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Studies on Physico-Mechanical and Explosive Characteristics of RDX/HMX-Based Castable Plastic-Bonded Explosives

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ABSTRACT

Conventional cast explosives (RDX/TNT) have major drawbacks of poor mechanical properties, shrinkages and higher sensitivity. These properties can be improved by applying plastic binder systems. The plastic-bonded explosive (PBX) is a composite material in which solid explosive particles are dispersed in a polymer matrix. The present paper describes the development of a nitramine/hydroxy-terminated polybutadiene (HTPB)-based castable PBX. The PBXs were processed as per standard procedures. Bimodal/trimodal particle size system was selected to reach a solid loading of 88 wt per cent. High solid loading was made possible through proper combination of coarse/fine ratio of solid ingredients, which was based on a number of tap density experiments. Processability of the binder system was studied by using various wetting agents as well as by selecting binder/plasticizer ratios. Mechanical properties of the PBXs were enhanced by different crosslinking agents. The explosive properties of PBXs including detonation velocity, processability and sensitivity to different types of stimuli, were studied. The results show that PBXs can be manufactured with detonation properties better than those of composition B/octol with the added advantages of superior thermal and sensitivity characteristics.

NOMENCLATURE

RDX	Cyclotrimethylene trinitramine
TNT	Trinitrotoluene
Composition B	40 % TNT/60 % RDX
Octol	30 % TNT/70 % HMX
HMX	Cyclotetramethylene tetranitramine
HTPB	Hydroxy-terminated polybutadiene
DDI	Diphenyl methane diisocyanate
DOA	Di(2-ethyl hexyl) adipate
TMP	Trimethylol propane
TEPAN	Tetraethylene pentamine and acrylonitrile
DTA	Differential thermal analyser
VOD	Velocity of detonation

1. INTRODUCTION

In the field of explosive composition for military uses, the search for insensitive high explosive composition is one of the most important goals today. Conventional explosives like TNT, composition B and octol are still used on a large scale as the main charges in ammunition. Because of the drawbacks associated with these explosives, there is a demand for less sensitive explosives. These explosives avoid chain reactions after a bullet or fragment impact, and also avoid chain reactions in storage during peace time in view of increasing safety standards. Furthermore, with conventional explosives it is difficult to meet the

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requirements regarding mechanical and thermal properties of explosives for their use in modern weapon systems. The application of plastic binder systems in explosives could be a solution. Among the different families of military explosive composition (melt cast explosives, pressed plastic-bonded explosives (PBXs) and cast PBXs), cast PBXs are the most suitable ones and their use is the most promising way of answering the requirements for no vulnerability or low vulnerability on fire or against bullet or fragment impact under heavy confinement[1]. Cast PBXs are suitable for filling main bursting charges of large calibre ammunition. The polymer matrix gives mechanical strength to the product. If the polymer is elastic, it can also reduce, for instance, the shock sensitivity by spreading a local impulse over a large area and in this way reduce the probability of initiation. However, it will be more difficult for accidental reactions to lead to a fatal detonation and so the effects of an accident will be less severe[2-6]. Different binders have been reported for use as binders in PBX composition[7-12]. The binders to be used for preparing castable PBXs should have the ability to form processable slurry at high solid loading. The rheology is influenced by the type of polymer backbone, chain length, funtionality and nature of the reactive end groups. All modern PBXs utilise soft, rubbery binders[13].

2. EXPERIMENTAL WORK

PBXs were processed by mixing the components in a planetary mixer for about 3 hr under vacuum at 45 °C. They were cast under vacuum at ambient temperature. Finally, the charges were cured at ambient temperature for 2 days. A batch of 5 kg of PBXs was prepared by this method. The hazards associated with handling dry RDX/HMX were minimised by coating them with 2 per cent desensitiser by slurry method. The product was then dried in a water jacketed oven. To reach a high solid loading in RDX/HMX and HTPB-based PBXs, attention was paid to particle size distribution of the explosive component. Bimodal and trimodal mixtures of the explosives were used to reach a solid loading of 88 wt. per cent. The influence of the particle size was studied by varying the ratio of the coarse and fine fraction in the bimodal/trimodal mixtures. Tap density experiments were carried out with combination of the coarse and fine grades of explosives to establish the properties required to give optimum packing in the PBX. Hydroxy-terminated poly butadiene (HTPB) and diphenyl methane diisocyanate (DDI) were selected for their low viscosity as well as for the ambient curing of the explosive charge. To attain a high solid loading and a castable composition, the viscosity had to be reduced further. This was achieved by using di(2-ethyl hexyl) adipate (DOA) as the plasticizer with binder/plasticizer ratio 60/40 for getting optimum results. Processability of the binder system was studied by using various wetting agents like lecithin, silicon oil and liquid paraffin. Crosslinking agents were used to improve the bonding between the explosive particles and the binder. The tested crosslinking agents used were trimethylol propane (TMP), an adduct of tetraethylene pentamine, and acrylonitrile (TEPAN), pyrogallol and hexane triol.

The impact and friction sensitivities were determined by standard fall hammer and Julius Peter apparatus, respectively. Charges of 30 mm . 30 mm dimensions were cut for the measurement of compression strength and percentage compres- sion using Universal testing machine (Instron Model-1185, UK). Viscosity measurements were made using Brookfield model. Thermal decomposition characteristics were determined by using a micro-differential thermal analyser assembled indigeneously. Compatibility of the various PBX formulations was studied on the basis of standard vacuum stability test. For the measurement of velocity of detonation (VOD), charge of the required dimensions [150 mm(l) . 60 mm(d)] was machined. VOD was measured by the probe method and by high speed photography.

3. RESULTS & DISCUSSION

Large calibre explosive charges prepared for use in different ammunition are designed primarily to scatter the container fragments to large distances at high velocities. This is achieved by using formulations which have a high VOD and a high detonation pressure. The quantity and type of explosive ingredients in a charge determine the characterstics of the final formulation. Attempts have hence been made to achieve high solid loading of the two most widely used powerful explosives, RDX and HMX, in the HTPB matrix. The properties of the different PBXs prepared have been compared with those of composition B and octol, the standard cast explosive composition used in a number of ammunition. The limits of particle size distribution and the percentages used in the bimodal and trimodal mixtures are given in Table 1. The ratio of coarse and fine particles is decided on the basis of a number of tap density experiments with varying percentages of coarse and fine explosive particles. The optimum packing, i.e. optimum density, is achieved with a bimodal mix of RDX and trimodal mix of HMX having a size ratio of at least 80:20 (coarse:fine) using particles with a narrow size distribution. By selecting the proper combination of explosive particle size, 88 wt per cent solid explosive loading was possible for making castable PBX composition. The solid explosive particles are coated with 2 per cent DOA for two main reasons: (i) safety in handling, and (ii) ease of processing. Binder/plasticizer ratio of 60/40 is adopted for getting optimum viscosity of the binder/plasticizer system and compression strength of the composition. The effect of binder/plasticizer ratio on the compression strength of PBX is shown in Table 2. The binder system must have low viscosity for easy castability. However, high surface tension of the liquid binder can hamper wetting of the explosive particles. In that case, appropriate mixing and casting of the product is impossible. To overcome this problem, the use of a surface active agent (wetting agent) to reduce the surface tension is recommended. Values of viscosity of 0.5 per cent solutions of various wetting agents with 60/40 HTPB/DOA ratio are given in Table 3. It has been found that a combination of lecithin and silicon oil gives satisfactory viscosity and processability.

Table Particle size distribution of the explosives and the percentage used in bimodal and trimodal mixtures

Explosive	Particle size (μm)	Weight %
RDX	250-500	80
	5-10	20
HMX	500-850	50
	250-500	30
	10-50	20

Table 2. Compression strength as a function of binder/plasticizer ratio (RDX/HTPB, 80/20)

HTPB/DOA ratio	Density (g/cc)	Compression strength (kg/cm^2)	Compres: (%)
50/50	1.50	07.2	25.6
60/40	1.49	12.8	18.8
70/30	1.51	15.3	16.6

Table 3. Viscosity data for various wetting agents

Composition	Viscosity (cps)
HTPB/DOA 60/40 (A)	740
A + Liquid paraffin (0.5 part)	
A + Lecithin (0.5 part)	
A + Silicon oil (0.5 part)	
A + Lecthin (0.3 part) + Silicon oil (0.2 part)	

The polymer binder consists of aliphatic (apolar) chains. However, the explosives is a rather polar compound due to its nitro groups. This means that inspite of good wetting, the adhesion between HTPB and the explosive can still be insufficient. This adhesion is probably of great importance for the sensitivity of PBX. When under tension, the binder gets loose from the particle, the neighbouring particle gets under increase tension and so the phenomenon propagates throughout the PBX, resulting in cracks. This has a detrimental effect on sensitivity, because these cracks can form hot spots under pressure and cause temperature increase, which may lead to initiation of explosion. Crosslinking agents improve bonding between the explosive and the binder. It has beeen found that a combination of 0.25 part of TMP and 0.05 part of pyrogallol gives more than 50 per cent increase in the compression strength of the PBX charge.

Results showing the effect of different crosslinking agents are given in Table 4.

Table 4. Compression strength as a function of different crosslinking agents

Wetting agent and part added	Density (g/cc)	Compression strength (kg/cm^2)	Compression (%)
RDX/HTPB, 80/20 (B)	1.49	12.8	18.8
B + TMP (0.3 part)	1.47	22.2	12.3
B + TEPAN (0.3 part)	1.50	17.2	17.4
B + Pyrogallol (0.3 part)	1.51	21.3	12.2
B + Hexane triol (0.3 part)	1.50	20.5	14.6
B + TMP (0.25 part) + Pyrogallol (0.05 part)	1.51	22.5	12.2

Table 5. Compression strength as a function of *NCO/OH* ratio (RDX/HTPB, 80/20)

NCO/OH ratio	Density (g/cc)	Compression strength (kg/cm^2)	Compression (%)
0.90		12.0	18.2
1.00		12.8	18.8
1.10		16.2	15.0

The amount of trifunctional cross linkers and *NCO/OH* ratio determine the crosslink density. The crosslink density, in turn, determines the mechanical properties. The higher the crosslink density, the higher is the hardness of PBX. The effect of variation of *NCO/OH* ratio on the compression strength of PBX is shown in Table 5. However, the *NCO/OH* ratio was maintained at 1:1 to get similar crosslink densities in all PBXs prepared and also to get optimum results in the presence of wetting and crosslinking agents. The composition, density, VOD and sensitivity characteristics of the PBXs prepared in the present study are given in Table 6. Density is a measure of the distribution of solid in the polymer matrix and depends on solid loading, density of the explosive used, particle size distribution of the filler and crosslink density of the polymer among other factors. Density values of PBXs increased with increase in solid loading as all other factors were maintained constant during processing. Density observed was around 95 per cent of the theoretical maximum density. The sensitivity of RDX and HMX is reduced considerably compared to those of the pure compounds by their incorporation in the polymer matrix. Compared to composition B, which is considered safe for processing, PBX with RDX or HMX with as high as 88 wt per cent explosive loading is less sensitive and thus more safe for handling and processing. VOD of the composition increases with the increase in explosive loading and has been found to be in the range 7850-8330 m/s and 8100-8600 m/s for RDX and HMX-based composition, respectively.

The thermal properties and vacuum stability data for some of the PBXs prepared are presented in Table 7. The onset of a thermal change in the PBXs studied is above 208 °C. This is due to the high thermal stability of the polymer matrix compared to trinitrotolunene (TNT), which exhibits a phase change at 80 °C. As a result, TNT-based composition will not be able to retain the structural integrity, when the ammunition experiences heating

Table 6. Composition and sensitivity parameters of PBX formulations

Composition and sensitivity parameters of PBXs formulations	Density (g/cc)	VOD (m/s)	Impact sensitivity (Ht. for 50 % explosion) (cm)	Friction sensitivity (Wt. on the moving arm) (kg)
RDX/HTPB, 80/20			142	> 36.0
RDX/HTPB, 84/16			126	> 36.0
RDX/HTPB, 88/12			100	32.4
Composition B, 60/40			95	24.0
HMX/HTPB, 80/20			130	36.0
HMX/HTPB, 84/16			120	32.4
HMX/HTPB, 88/12			102	28.4
Octol, 70/30			61	16.8

Table 7. Stability characteristics of PBXs

Explosive formulation	Thermal stability (onset of thermal change) (°C)	Vacuum stability (Vol. of gases at 120 °C for 48 hr) (ml)
RDX/HTPB, 84/16	208 (exotherm)	0.85
Composition B, 60/40	80 (endotherm)	0.95
HMX/HTPB, 84/16	272 (exotherm)	0.40
Octol, 70/30	80 (endotherm)	0.70

due to the frictional forces while moving at high speeds. This temperature limit has, at times, an adverse effect on the storage life of the ammunition, especially in the desert regions. The better storage life of the PBXs is indicated by the results of the vacuum stability test as well. Compared to 0.95 ml of oxides of nitrogen liberated from a 5 g sample of composition B at 120 °C, RDX and HMX-based PBXs release only 0.85 ml and 0.40 ml oxides of nitrogen, respectively. The corresponding values for pure RDX and HMX are 1.0 ml and 0.49 ml, respectively. This improvement in stability is ascribed to the perfect coating of the explosive by the stable polymer matrix. Thus, the PBXs prepared have considerable advantage over the conventional formulations with respect to storage as well as application in high velocity projectiles.

4. CONCLUSIONS

By using the optimum combination of coarse and fine explosive particles, it is possible to manufacture a PBX based on HTPB-DDI binder with high percentage of RDX or HMX. The results obtained show that PBX composition are safe, thermally stable and have better mechanical properties compared to conventional composition without compromising with the explosive power. The data generated in this study also show that HTPB is a promising binder for making castable PBXs.

REFERENCES

Freche, A. Low vulnerability cast plastic-bonded explosive. Proceedings of the International Symposium on Pyrotechnique and Explosives, China, 1987. pp 276.

2 Oberth, et al. Polyurethane-based propellants. *Adv. Chem. Series*, 1988, **88**. 84-121.

3 Cristie, et al. Castable composite explosives; evaluation of thermophysical properties, 1973. Report No DREV TN- 2057/73.

4 Perrault, et al. Composite Explosives. US Patent 4,116,734, 1978.

5 Welden, et al. High temperature stability of HTPB-based polymer-bonded explosives and their ingredients. Fifth Symposium on Chemical problems connected with the stability of explosives, 1979.

6. Consaga. Dimethyl hydantoin bonding agents in solid propellants. US Patent 4,214,928, 1980.

7. Wright, S.B. Granular explosive molding powder. US Patent 3,173,817, 1965; *Chem. Abstr.*, 1965, **62**, 12968.

8. Vacekand, J. & Skrivanek, A. Self supporting explosives. Czeck. Patent 127990, 1958; *Chem. Abstr.*, 1969, **70**, 107929.

9. Evans, W.L. Flexible high velocity explosives. US Patent 3,723,204, 1973; *Chem. Abstr.*, 1974, **80**, 110525.

10. Kegler, W. Plastic bonded explosives. German Patent 2,327,107, 1975; *Chem. Abstr.*, 1975, **83**, 12992.

Rothenstein, J. Flexible, self-supporting explosive composition. US Patent 3,888,707, 1975; *Chem. Abstr.*, 1975, **83**, 149788.

12. Vandersteen, A. & Verbeck, R. *Prop. explos. Pyrotech.*, 1900, **15**(19).

13. Anderson, Erwin. Explosives, tactical missile warheads. American Institute of Aeronautics and Astronautics, Inc., Washington, DC.

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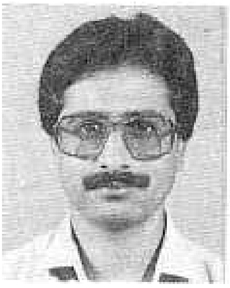

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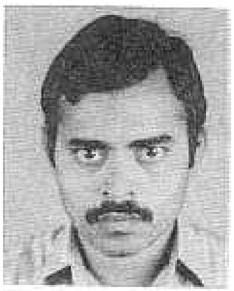

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