	Naval Air Warfare Center Weapons Division, China Lake, California
SCO	slow cookoff IM test