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NON-NEWTONIAN LIQUID PROPELLANT (NNLP) SENSITIVITY: PRELIMINARY STUDIES

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Samples of non-Newtonian liquid propellants containing various concentrations of RDX, TAGN, and TAE tested for sensitivity to impact, friction and electrostatic discharge, and hot fragments (vulnerability) were compared against similar test results obtained from solid propellants (M30 and XM39 LOVA) and liquid propellants (NOS 365 and OTTO Fuel II). The data indicated that high energy non-Newtonian liquid propellants can be safely processed. Keywords:

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INTRODUCTION

A propellant may be defined as an energetic material that will **safely** provide the necessary **force** to hurl a projectile swiftly and accurately to a specific target. Of the two goals, safety is more important and quite often a more difficult achievement. As a result, specific laboratory safety tests have been devised for materials which categorize propellants with respect to sensitivity to various stimuli. Materials displaying sensitivity levels that exceed prescribed "safe" limits can be either eliminated from further consideration or modified in some way to make then conform to acceptable sensitivity standards.

The purpose of this study is to screen a few experimental gel propellant (GP) formulations which are special types of non-Newtonian propellants for sensitivity to impact, friction, electrostatic discharge, and hot fragment conductive ignition (vulnerability) in order to guide future formulation efforts. Unfortunately, since no experimental data base for gel propellants is currently available, sensitivity data acquired from selected solid and liquid propellants had to be used as the initial basis of comparison.

These particular GP formulations contain two major ingredients, solid oxidizer and energetic liquid (fuel), and a minor ingredient which for convenience shall be referred to as a gelling agent. In the course of propellant processing, one or more solid oxidizers are dispersed into the energetic liquid with the aid of a modicum of gelling agent. The purpose of the addition of gelling agent is to ensure propellant structure stability. In a previous GP study (ref 1), the selected gel propellants were formulated with triaminoguanidinium nitrate (TAGN) and cyclotrimethylenetrinitramine (RDX) as the oxidizers and with either 2-azidoethanol (TAE) or bis (2,2-dinitropropyl) acetal-formal (BDNPA-F) as the energetic liquids.

The referenced investigation demonstrated that GP containing BDNPA-F displayed color changes during a six-month storage period which is indicative of potentially unstable properties and low combustion rates which did not meet targeted requirements. As a result, BDNPA-F was considered unsuitable for use in GP formulations and, accordingly, was eliminated from this program.

The GP candidates discussed in the present study feature only TAE as the energetic liquid, because TAE did not display any of the problems observed with BDNPA-F. The compositions, energy levels, and flame temperatues for the GP candidates are presented in table 1.

EXPERIMENTAL

Because the baseline of the sensitivity tests for gel propellants has not been established, the conventional solid propellant sensitivity evaluation tests were employed to screen gel propellant candidate. These tests include impact, impact cavity drop, sliding friction, electrostatic discharge and hot fragment conductive ignition tests. Impact testing was performed by both the laboratories of the Army at ARDEC, Picatinny Arsenal, NJ and the Navy Safety Office at Naval Ordnance Station (NOS), Indian Head, MD. The hot fragment conductive ignition test was conducted at ARDEC. All other tests, including the impact cavity drop, sliding friction, and electrostatic discharge were performed at NOS.

Impact Test

The impact sensitivities of several GP samples were measured by a standard technique in order to compare the results with values obtained with reference energetic materials. Impact sensitivity is defined as the minimum impact energy required to ignite a propellant or explosive. In general, it is measured in the laboratory by determining the minimum distance a given weight must fall onto an energetic material to induce ignitions.

At ARDEC, testing was conducted with an Explosive Research Laboratory (ERL) type 12 impact tester, which uses a 2.5-kg steel drop weight and a 30-mg sample placed on sand paper positioned between two steel anvils. The drop height corresponding to 50% probability of initiation measured by means of the Bruceton up-and-down method is used as a measure of impact sensitivity. The criterion for initiation was the observation of either burning or deflagration upon impact of the sample. A detailed description of the apparatus is contained in reference 2.

Although the NOS Safety Office employs a similar technique for the impact test with the Drop-Weight tester, there are specific differences such as a heavier drop weight (5.0 kg) and a smaller sample size (20 mg). The data are reported as the minimum drop height required to produce three successive initiations. A description of the apparatus is contained in reference 3.

Impact Cavity Drop Test

Impact cavity drop testing was also performed by NOS using a similar technique in which a 0.03-ml sample was placed in a cup rather than on sand paper positioned between two steel anvils. In this case, 2.0-kg drop weight was substituted for the 5.0-kg one. The test results were reported as the drop heights at which initiation is 50% probable. In this test, propellants are initiated by a complex compression mechanism involving propellant pressurization rate, heat transfer, thermodynamic gas/liquid properties, and hydrodynamic properties. Although the significance of this test is not fully understood, it is a useful, simple, and rapid laboratory tool to compare the sensitivities of nonsolid propellants on a relative scale. The test method and procedures used in this test are employed and recommended by the majority of the liquid propellant community as a standardized test technique (ref 4).

Electrostatic Discharge

The electrostatic sensitivity tests performed at NOS determine the minimum electrostatic discharge energy required to ignite the sample. This is accomplished with an approaching electrode apparatus in which electrostic energy is stored in a capacitor connected to the electrode. The capacitor is allowed to discharge into the sample at varying energy levels. The minimum electrostatic energy required to achieve ignition is then determined. If any evidence of combustion is observed such as the generation of smoke, flame, odor, or noise, the test is considered positive. Discharge energy is then adjusted until 20 consecutive positive tests can be achieved. A detailed description of this apparatus is contained in reference 3.

Sliding Friction Test

The sliding friction sensitivity test (ref 3) determined the minimum frictional energy required to ignite propellant samples. In this test procedure, a 50-mg sample is placed between a block and a wheel that is attached to a hydroulic ram which adjusts the force on the sample surface. A pendulum of selected weight is then allowed to strike the end of the block which causes the wheel to roll over the sample with a known frictional force. The maximum frictional force is then determined and can be applied to the sample without causing decomposition.

Hot Fragment Conductive Ignition Test

Hot fragment conductive ignition (HFCI) tests were performed to compare the relative vulnerability of the samples to ignition by an imbedded hot steel fragment. This test was developed by the Ballistic Research Laboratory as an experimental technique to screen new propellant formulations for vulnerability. The results give a crude approximation to the large-scale vulnerability test such as shaped-charge jet generated spall test which simulates one of the principal threats faced by tank systems during combat (refs 5, 6, and 7). The HFCI test was designed to model the conductive ignition from spall and to obtain a quantitative measure of a propellant's susceptibility to ignition stimuli.

In this test, a steel ball is heated in a tube furnace to preselect temperature and then dropped onto a propellant bed (approximately 10 grams) housed in a small glass beaker maintained at ambient conditions. The response of the propellant to this external stimuli is determined by observing if ignition occurs. The temperature is then raised or lowered by a 25°C increment depending on the response of the propellant. The test is iterated until the transition between ignition and nonignition is defined. Four fragments ranging from 0.43 g to 3.50 g were selected in this test to cover the spectrum of spall sizes most commonly generated by shaped charges.

RESULTS

Impact sensitivity data for GP samples tested at ARDEC (lots 7117 and 7117A) and at NOS (lots 7136, 7137, and 7138) (table 2) reveal that all the GP samples are less sensitive to impact than their referenced counterparts. In fact, the NOS tests indicate that the GP impact sensitivities equal or surpass the sensitivity limit (600 mm) of the NOS impact sensitivity device. Based on the NOS impact sensitivity guidelines (table 3), GP samples (lots 7136, 7137, and 7138) should be classified as having the lowest impact sensitivity. The other lots cannot be ranked on this scale because they were not tested under the same conditions (5.0 kg drop weight). However, all GP samples are significantly less sensitive than RDX and high energy LOVA propellant as indicated.

Impact cavity drop test data (table 2) indicate that the tested GP samples (lot 7136, 7137, and 7138) are all in the low sensitive region (table 3) and half as sensitive to impact than the known liquid propellant (LP) Otto Fuel II. Therefore, based on the results of the impact and the impact cavity drop test, it is suggested that gel propellants are insensitive to impact and are safe to handle in the propellant processing.

The electrostatic discharge data (table 4) indicate that 50-mg samples from lots 7136, 7137, and 7138 required 8.75, 6.25, and 2.75 joules, respectively, to achieve ignition. These values fall within the NOS low electrostatic sensitivity range of 1.125 to 12.55 joules (table 3) which suggest along with those values previously reported (ref 1) that no extreme electrostatic hazard exists in processing these gel propellants.

The data for friction sensitivity (table 5) indicate that GP samples 7136, 7137, and 7138 all fall within the low friction sensitivity range (750 to 1000 lb) with sliding friction values greater than 980 lb which is also the upper limit of the NOS friction testing device.

The vulnerability data (table 6) comparing gel propellants with M30 and standard LOVA XM39 solid propellants and NOS 365 and HAN 1845 liquid propellants indicate that all gel propellants tested were less sensitive than M30. GP samples 7121A, 7136, 7137, and 7138 were less vulnerable than XM39 LOVA and comparable to NOS 365 and HAN 1845 liquid propellants while the remainder were more vulnerable than XM39 LOVA and the liquid propellants.

CONCLUSIONS AND RECOMMENDATIONS

Although the data in this report are by no means comprehensive, the impact, friction, and electrostatic test results do, however, suggest that highly energetic gel propellants can be fabricated, processed, and handled safely. In addition, the vulnerability data indicate that highly energetic propellants of this type may well serve as high energy substitutes for solid LOVA propellants.

Future studies should include an investigation of the effect of oxidzer particle size on GP sensitivity and a comprehensive investigation on the effects of different gelling agents on GP properties.

Finally, testing techniques for nonsolid propellants (LP/GP) should be standardized and the results normalized to a meaningful standard scale.

Table 1. Gel propellant composition and thermochemistry

LOT	7117	7117A	7121A	7136	7137	7138
TAGN	20.0	30.0	23.3	10.0	10.0	10.0
RDX	40.0	30.0	45.6	50.0	55.0	55.0
TAE	40.0	40.0	31.1	40.0	35.0	33.6
AMMONIUM NITRATE	--	--	--	--	--	1.4
METHOCEL HB	1.0	1.0	--	--	--	--
ETHOCEL 10	--	--	0.5	0.5	0.5	0.5
IMPETUS, j/g	1165	1129	1205	1185	1223	1229
TEMP, K	2602	2479	2774	2707	2854	2888

Table 2. Impact sensitivity test results

	ARDEC	NOS	
Lot	2.5 Kg Wt* (mm)	5.0 Kg Wt** (mm)	Cavity Drop 2.0 Kg Wt* (mm)
RDX (CL–E)	230	150	---
HE LOVA II	448	300	---
OTTO II	---	---	105
7117	807	---	---
7117A	780	---	---
7136	---	600	239
7137	---	>600	304
7138	---	>600	208

* Height at which initiation is 50% probable

** Lowest height yielding 3 consecutive positive

Table 3. Range of sensitivity

TEST	RANGE		
	HIGH	MEDIUM	LOW
IMPACT,[1] mm	0–75	100–325	350–600
FRICTION[2]			
PROPELLANT, Lb	0–55	75–560	750–1000
INGREDIENT, Lb	0–30	40–420	560–1000
ELECTROSTATIC,[3] J	0.00125–0.00875	0.0125–0.865	1.125–12.5
CAVITY DROP,[4] mm	0–34	35–80	>80

NOTE:

1. 5.0 Kg DROP WEIGHT, LOWEST HEIGHT YIELDING 3 CONSECUTIVE POSITIVES
2. 8 ft/sec VELOCITY, MAXIMUM HEIGHT YIELDING 20 CONSECUTIVE NEGATIVES
3. 5 KV, MAXIMUM HEIGHT YILDING 20 CONSECUTIVE NEGATIVES
4. 2.0 Kg DROP WEIGHT, HEIGHT AT WHICH INITIATION IS 50% PROBABLE

Table 4. Electrostatic discharge test data

Lot	Discharge Energy @ 5 KV (joule)	Sensitivity Range
7136	8.75	Low
7137	6.25	Low
7138	2.75	Low

Table 5. Friction sensitivity test data

Lot	Sliding Friction @ 8 ft/sec (Lb_f)	Sensitivity
7136	>980	negative
7137	>980	negative
7138	>980	negative

Table 6. Hot fragment conductive ignition test

	FRAGMENT WEIGHT (g)			
	0.43	1.03	2.03	3.50
LOT	IGNITION TEMPERATURE (c)			
M30	363	338	313	288
LOVA STD	788	663	563	463
7117	488	463	388	363
7117A	538	488	438	413
7121A	>800	713	488	438
7136	>800	788	638	588
7137	>800	738	538	488
7138	788	763	688	488

NOTE: ABOUT 10g SAMPLE FOR EACH RUN

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