Defence Science Journal, Vol. 54, No. 4, October 2004, pp. 475-482

Influence of Aluminium on Performance of HTPB-based Aluminised PBXs

Vinay Prakash
Ordnance Factory, Dehuroad, Pune – 412 101

and

V.K. Phadke, R.K. Sinha, and Haridwar Singh
High Energy Materials Research Laboratory, Pune – 411 021

ABSTRACT

The paper describes the development of aluminised plastic-bonded explosives (PBXs) based on aluminium and nitramine explosives using hydroxy-terminated polybutadiene as polymer matrix. The PBXs were processed as per standard procedures. Compositions with different formulations were prepared by varying the percentages of aluminium and RDX and their explosive properties, including velocity of detonation (VOD), peak overpressure, duration, impulse and sensitivity to different types of stimuli, were studied. The experimental and theoretical values of the VOD have been compared. It is observed that about 15 per cent aluminium content in the aluminised PBXs shows the optimum VOD.

Keywords: Aluminised PBXs, polymer matrix, hydroxy-terminated polybutadiene, HTPB, RDX, velocity of detonation, plastic-bonded explosive, PBXs, impulse, peak overpressure

NOMENCLATURE

Al	Aluminium
Composition B	40 % TNT, 60 % RDX
DDI	Diphenylmethane diisocynate
Dentex	48.5 % RDX, 33.5 % TNT, 18.0 % *Al* 1 part wax
DOA	Di-(2-ethyl hexyl) adipate
FeAA	Ferric acetyl acetonate
HMX	Cyclotetramethylene tetranitramine
HTPB	Hydroxy-terminated polybutadiene
PBX	Plastic-bonded explosive
RDX	Cyclotrimethylene trinitramine
TMP	Trimethylol propane
VOD	Velocity of detonation
NCO	Isocyanate
AP	Ammonium perchlorate
GAP	Glycidyl azide polymer

Revised 30 December 2003

1. INTRODUCTION

When an explosive in a shell is detonated, the targets are generally defeated by high-velocity fragments generated from bursting of casing or due to high blast energy, ie, peak overpressure and impulse. The blast pressure is effective on a small and rigid structure but for destruction of a large and flexible structure, impulse is effective. Impulse[1] is defined as $\int_{P2}^{P1} Pdt$, where P is the peak overpressure and t is the time duration. Addition of energetic materials like RDX and HMX in higher proportions increases the fragment velocity because of higher detonation pressure and higher velocity of detonation (VOD) of energetic materials, but impulse improves with the addition of aluminium metal powder[2-5].

Exhaustive studies on blast parameters and properties of explosive compositions by varying the percentage of ingredients, particularly aluminium powder, in high-energy formulations have been carried out[6]. It is well known that in aluminised high explosives, the reaction of aluminium is relatively slow, so that aluminium at the Chapman–Jouguet (C–J) plane acts as a diluent or even as an endothermic component. The large amount of energy liberated by subsequent reactions of aluminium with primary detonation products, however, maintains a high pressure for a longer period than what would be obtained without aluminium[7].

The blast effect is improved by adding aluminium powder to the explosive compositions. Many studies have been carried out on the influence of aluminium powder on castable conventional explosives. Trinitrotoluene-based conventional explosives have major drawbacks like poor mechanical properties, defects due to shrinkage, low thermal stability, and high sensitivity to different types of stimuli. These drawbacks can be improved, to a large extent, in plastic-bonded castable compositions.

The aluminised plastic-bonded explosive (PBX) is a composite material in which solid explosive particles are dispersed in a polymer matrix, which includes three major components, such as polymeric binder, metal fuel, and nitramine explosive. The PBX system is characterised by high mechanical strength, low vulnerability, high thermal stability, and high-energy output.

The hydroxy-terminated polybutadiene (HTPB) has high-temperature resistance with the temperature range from –54 °C to + 71 °C. It also has low glass transition temperature (T_g) of –79 °C. The HTPB binder includes polymer, bonding agent, coupling agent, plasticiser, processing aid, and curing agent. These components of the binder make the mixture blending with good mechanical and physical properties[8-9].

Keicher[5], *et al.* studied the influence of aluminium on the performance and reaction behaviour of the formulations with RDX, aluminium, ammonium perchlorate (AP) and glycidyl azide polymer (GAP). The studied explosives had variation in formulation, aluminium particle size, and arrangement of particles of aluminium in the matrix. The different explosives were characterised by analysing the detonation products after blasting in a closed vessel. The performance was measured for charges of 70 g, 250 g, 500 g, and 1000 g. Charges with the same mass showed similar peak overpressures and impulses for formulations containing 15 per cent to 30 per cent of aluminium. Formulations with higher aluminium contents showed decrease in peak overpressure and impulse. No influence of aluminium content from 15 per cent to 30 per cent is surprising, and further study is required in this area. At the High Energy Materials Research Laboratory (HEMRL), Pune, methods have been established for preparing castable aluminised PBXs based on aluminium, RDX or HMX, using HTPB as polymer matrix. The results of the study consisting of aluminium, RDX ,and HTPB formulations are presented in this paper.

The present study aims to find the following corelations:

- Influence of RDX and aluminium on the VOD and detonation pressure
- Influence of different formulations on the sensitivity of aluminised PBXs
- Influence of RDX and aluminium on the thermal and mechanical properties of aluminised PBXs
- Influence of different aluminium particle sizes on the mouldability of aluminised PBXs.

2. EXPERIMENTAL WORK

For processing of PBXs, the ingredients were mixed in a planetary mixer for about 3 h under vacuum at 45 °C. The casting was done under vacuum at the ambient temperature. Finally, the charges were cured at the ambient temperature for 2 days. A batch of 5 kg of PBX was prepared by this method. The hazards associated with handling of dry RDX were minimised by coating it with 2 per cent desensitiser by the slurry method. The product was then dried in a water-jacketed oven. To achieve a high solid loading of RDX/HMX in HTPB-based PBXs, attention was paid to particle size distribution of the explosive component. Solid loading was optimised using bi-modal and tri-modal mixtures of the explosive[10].

Hydroxy-terminated polybutadiene (HTPB) and diphenylmethane diisocynate (DDI) were selected for their low viscosity and for the ambient curing of explosive charge. To attain a high solid loading and castable composition, the viscosity had to be reduced further. This was achieved using di-(2-ethyl hexyl) adipate (DOA), as a plasticiser with binder/plasticiser ratio 60:40 for getting the optimum results. The *NCO/OH* ratio was maintained at 1:1 to get similar cross-link densities in all PBXs prepared and also to get the optimum results in the presence of wetting and cross-linking agents.

For casing requirement, the binder system must have low viscosity. However, a high surface tension of liquid binder can hamper the wetting of explosive particles. In that case, good mixing and casting of the product is impossible. To overcome this problem, lecithin, a surface-active agent was used. Lecithin is a natural compound that lowers the surface tension. A typical castable PBX formulation is given in Table 1. The impact and friction sensitivities were determined by the standard fall hammer method and the Julius Peter apparatus, respectively.

Table 1. Castable plastic-bonded explosive formulations

Weight percentage	Component	Example
60 - 90	Explosive	RDX
05 - 25	Metal powder	Aluminium
20 - 10	Binder Plasticiser Curative	HTPB DOA TDI, DDI
0.50	Cross-linking agent	TMP
0.01	Catalyst	FeAA
0.30	Process aid Surface-active agent (wetting agent)	Lecithin Silicon oil

Charges of 30 mm diameter and 30 mm height were used for the measurement of compression strength using Universal Testing Machine (Instron model-1185, UK). The compatibility of various PBX formulations was studied on the basis of standard vacuum stability test. For the measurement of VOD, the charge of the required dimensions (30 mm diameter, 150 mm length) was used. The VOD was measured by the pin oscillographic technique. Both the blast pressure and its duration were measured at various distances using piezoelectric gauges and oscilloscope. The detonation pressure was determined by the sulphur-coated pin oscillographic technique[11].

3. RESULTS & DISCUSSION

The composition, measured density, theoretical maximum density (TMD), VOD, theoretical VOD, and C-J pressure (detonation pressure) of PBXs prepared in the present study are shown in the Table 2.

The density is a measure of the distribution of a solid in the polymer matrix and depends on solid loading of the explosive used, particle size distribution of the filler, and cross-link density of the polymer among other factors. Density of the charge was obtained around 97 per cent of the theoretical maximum density.

The plots of VOD versus aluminium content, and detonation pressure versus aluminium content are shown in Figs 1 and 2. It is discernable from the plots that, initially VOD and detonation pressure decrease gradually with incorporation of aluminium up to 10 per cent, followed by an increase up to 15 per cent. On further increase of aluminium content, the detonation parameters decrease steadily.

Table 2. Composition and explosive properties of aluminised PBX formulations

Composition and percentage	TMD (g/cc)	Experimental density (g/cc)	VOD (m/s)		C-J pressure (m bar)	
			Theoretical	Experimental	Theoretical	Experimental
RDX 85 % *Al* 0 % HTPB 15 %	1.586	1.578	7750	7658	0.24093	0.23800
RDX 80 % *Al* 5 % HTPB 15 %	1.609	1.594	7586	7530	0.23394	0.22900
RDX 75 % *Al* 10 % HTPB 15 %	1.630	1.610	7536	7500	0.23049	0.22300
RDX 70 % *Al* 15 % HTPB 15 %	1.670	1.630	7613	7580	0.23591	0.22400
RDX 65 % *Al* 20 % HTPB 15 %	1.680	1.646	7570	7257	0.23111	0.22000
RDX 60 % *Al* 25 % HTPB 15 %	1.709	1.680	7538	7108	0.22811	0.21800

A similar trend was observed for the theoretical values from the BKW method[12].

The recorded values are close to the theoretical ones and within the experimental errors. The impact and friction sensitivities, the thermal properties, and the vacuum stability for the PBXs prepared are presented in the Table 3.

The sensitivity of the composition of RDX and aluminium is reduced considerably compared to the sensitivity of the compositions of pre-ingredients, by their incorporation in the polymer matrix. Compared to composition dentex, which is considered safe for processing, PBX with RDX and aluminium (with as high as 85 per cent solid loading) is less sensitive and thus, more safe for

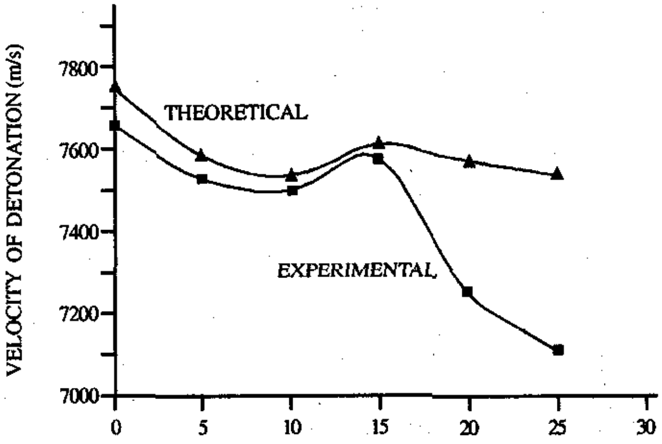


Figure 1. Variation of VOD with aluminium content

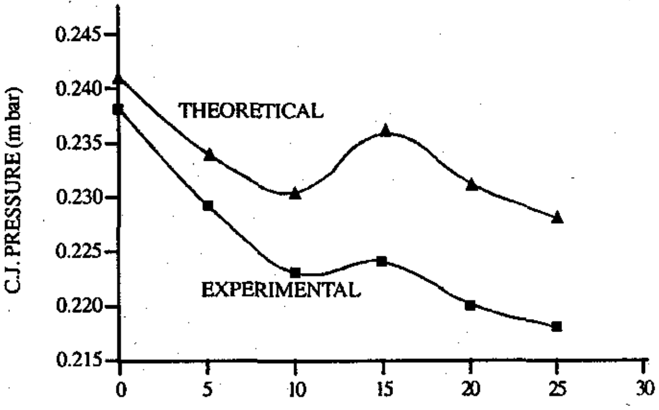


Figure 2. Variation of C-J pressure with aluminium content

Table 3. Results of sensitivity parameters and stability characteristics of PBX formulations

Composition and percentage	Impact sensitivity (Height for 50 % explosion) (cm)	Friction sensitivity (Weight on the moving arm) (kg)	Thermal stability (onset of thermal change) (°C)	Vacuum stability (Vol. of gases at 120 °C for 48 h) (ml)	Compression strength (kg/cm²)
RDX 85 % *Al* 0 % HTPB 15 %	115.0	36	204	0.86	9.8
RDX 80 % *Al* 5 % HTPB 15 %	100.0	36	204	0.86	10.1
RDX 75 % *Al* 10 % HTPB 15 %	119.0	36	204	0.86	10.3
RDX 70 % *Al* 15 % HTPB 15 %	120.5	36	204	0.86	10.5
RDX 65 % *Al* 20 % HTPB 15 %	123.5	36	204	0.86	11.2
RDX 60 % *Al* 25 % HTPB 15 %	129.0	36	204	0.86	11.8

handling and processing. The onset of a thermal change in the aluminised PBXs is above 203 °C. This is due to the high thermal stability of the polymer matrix as compared to trinitrotoluene, 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 due to the frictional forces while moving at high speeds. This temperature limit has, at times, an adverse effect on the storage life of ammunition, especially in the desert regions. The better storage life of the aluminised PBXs is indicated by the vacuum stability test as well. The data of peak overpressure, duration, and impulse are given in the Table 4. The characteristics of PBX prepared in the present study are compared with dentex in Table 5. It is observed from the comparative study that sensitivity of both the compositions is comparable but the VOD of aluminised

Table 4. Peak overpressure and impulse of aluminised PBX compositions and dentex

Composition and percentage	Density (g/cc)	Blast parameters							
		Peak overpressure (kg/cm^2) [duration (ms)]				Impulse ($kg.ms/cm^2$)			
		0.5 kg		1.0 kg		0.5 kg		1.0 kg	
		1.0 (m)	1.5 (m)	1.5 (m)	2.0 (m)	1.0 (m)	1.5 (m)	1.5 (m)	2.0 (m)
Dentex RDX 48.5 % TNT 33.5 % *Al* 18.0 % Wax 1.0 part	1.75	5.51 [0.60]	3.08 [0.47]	5.11 [0.60]	---	1.65	0.72	1.53	---
PBX RDX 70 % *Al* 15 % HTPB 15 %	1.63	5.54 [0.60]	2.82 [0.60]	5.0 [0.60]	2.67 [0.64]	1.66	0.85	1.50	0.85

Table 5. Characteristics of aluminised PBX compositions compared with dentex

Composition & percentage	TMD (g/cc)	Exptl. density (g/cc)	Impact sensitivity 50 % explosion (cm)	Friction sensitivity (kg)	Thermal stability (onset of thermal change) (°C)	Vacuum stability (volume of gases at 120 °C for 48 h) (ml)	VOD (m/s)
Dentex RDX 48.5 % TNT 33.5 % *Al* 18.0 % Wax 1.0 part	1.86	1.75	125	16.8	80 endotherm	0.95	7780
PBX RDX 70 % *Al* 15 % HTPB 15 %	1.67	1.63	120	36.0	204 exotherm	0.86	7580

PBX is less than that of dentex. The values of peak overpressure and impulse are almost equal.

Values of viscosity of compositions of aluminised PBXs containing different particle sizes of aluminium are given in the Table 6. Low viscosity is better for casting the composition. For achieving the low viscosity, the particle size of aluminium between 250–120 μm is found suitable.

Table 6. Viscosity parameter and mechanical characteristics of aluminised PBXs containing different particle sizes of aluminium

Composition & percentage	Particle size of *Al* (μm)	Viscosity (kp)	Compression strength (kg/cm²)
PBX RDX 70 % *Al* 15 % HTPB 15 %	1680–860	3.25	9.82
	850–250	2.81	10.20
	500–250	2.25	12.52
	250–120	1.27	13.83

4. CONCLUSIONS

In the aluminised PBX composition, about 15 per cent aluminium content is suitable for achieving the optimum explosion effect by blast wave in air. At about 15 per cent aluminium content in the composition, optimum VOD, peak overpressure, and impulse are achieved. This has also been proved by Keicher[5], *et al.* The mechanical properties, thermal stability, and impact sensitivity of the composition can be improved by performing further studies on the polymer matrix.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the guidance and support given by Dr K.U.B. Rao, Scientist for the present work and are also thankful to Sarvashri S.R. Vadali and P.V. Kamath for their valuable suggestions and help.

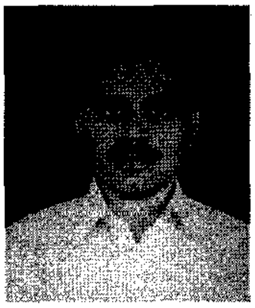
REFERENCES

1. Principles of explosives behaviour. *In* Engineering Design Handbook. AMCP-706-180, 13-1.
2. Roth, G. Performance of explosives. German Patent No. 1,733,271,900.
3. Gharia, J.S.; Athawale, B.K. & Sathey, P.D. HE compositions for enhanced blast effect. *In* Symposium on Warhead Technology, 3-4 March 1983, TBRL, Chandigarh. pp.152-61.
4. Maranda, A. Research on the process of detonation of explosive of mixtures of the oxidiser fuel type containing aluminium powder. *Propell. Explos. Pyrotech.*, 1990, **15**, 161-65.
5. Thomas, Keicher ; Andreas, Happ & Alois, Kretschmer. Influence of aluminium/ammonium percholorate on the performance of underwater explosives. *Propell. Explos. Pyrotech.*, 1999, **24**, 140-43.
6. Gharia, J.S.; Athawale, B.K.; Visal, S.R. & Phadthare, V.V. Effect of aluminium particle size and percentage on blast compositions. *In*

Symposium on Warhead Technology, 3-4 March 1983, TBRL, Chandigarh. pp.144-51.

7. Stromose, E. & Eriksen, S.W. Performance of high explosives in underwater application, Part 2: Aluminised explosives. *Propell. Explos. Pyrotech.*, 1990, **15**, 52-53.
8. Yann-Chyn Jeng; Huey–Cherng Perng; His-Cherg Yeh & Ming – Ju Charg. Optimising the mixture blending for castable aluminised plastic-bonded explosives. *Propell. Explos. Pyrotech.*, 1992, **17**, 292-94.
9. Bellerby, J.M. & Kiriatnikon, C.H. Explosive-binder adhesion and dewetting in nitramine-filled energtice materials. *Propell. Explos. Pyrotech.*, 1989, **14**, 82-85.
10. Gharia, J.S.; Sinha, R.K.; Tadas, V.V.; Prakash, Vinay & Phadke, V.K. Studies on physico-mechanical and explosive characteristics of RDX/HMX-based castable plastic-bonded explosives. *Def. Sci. J.*, 1998, **48**(1), 125-30.
11. Yadav, H.S. & Kamath, P.V. Shock velocity measurement in water by sulphur probes. *Propell. Explos. Pyrotech.*, 1986, **11**, 150-54.
12. Mader, C.L. Fortran BKW: A code for the detonation properties of explosives. Los Alamos Scientific Laboratory. Report No. LA-3704, 1963.

Contributors



Mr Vinay Prakash joined DRDO at the High Energy Materials Research Laboratory (HEMRL), Pune. His areas of research include: Development of processes for the production of dense nitrocellulose and plastic-bonded explosives and pyrotechnics. Presently, he is working as Works Manager under IOFS.

Dr(Ms) V.K. Phadke obtained her PhD (Chemistry). She joined DRDO at the HEMRL, Pune. Her area of work includes the development of plastic-bonded explosives.