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Studies on Sensitivity of Nitrate Ester Plasticized Hydroxyl Terminated Prepolymer Based Energetic Solid Rocket Propellants

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Abstract: The sensitivities of energetic materials as well as advanced energetic solid propellants are invariably associated with the nature of the stimuli that are responsible for the initiation of their decomposition. Hence it is important to study the chemical processes involved with these decompositions. While assessing the potential application of new propellant formulations containing energetic materials, it is important to assess their sensitivity to the hazards involved during their handling, transport, storage and use. This paper reports the results of impact, friction, heat, spark and shock sensitivities of advanced high energy solid rocket propellant formulations based on nitrate ester plasticized, hydroxyl terminated prepolymer (SPB-255) as an energetic binder loaded with solid ingredients like ammonium perchlorate (AP), aluminium (Al) and cyclotetramethylenetetranitramine (HMX). The results of the small card gap test showed that they are more sensitive than a composite modified double base (CMDB) propellant, which in turn is more sensitive than double base (DB) as well as composite propellants. Deflagration to detonation transition (DDT) tests carried out for the advanced energetic propellant did not show any detonation phenomena. Trinitrotoluene (TNT) equivalence and super large scale gap (SLSG) tests have been carried out for the determination of hazard classification of the energetic solid rocket propellant. The requirements to achieve both higher performance in terms of improved energy (*i.e.*, specific impulse, Isp) and reduced sensitivity for the same propellant composition are contradictory; one should be sacrificed for the other, within manageable limits.

Keywords: sensitivity, impact, friction, card gap test, DDT test, SLSG test

1 Introduction

The ease with which decomposition of a material can be initiated is commonly described by the parameter called sensitivity, and different modes of initiation of decomposition reactions are described by different sensitivities, such as impact, friction, heat, spark, shock, *etc*. Sensitivity is the parameter that is commonly used to describe the ease with which decomposition of an explosive material can be initiated. In the solid state, the properties of isolated molecules can be altered by adjacent atoms or molecules and overlapping electrical fields. Furthermore, macroscopic properties such as the particle sizes of solid ingredients, the presence of cracks and voids in the solid propellant grains and the degree of confinement can dramatically alter the rate of energy release and thus can trigger a shift from deflagration to detonation phenomena (DDT). Typical reaction times of explosives and propellants are 10^{-6} s and 10^{-2} s, respectively [1].

Generally, the weakest bonds are the first to break, forming radicals or ions. Electronically or vibrationally excited states could also play a role. As the reaction proceeds and spreads, a front is formed, and depending on the rate of energy release, a deflagration or a detonation develops. Depending on the nature of the stimulus, different kinds of sensitivity can be defined. Thermal sensitivity refers to the combination of temperature and rate of heating. This results in ignition. The intensity of the shock pulse that can initiate and cause an explosion is a measure of shock sensitivity [2]. Energetic materials can also be initiated by friction and electrostatic charge, which are referred to as friction and electrostatic spark sensitivity respectively. The ease with which an explosive can be set off by impact, friction, electrostatic spark, heat and another explosive charge represents the sensitivity of a material. The sensitivities of energetic materials are often related to their thermal characteristics.

Energetic materials are composed of metastable molecules possessing high reactivity. They decompose producing smaller molecules and large amounts of energy (1-3 kcal/g). Traditionally, initiation has been thought to be due to the creation of high temperature by stimuli in the bulk or at localized sites, depending on the homogeneity of the material. When the rate of heat generation exceeds that of heat loss in the region of the hot spots, propagation and finally an explosion reaction occurs [3].

The sensitivity characteristics of any energetic material, whether it is an individual ingredient or an energetic formulation such as an advanced energetic solid propellant, referred to in this study, are of primary concern for handling such materials with utmost safety. Consequently, the sensitivities of advanced energetic solid propellants based on nitrate ester plasticized SPB-255 polymer with respect to heat, shock, friction, electric spark, *etc*. were studied. The impact and friction sensitivities of the individual energetic oxidizers such as AP and β-HMX were also determined to ascertain and compare their individual contributions towards the sensitivities of the formulations. Keeping in view the practical applicability of a nitrate ester plasticized SPB-255 polymer as an energetic binder for formulating advanced energetic solid propellant systems, the sensitivities of a representative SPB-255 polymer based propellant matrix, in terms of small card gap test, DDT test, SLSG test and TNT equivalence test, were also evaluated. The present work is in continuation of our earlier work on advanced energetic solid rocket propellants based on nitrate ester plasticized SPB-255 polymer. The density, specific impulse and characteristic velocity of detonation of the energetic propellant composition based on nitrate ester plasticized SPB-255 polymer have been found to be significantly higher than those of HTPB based composite propellants [4, 5].

2 Experimental

The polymer (SPB-255) under study is a polycaprolactone-based hydroxyl terminated prepolymer, synthesized in-house [6]. SPB-255 polymer is a soft white waxy solid having hydroxyl functionality 3.7-3.9, OH value 38-40 mg KOH/g and molecular weight, *Mn*, in the range of 5200-6200 by vapour-phase osmometry (VPO). All of the other major ingredients, such as nitroglycerine (NG), 1,2,4-butanetriol trinitrate (BTTN), ammonium perchlorate (AP), aluminium (Al) and cyclotetramethylenetetranitramine (HMX) were of Indian origin, whereas minor ingredients such as toluene di-isocyanate (TDI), isophorone di-isocyanate (IPDI), and dicyclohexylmethane-4,4′-di-isocyanate (H_{12}MDI), chain extenders such as *n*-butanediol (*n*-BD), cross linkers such as trimethylolpropane (TMP) and curing catalysts such as ferric acetylacetonate (FeAA), and triphenyl bismuth (TPB) used for this study were procured from Sigma-Aldrich (India) and used directly without further purification.

Advanced high energy propellant formulations, based on nitrate ester (NE) plasticized SPB-255 polymer, an energetic binder, loaded with HMX-AP-Al and cross-linked with IPDI were processed and the samples were evaluated for their sensitivities with respect to heat, shock, friction, electric spark, *etc*. The sensitivities of desensitized nitrate esters (NEs), cured energetic binder sheet and cured propellants to impact stimuli were determined using the Fall Hammer Method (2 kg drop weight) on a Julius Peters Apparatus as per the Bruceton stair case approach [7] and the results are given in terms of 50% probability of explosion (h_{50}) obtained statistically. The friction sensitivities of all of the compositions were determined by using a Julius Peters (Germany) apparatus as per BAM standards [8]. The values reported in this paper are as the maximum weight at which none out of six tests exploded. The shock sensitivities were determined as per the standard small Card Gap Test. The other measured sensitivity parameters were spark sensitivity, ignition temperature, Deflagration-to-Detonation test (DDT), trinitrotoluene (TNT) equivalence and Super Large Scale Gap (SLSG) test.

3 Results and Discussion

The impact sensitivities for the individual energetic nitrate ester plasticizers *viz*. nitroglycerine (NG), 1,2,4-butanetriol trinitrate (BTTN), trimethylolethane trinitrate (TMETN) were taken from the literature [9], and their combinations with the non-energetic plasticizer diethyl phthalate (DEP) and SPB-255 polymer as desensitizers are presented in Table 1.

Table 1. Impact sensitivities of energetic NEs and desensitized NEs

Nitrate Ester	Hight of 50% explosion [cm] (2 kg weight)
NG	15
BTTN	58
TMETN	47
Desensitized Nitrate Ester	
NG : DEP / 80 : 20	160
NG : SPB-255 / 80 : 20	170
NG : SPB-255 / 90 : 10	170
NG : SPB-255 / 95 : 5	119
BTTN : SPB-255 / 95 : 5	170
TMETN : SPB-255 / 95 : 5	170

Note: 170 cm was the limit of the apparatus

It may be seen from the results in Table 1 that replacement of 20% DEP with the same percentage of SPB-255 has a similar height value for 50% explosion (170 cm). However, if the percentage of SPB-255 polymer is reduced to 10%, the sensitivity of the composition remains the same for NG, and on further reduction of the quantity of the SPB-255 polymer to 5%, the sensitivity of the composition increases. A composition with 10% SPB-255 polymer gave a height for 50%

explosion of 170 cm in the case of NG. In the cases of BTTN and TMETN, addition of only 5% of SPB-255 polymer is sufficient to desensitize these nitrate esters, giving heights of 50% explosion of 170 cm. Thus, comparatively lower percentages of prepolymer could offer a better degree of desensitization compared to DEP. The prepolymer (SPB-255 polymer) can be used effectively both as a binder and as a desensitizer for highly sensitive nitrate esters and the use of conventional non-energetic plasticizers such as DEP, dioctyl phthalate (DOP) or triacetin (TA), *etc*. can be eliminated from the propellant formulations. The reduction in impact sensitivity may be due to the molecular structure and large molecular size of the prepolymer compared to the small molecules of non-energetic plasticizers.

Total elimination of the non-energetic plasticizer from the propellant formulation also lowers the overall plasticizer content in the propellant composition by 7-8% and this further helps to reduce the migration of plasticizer during storage. Moreover, the nitrate ester is the only major liquid ingredient used at a lower level (approximately 16-17%) for wetting the solid particles (approximately 75%) in the energetic propellant composition, which becomes evenly distributed in the entire binder matrix. Highly sensitive energetic nitrate esters (*e.g.* NG), and other high-energy ingredients such as AP, RDX or β-HMX, when mixed with the SPB-255 polymer exhibited low sensitivity to impact. The friction sensitivity of AP, RDX and β-HMX was also decreased when used with SPB-255 in combination with NG (Table 2).

Table 2. Impact and friction sensitivities of individual energetic ingredients and various combinations of mixed ingredients (at ambient temperature: 30 ± 2 °C and RH: 55-60%)

Ingredients*	Hight of 50% explosion [cm] (2 kg weight)	Friction sensitivity Insensitive up to [kg]
AP	93	36
RDX	27	18
β-HMX	26	14.4
SPB-255 : NG / 10 : 25	170	36
SPB-255 : NG : AP / 10 : 25 : 25	170	18
SPB-255 : NG : AP / 10 : 25 : 50	119	11
SPB-255 : NG : RDX / 10 : 25 : 25	154	25
SPB-255 : NG : RDX / 10 : 25 : 50	107	22
SPB-255 : NG : β-HMX / 10 : 25 : 25	87	18
SPB-255 : NG : β-HMX / 10 : 25 : 50	49	15

*Particle size of the ingredients: AP 200 μm, RDX 25 μm and HMX 12-14 μm

These results also indicate that SPB-255, which is basically an insensitive material, renders all high-energy additives relatively insensitive to both impact and friction. When compared with similar combinations of ingredients in propellant formulations, the SPB-255 : NG : β-HMX combination appears to be more impact sensitive than the other SPB-255: NG : RDX and SPB-255 : NG : AP combinations. However, the SPB-255 : NG : AP combination is more friction sensitive than the other two combinations.

Keeping in view the practical applicability of the nitrate ester plasticized SPB-255 polymer as an energetic binder for formulating advanced high-energy case-bonded propellant systems, the sensitivities of other representative SPB-255 polymer based propellant matrices were also evaluated. Table 3 provides the impact and friction sensitivities of SPB-255 polymer based propellants. These results are compared with other conventional propellants.

Addition of RDX/HMX increased the friction sensitivity of the formulations as expected. The trends in impact and friction sensitivities on inclusion of SPB-255 polymer remained by and large the same as for CMDB propellants. On replacement of both DEP and nitrocellulose (NC) in the formulation by SPB-255 polymer and the addition of a higher percentage of RDX/HMX (20-28%) in the composition, along with AP and Al, the sensitivity values were comparable to the CMDB propellant. Thus, a propellant made up of NG plasticized SPB-255 polymer based binder loaded with a higher percentage of solid fillers such as HMX-AP-Al (total solids ~75%) shows similar sensitivities to CMDB propellants, which have comparatively lower solid loading (AP-Al: 35%) in an NC-NG matrix. Similarly, an NG-SPB-255-HMX-AP-Al based propellant exhibits sensitivity values comparable to those of a nitramine-based composite propellant (CP) and a non-aluminized composite propellant.

A propellant matrix becomes more sensitive with a higher percentage of fine particle solid ingredients, particularly when fine AP (about 5-6 μm) at a higher content level is in the composition. A composition containing the highest percentage of fine AP (5-6 μm), in combination with RDX/HMX, was found to be the most friction sensitive (6.4 kg). However, an HTPB-based aluminized composite propellant matrix containing a high percentage of AP (67%) was comparatively less friction sensitive (14.6 kg) than an SPB-255-NG-HMX-AP-Al based high energy propellant. Non-aluminized composite propellants are highly sensitive. For the same level of solid loading (75%), both the impact and friction sensitivities of propellant compositions containing RDX and HMX were found to be marginally different.

Table 3. Impact and friction sensitivities of NG plasticized SPB-255 based propellants compared to other conventional propellants

Propellant composition	Hight of 50% explosion (2 kg wt.) [cm]	Friction sensitivity Insensitive up to [kg]
DBP NC : NG : DEP : Carbamite 59 : 33 : 5 : 3	22.5	14.4
Nitramine-DBP NC : NG : Carbamite : RDX 54 : 39 : 5 : 2	22	12.8
Composite propellant (CP) HTPB : DOA : AP : Al 9.5 : 3.5 : 67 : 16	36	14.6
Nitramine-CP (reduced smoke) HTPB : DOA: AP : Al : RDX 11 : 4 : 80 : 1 : 2.5	26	11.2
CMDB propellant SNC : NG : DEP : AP : Al 28 : 28 : 7 : 21 : 14	25	8.1
Nitramine-CMDB propellant NC : NG : DEP : AP : Al : RDX 41 : 33 : 5 : 6 : 3 : 12	18	12.8
SPB-255 based high energy propellant compositions		
Control Composition SPB-255 : NG : AP : Al 8 : 17 : 57 : 18	34	9.2
SPB-255 : NG : RDX : AP : Al 8 : 17 : 20 : 37 : 18	31	9.6
SPB-255 : NG : β-HMX : AP : Al 8 : 17 : 20 : 37 : 18	28	9.1
SPB-255 : NG : RDX : AP : Al 8 : 17 : 28 : 29 : 18	28	8.4
SPB-255 : NG : β-HMX : AP : Al 8 : 17 : 28 : 29 : 18	26	8.2
SPB-255 : NG : β-HMX : AP (all fine) : Al 8 : 17 : 28 : 29 : 18	19	6.4

Particle size of ingredients: AP 200 μm and 5-6 μm (3:2 ratio); RDX 25 μm and HMX 12-14 μm

Anderson [10] developed an expression for the friction coefficient of a material in terms of parameters that control the friction shear. This expression, in conjunction with the frictional equation, describes the hot-spot temperature produced in a frictional event. The hot-spot temperature increases with increases in the particle size and the shear strength of the explosive material, with an increase in loading pressure (shock) and friction velocity and a decrease in the thermal conductivity of the material.

The decrease in the impact and friction sensitivities of NG, BTTN and TMETN can be explained on the basis of the fact that the addition of a desensitizer decreases the heat of reaction per unit mass, which is more pronounced in the case of the addition of a prepolymer (larger molecule) such as SPB-255 polymer as compared to the smaller plasticizer molecules such as DEP, DOP or TA. Also, NG plasticized SPB-255 polymer based high-energy propellants do not appear to be sensitive to electrostatic discharge (>5 J). The ignition temperature of an NG plasticized SPB-255 polymer based advanced energetic propellant containing 20% HMX was found to be 200-205 °C. The major advantage of SPB-255 polymer based advanced energetic propellants is the replacement of the nitrocellulosic polymer by the SPB-255 polymer, which can absorb a higher plasticizer as well as a higher solid loading, although lower than CP, but much higher than CMDB propellants.

3.1 Small Card Gap test

The card gap test is used to determine the sensitivity to shock pressure of individual explosive ingredients, ingredient mixtures, and cured materials. The test consists of a booster charge and a blasting cap to supply shock pressure, a variable gap to attenuate the shock, the test material, a steel tube container, and a witness plate to verify detonation. The sensitivity is determined by increasing the gap until the test material fails to detonate. The criterion for detonation is a hole punched through the steel witness plate. The card gap test measures the sensitivity of a sample to shock. The booster and sample are separated by varying numbers of cellulose acetate cards. The results are reported as the number of cards necessary to prevent detonation. 70 cards represent the dividing line between a high explosive (HD 1.1) and a low explosive (HD 1.3). The larger the spacer gap which still allows detonation of the sample, the more shock sensitive the material is.

The test was carried out to evaluate the shock sensitivity to detonation of one of the representative high-energy propellant samples. Four propellant charges were fired for this evaluation. The propellant samples weighing about 420 g and having a length of about 150 mm and diameter 44.5 mm were firmly fitted in a mild steel tube and evaluated for their shock sensitivity, using a high explosive detonator charge, *i.e.* pressed tetryl ($\rho = 1.51\ g{\cdot}cm^{-3}$) along with an electrical detonator. Cellulose acetate (CA) sheets/cards (120 mm × 120 mm × 0.19 mm) were used for shock attenuation and the criterion of detonation was the dent in the mild steel (MS) witness plate (120 mm × 120 mm × 12 mm). Photographs of the tests taken before and after firing are shown in Figure 1.

a b c d

Figure 1. Test photographs of Card Gap test: (a) Propellant grain, mild steel tube and CA sheets; (b) Witness plate, sample tube, donor charge and CA sheets; (c) Detonation; (d) No detonation

The shock amplitude values were determined by using formula [11]: $P = 105e^{-0.0358x}$, where P is the shock amplitude value in kbar and x is the thickness of the cards in mm. From the card gap test, it was observed that the card gap value for the advanced energetic propellant containing 20% HMX was about 155 cards. DB propellants have card gap values of around 85-90 cards and that of CMDB propellant is 130-135 cards. The increase in card gap values compared to those of DB propellants is due to the addition of a higher level of energetic solid ingredient such as HMX. The corresponding shock amplitudes were computed and are shown in Table 4 and Figure 2.

Table 4. Comparative data of Card Gap tests

Propellants	Approx. thickness of CA sheets [mm]	No. of CA sheets/cards (0.19 mm each)	Approx. shock amplitude [kbar]
Composite	0	0	105
Double base	17	85-90	47
CMBD	25	130-135	42
Energetic propellants	30	155-160	35

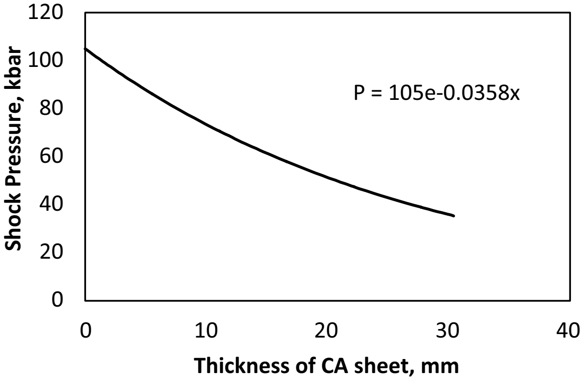


Figure 2. Shock pressure *vs*. attenuation thickness

3.2 Deflagration-to-Detonation Transition (DDT) test

A fundamental understanding of the behaviour of a propellant under stress is important. The Deflagration-to-Detonation Transition (DDT) is the phenomenon of a deflagration being transformed into a detonation. The DDT test is carried out to study the sensitivity of a propellant and to assess its safety pertaining to the vulnerability of rocket systems either to macroscopic properties such as particle size and shape of the energetic ingredients, the degree of confinement or to any impact like dropping during its handling and transportation.

Thick-walled mild steel tubes of total length 560 mm, OD 62 mm and ID 22 mm with end closure screw caps having 30 mm screw length were used for the evaluation. Two pieces of solid rod of advanced energetic propellant having 22 mm diameter were machined to fit into the DDT tube and the total length of the propellant charge was 488 mm. Three such DDT test tubes were prepared and evaluated. The propellant in each DDT tube, weighing about 300 g, was pushed firmly into the tube and closed with the end closure caps. The propellant was initiated by 0.5 g of boron/KNO_3 based igniter and an electric fuse. The tube had 6 equidistant orifices, each of 1 mm diameter, for the positioning of optical fibre sensors. These sensors detect the passage of the flame front by generating an electric voltage and the corresponding signals were recorded on a High Speed Data Acquisition System: ScopeCorder DL750 to determine the point to point variation in the velocity of the flame front. The starting point is the interface between the igniter and the propellant charge. Figure 3 shows the experimental arrangement; the legend in the insets indicates the locations of the optical fibre sensors along the propellant charge bed. Figure 4 shows the record of the optoelectronic sensors and Figure 5 shows photographs of the DDT test carried out for a representative sample of the advanced energetic solid propellant.

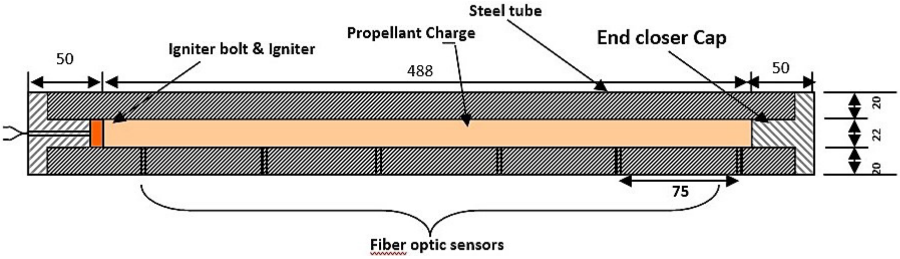


Figure 3. Experimental arrangement for the DDT test (dimensions in mm)

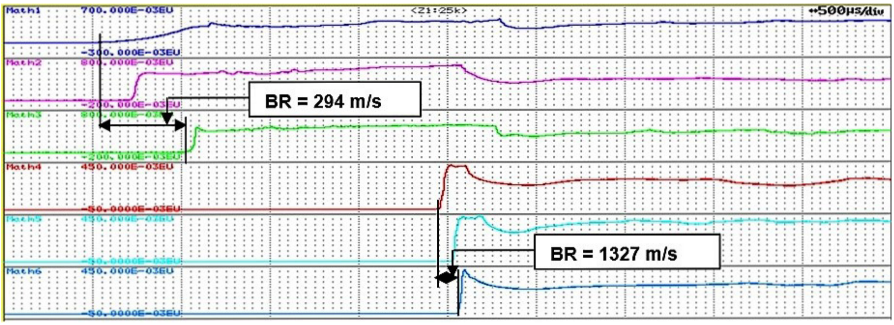


Figure 4. Record of optoelectronic sensors of the DDT test

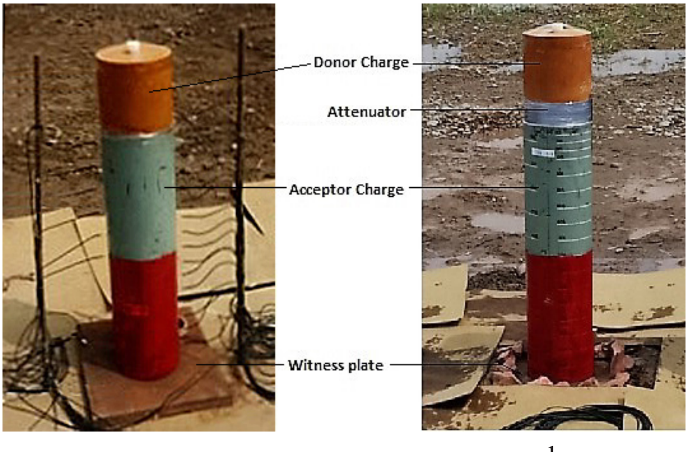
Figure 5. Actual test photographs of the DDT test: (a) DDT tube and propellant; (b) Test set up; (c) No detonation; (d) Detonation [13]

From the experiment, it may be observed that the acceleration of the flame front does not indicate a deflagration-to-detonation transition (DDT) in the case of the advanced energetic propellant under study. Ignition followed by slow initial convective deflagration to the compressive stage results in a very high burn rate leading to the build up of a compressive wave (~1300 m/s). However, this was insufficient to produce a detonation wave, as seen from the results. This was confirmed as the tubes did not undergo fragmentation. The propellant under study is a visco-elastic material that can undergo extensive elastic deformation under mechanical load (compression). The experimental results indicate that the advanced energetic propellant under study increases its transition rate during deflagration in a closed container, indicating its high sensitivity. However, the rate of deflagration is not sufficient to convert it into a detonation transient.

The propellant has good mechanical properties, particularly high elongation, and its lower modulus exhibits some characteristics of elastomeric polymers undergoing quasi-rubber-like deformation. If a microcosmic change and damage occurs in the propellant's internal structure, *e.g.* crack formation, because of external impact during handling, transportation *etc*., there will be a greater change in combustion characteristics. This may become compressive combustion and under the conditions of certain environmental restrictions, it is possible that a deflagration to detonation transition may occur. However, the deflagration-to-detonation transition (DDT) test of the advanced energetic propellant containing 20% HMX under study showed only a deflagration pattern and did not show any detonation phenomena [12, 13].

3.3 Super Large Scale Gap Test

For the safe handling and transportation of an advanced energetic propellant, it is necessary to ascertain the safety classification of the propellant with respect to HD 1.1 or HD 1.3. An HD 1.1 class propellant poses a mass explosion hazard whereas an HD 1.3 one poses mass fire, minor blast or fragment hazard. The Super Large Scale Gap Test (SLSGT) is an established test to ascertain the hazard division of explosive substances.



a b

Figure 6. SLSGT set up without (a) and with (b) gap

The test method designated for SLSGT includes three main steps: 1. a witness plate (400 mm × 400 mm × 40 mm) of mild steel is placed horizontally on the ground; 2. the acceptor charge (containing the energetic solid propellant) of L/D = 4 (in this study, length, L, was ~800 mm and diameter, D, was ~200 mm; one half of the motor tube was painted red for visibility from a distant camera) is positioned vertically on the witness plate, and 3. the donor charge (RDX/TNT) of L/D = 1 (in this case, L = 200 mm and D = 200 mm) is not confined in a thick steel case. Photographs of the SLSGT arrangement are shown in Figure 6. Figure 6a is without a gap/attenuator and the shock wave subjected to the acceptor charge was ~280 kbar while Figure 6b is with a gap/attenuator (~70 mm thick) and the shock wave subjected to the acceptor charge was 70 kbar. The attenuator was made of seven polymethyl methacrylate (PMMA) sheets of 10 mm each.

Figure 7a. Witness plate after detonation

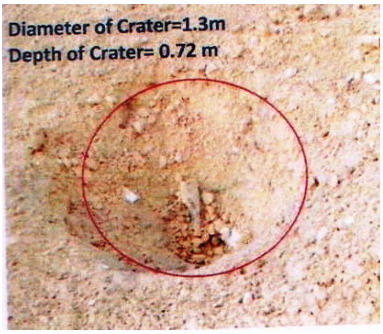


Figure 7b. Formation of crater detonation

The assessment of the reaction severity was then obtained in three forms. Firstly, the shock velocity in the acceptor was determined by placing fibre optic sensors/pins at 50.8 mm intervals along the centerline of the charge. The pins generate a time of arrival signal from the shock/detonation wave. Secondly, the case-wall fragment sizes and shapes were examined. The size and shape of the case-wall fragments are determined by the reaction rate of the acceptor explosive. If the acceptor charge detonates then the fragments will be small and have a distinctive shear plane. If the item experiences a decaying reaction, the case-wall will be broken into large pieces. If no explosive reaction occurs, the acceptor case will be recovered typically in one piece. Finally, the witness plate was observed for damage. The witness plate furnishes backup data. If the explosive detonates, a hole will be punched in the center of the plate or will break into pieces. If it experiences a decaying reaction the plate may remain intact. In all three forms, the reaction severity was considered when the acceptor charge was exposed to a 70 kbar shock wave. In this study, the case-wall was broken into small pieces and the witness plate was also broken into pieces. Figure 7a shows a witness plate after detonation and Figure 7b shows the formation of a crater. Based on the test results and information available from the literature, the energetic solid propellant under study qualifies to be graded as an HD 1.1 class of propellant [14].

3.4 TNT Equivalence test

Composite propellants are usually not capable of undergoing stable, high-velocity detonations. However, when subjected to shocks from high explosives, they do generate blast waves of appreciable force. The magnitude and shape of the blast waves generated by propellants greatly influence the degree and nature of the interaction with structures. Damage can be more extensive than with the same mass of high explosive, even though the latter may have a higher peak pressure. It was the purpose of this study to examine the air-blast characteristics of energetic solid propellants as compared to those of conventional high explosives. Peak side-on overpressures as a function of distance were determined and then related to that of an equivalent amount of TNT (2,4,6-trinitrotoluene).

The TNT equivalency is defined as the ratio of the weight of TNT to the weight of the sample of energetic material that would produce the same overpressure (or impulse) at the same distance. TNT equivalency is a simple method of comparing a known energy of an explosive to an equivalent mass of TNT or comparing the properties of an explosive with TNT (which is considered as a standard). TNT equivalence of an explosive is an important element as it provides a foundation for risk assessment and design of an appropriate process/storage building.

TNT Equivalence = P_{op} of explosive / P_{op} of TNT,
where P_{op} is peak overpressure.

The test arrangement for TNT equivalence measurement is similar to that of the SLSG test with zero gap. Firstly a dummy motor tube filled with dry sand was exploded to measure the donor charge pressure. Then the TNT filled motor tube and the propellant filled motor tube were exposed to similar donor charges. Equivalent weights of propellant and TNT were filled into the respective motor tubes. A total of 15 pencil probes were deployed at 12 m, 15 m, 18 m, 21 m and 24 m stand-off distances from the firing point to measure the blast pressures. These gauges were deployed in three different lines around the charge assembly at an angle of ~120° with respect to each other. The blast parameters were recorded at the different locations. The TNT equivalence was determined from the average values of the blast pressures acquired at 12 m, 15 m, 18 m, 21 m and 24 m distances from the firing point (Table 5) [15].

Table 5. TNT equivalence of the Advanced Energetic Propellant (AEP)

Sr. No.	Distance of blast probe [m]	Average blast pressure [kg/cm^2]			TNT equivalence of AEP at the measured distances	TNT equivalence of AEP (without gap configuration)
		Donor	TNT	AEP		
1	12	0.36	1.15	1.44	1.25	1.2
2	15	0.24	0.74	0.81	1.09	
3	18	0.17	0.43	0.57	1.32	
4	21	0.13	0.35	0.40	1.14	
5	24	0.10	0.26	0.32	1.23	

4 Conclusions

SPB-255 polymer in combination with various high-energy ingredients considerably decreased their sensitivities to impact and friction. In addition, SPB-255 polymer also acts as an effective desensitizer for highly sensitive nitrate ester plasticizers like NG, BTTN, *etc*. This further helps in processing the propellants without the use of a non-energetic plasticizer, *viz*. DEP, DOA, *etc*. The incorporation of a high percentage of fine particles of AP (5-6 µm) and HMX increased the impact and friction sensitivities. An increase in sensitivity due to the incorporation of HMX at higher percentages was also observed by the card gap test carried out for advanced energetic propellants. The DDT test carried out for the advanced energetic propellant did not exhibit any detonation behaviour of the propellant under the test conditions. However, the SLSG test carried out for the energetic solid propellant shows that it comes under class HD 1.1 and the TNT equivalence of the propellant, calculated by using blast pressure data, was 1.2.

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