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Involving PETN explosive into polyurethane polymer matrix for reactive armour applications

Involving PETN explosive into polyurethane polymer matrix for reactive armour applications

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Abstract: This paper describes some formulations of plastic bonded explosives (PBXs) in the form of flexible material (sheet explosive) for military and civilian applications. Different compositions based on (70 wt%, 75 wt%, 78 wt%, 80 wt%) of PETN as high explosive filler were prepared by casting technique using HTPB polyurethane binder material. The production technique of the prepared explosive sheets was described in this research. Sensitivity to impact and friction were also measured. In addition, heat of combustion was determined. Besides, the detonation velocity was measured experimentally and the detonation characteristics were calculated using EXPLO 5 thermodynamic code. For comparison, standard commercial available plastic explosives such as EPX-1 and Datasheet C were studied. By comparing the obtained results, several relationships based on the results were observed. A good agreement between the measured and the calculated results was confirmed. Sample containing 78 wt% of PETN bonded by the polyurethane matrix is an optimum for the application of reactive armours.

Keywords: sheet explosive, sensitivity, detonation, PETN.

1. Introduction

The developing ballistic threat in the main battle tanks (MBT) requires the study and the development in new systems of non-conventional protection. Research and development (R&D) in the field of explosive reactive armour (ERA) design has led to the emergence of new classes of explosive known as plastic bonded explosive (PBXs) in the form of flexible sheet explosive [1, 2]. PBXs have been studied in several publications such as warheads and demolition applications [3-6]. Sheet explosive is considered a particular type of plastic bonded explosive (PBXs) that is defined as a composite material between energetic materials and a polymeric matrix [1]. The dough can be prepared by different techniques; one of the most common techniques is cast cured technique, which contains polyurethane binders based on terminated prepolymers such as HTPB, GAP, BAMO and others [7-10]. Moreover, sheet explosives are prepared by calendaring process using rolling or extrusion technique, in which the dough is placed between the two rollers in order to obtain sheet with certain dimensions [11]. Sheet explosives have a wide range of application in civilian applications such as welding of materials, cladding, material hardening and demolition [12]. On the other side, it is used in military applications such as under water explosion and explosive reactive armor (ERA) [13-15]. EPX-1 is a new plastic explosive based on PETN with a thermoplastic binder (unpublished details), which has several

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applications [16]. Datasheet C also is a plastic explosive that is based on PETN with a non-energetic plasticizer [17]. This study includes preparation and characterization of different compositions based on (70%, 75%, 78%,80%) PETN as a high explosive filler. These compositions were prepared by casting technique based on HTPB polyurethane binder matrix. For comparison, other types of plastic explosives were also studied. The detonation parameters were calculated by EXPLO 5 thermodynamic code [18].

2. Experimental

2.1. Preparation of Explosive Sheets

Four different formulations of PETN-based PBX'S were prepared in Abo zabal Company for Chemical Industries, Egypt. PETN powder has two grades of mean particle size 150-200 µm as a coarse and 38 µm as fine crystals, which are produced in Heliopolis Company for Chemical Industries, Egypt. Inert thermoset binder hydroxyl terminated poly butadiene (HTPB) with 0.78 NCO/OH ratio are cured with Hexamethylenediisocyanate (HMDI Shandong YuchengYiao Technology Co., Ltd China) are used in these formulations. To decrease the viscosity of the mixture and make the mixing and casting process easier, Dioctyl Azelate (DOZ) has been used as a plasticizer. The compositions were processed by cast cured technique (solvent less technique), in which polymeric binder (HTPB) with plasticizer (DOZ) and MAPO (Tris-1- (2-Methyl Aziridinyl) Phosphine Oxide) are transferred under vacuum using stainless steel vertical mixer at 60 ºC for 7 minutes to ensure uniform distribution. High explosive powder; PETN was then added in small portion 2-3 installments during mixing without vacuum at 60 °C for 2-3 h. Mixing operation is continuing for 30 min with vacuum at 60 ºC to ensure complete coating after complete addition of high explosive. Temperature of the mixture was then cooled to 40 ºC and Hexamethylenediisocyanate (HMDI) is added followed by mixing for about 25 min to obtain uniform dough. The formed product (paste) was then casted into the mold under vacuum. The prepared paste was cured for 10-15 days at 55-60 °C. The paste is then cut into sheets with favorite dimensions. The different prepared formulations for PBXs based on PETN and HTPB are shown in table (1). In order to make characterization of the prepared sheets, some species of dumbs shape of dimensions (1.5 mm-2.5mm-7 mm) were prepared.

Table 1. Compositions of the prepared PBXs based on PETN

Abbreviations	PETN (wt. %)	HTPB (wt. %)	HMDI (wt. %)	DOZ (wt. %)	MAPO (wt. %)
SE1	70	24.85	1.19	3.46	0.5
SE2	75	23.22	1.28	-	0.5
SE3	78	17.08	0.96	3.46	0.5
SE4	80	15.18	0.86	3.46	0.5

2.2. Impact sensitivity measurements

Sensitivity of the prepared explosive sheet compositions to impact stimuli was measured using a drop hammer test (Julius Peters [19]). The results are given in the terms of statistically obtained 50% probability of explosion (h_{50}). The sensitivity measured are presented in Table (2).

2.3. Friction sensitivity measurements

Sensitivity of the explosive compositions to friction stimuli was obtained by A FSKM 10 BAM friction test produced by OZM Research, Czech Republic [19]. 0.01g of each studied explosives in the form of thin layer are tested under the effect of normal force between rough surfaces [19]. The 50% probability of initiation of each sample is presented in Table 2.

Table 2. The measured parameters of the studied samples

No.	Composition	Impact sensitivity (J)	Friction Sensitivity (N)	Density ($g \cdot cm^{-3}$)	Detonation velocity Measured (m/s)
1	SE1	29.4	>360	1.40	6684 ± 64
2	SE2	26.8	340	1.42	6826 ± 72
3	SE3	24.2	324	1.45	6938 ± 81
4	SE4	21.7	320	1.46	7010 ± 68
5	EPX-1 [16]	13.9	180	1.55	7636
6	Datasheet C	31.5	>360	1.45	6660

2.4. Detonation velocity measurements

The detonation velocity of the compositions was determined by an hand-held detonation velocity tester VOD-812 produced by OZM Research, Czech republic [21]. The tested compositions were prepared as sheets with 20 mm thickness, 40 mm width and 200 mm length. The VOD-812 measures the time intervals (in micro seconds) between the start and end probes of the illumination fiber optic. The detonator was inserted in the side of the specimen then the first side of the optical probe is fixed at a distance 50 mm from the detonator and the other optical probe is placed at a distance 100 mm of the first probe. The sample was tested triple times and the mean value (max $81 ms^{-1}$) is recorded in Table 2.

2.5. Calculation of the detonation characteristics

The detonation properties of all the prepared sheet explosives as well as pure PETN explosive were calculated by using of EXPLO5 thermodynamic code [22]. BKWN set of parameters for the BKW EOS was applied, these parameters are: $\alpha = 0.5$, $\beta = 0.298$, $k = 10.50$, $\Theta = 6620$. The detonation properties of the tested samples are presented in Table 3.

Table 3. The calculated detonation characteristics of the tested explosives

No.	Explosive type	Density ($g \cdot cm^{-3}$)	EXPLO5 detonation velocity ($m \cdot s^{-1}$)	EXPLO5 detonation pressure (GPa)	EXPLO5 detonation Heat ($J \cdot g^{-1}$)
1	SE1	1.40	6722	16.70	5080
2	SE2	1.43	6887	17.00	5192
3	SE3	1.45	6996	17.20	5268
4	SE4	1.46	7068	17.30	5328
5	EPX-1 [16]	1.55	7398	21.17	5742

3. Results and Discussion

A comparison between the results of impact and friction sensitivities is presented in Fig. 1. All the studied plastic explosives are based on PETN and the comparison proved that all the polymeric matrices had an obvious effect on decreasing the impact and friction sensitivities of PETN. Regarding to the friction sensitivity, all the studied plastic explosives have friction force lies between 180 and

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360 N as shown in the Fig. 1; while the prepared sheet explosive based on 78% PETN has friction force of 340 N that is very less sensitive compared with EPX-1 and some other prepared compositions. Regarding to the impact sensitivity, all the studied samples except EPX-1 have impact energy of initiation lies between 23.5 and 31.5 J. The prepared sheet explosive based on 78% PETN has excellent value of the impact energy of initiation.

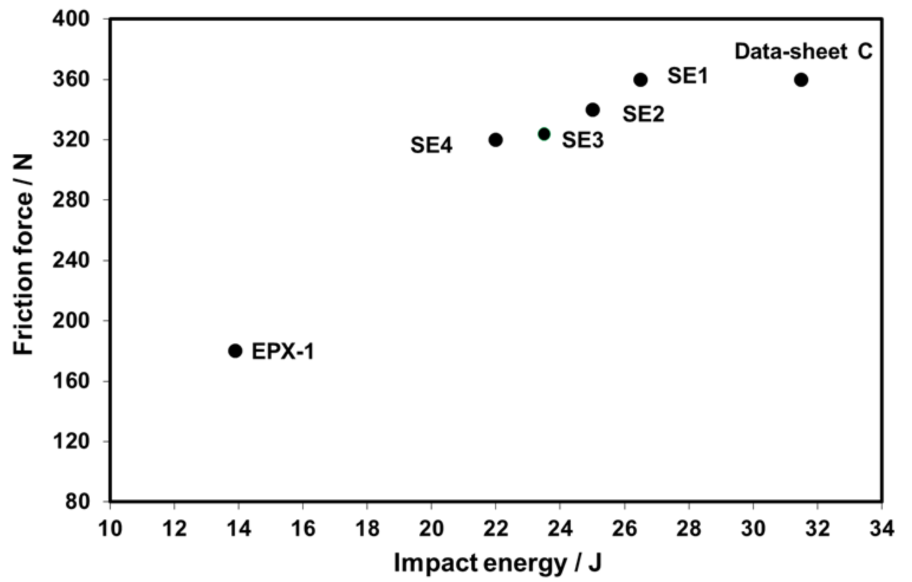

Figure 1. Results of the impact and friction sensitivities

Fig. 2 presents a well-known relationship between the density and the detonation velocity of the studied samples [23-25] in order to compare among them. A linear relationship between the loading densities and the detonation velocities of all the studied samples has been obtained. The detonation velocity of the PBX formulations increases as the weight percent of PU binder decreases, which confirms the fact that PU binder is a non-energetic material that has a negative effect on the detonation velocity. The prepared sheet based on 78% PETN has a detonation velocity close to the other sheet explosive (i.e. the difference in the detonation velocity of the 78% PETN and that of the maximum measured one for 80%PETN is only 1.03 %) which means that SE3 based on 78% PETN can be selected as optimum one. The prepared sheet based on 78% PETN has a loading density 1.45g/cm3 and has a detonation velocity 6938 m/s that is higher than formulation Datasheet C that is around 6660 m/s. EPX-1 has a high loading density around 1.55 g/cm3 due to the presence of aluminum and has a high detonation velocity.

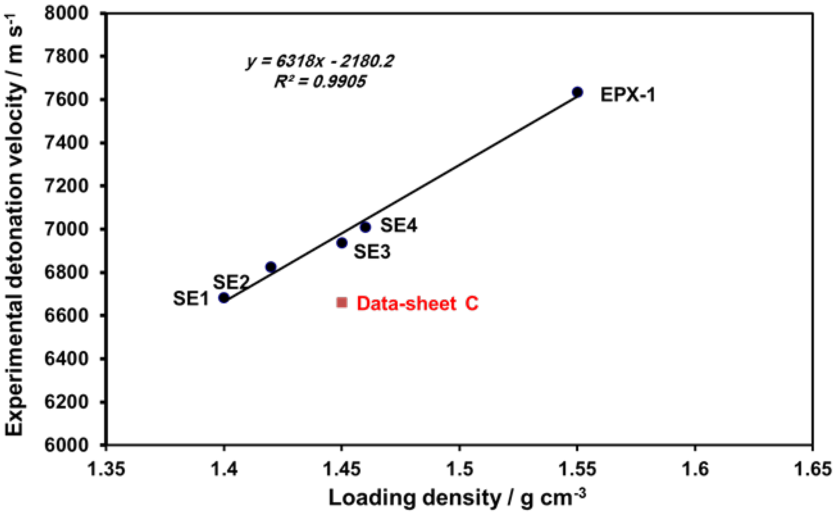

Figure 2. Relationship between the loading densities and experimental detonation velocities of the studied samples

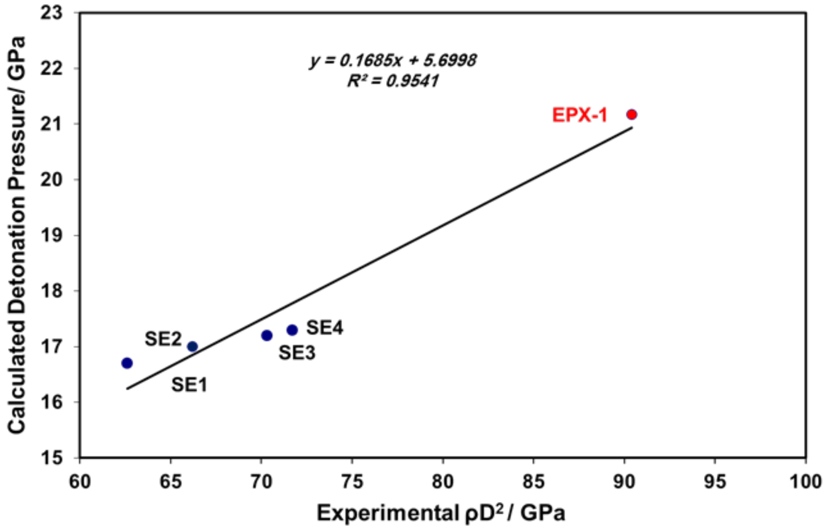

Figure 3. Relationship between the calculated detonation pressure and the experimental ρD2 (ρ-loading density, D- experimental detonation velocity)

Figure 3 represents the relationship between the calculated detonation pressure and the experimental ρD2 (ρ-loading density, D- experimental detonation velocity). It can be concluded that increasing the density of the used explosive is attributed to the variation in the present matrix composition ingredients as tabulated in Table 3. Based on the hydrodynamic theory of detonation theory, the higher the loading density of the explosive could be the higher detonation velocity and the higher detonation pressure. This is because the detonation pressure depends on the square the detonation velocity. This means when the detonation velocity is increased by 100 m/s, the pressure will be increased by 10 kPa. This value shows the sensitivity of the detonation pressure to the obtained detonation velocity of a certain explosive. EPX-1 exhibited the largest detonation pressure as shown in the same Fig 3; but its higher sensitivity to impact and friction limits its usage in the current reactive armor, especially when compared to the optimized SE3 based on 78% PETN.

4. Conclusion

Sheet explosives based on PETN with different compositions (65%, 70%, 78%, 80%) were successfully prepared. The composition based on 78% PETN has a good reasonable value of impact and friction sensitivities compared to other prepared sheet formulations. SE3 based on 78% PETN has a detonation velocity around 6938 m/s that is better than Datasheet explosive that is around 6660m/s. These results together with the accepted moderate sensitivity give a good indication that SE3 sheet based on 78% PETN can be implemented successfully in various reactive armors (ERA) applications. Relationships and comparisons had been carried out and proved the good agreement between the calculated detonation parameters by EXPLO5 code and the measured parameters.

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