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Effect of Different Polymeric Matrices on the Sensitivity and Performance of Interesting Cyclic Nitramines

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Abstract: Different polymeric matrices, based on butadiene-styrene rubber, polymethyl-methacrylate and silicone binders, were investigated for their ability to decrease the sensitivity of explosives to different mechanical stimuli. A series of plastic explosives based on four different nitramines, namely RDX (1,3,5-trinitro-1,3,5-triazacyclohexane), *β*-HMX (*β*-1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane), BCHMX (bicycloHMX, *cis*-1,3,4,6-tetranitro-octahydroimidazo-[4,5-*d*]imidazole) and *ε*-HNIW (*ε*-2,4,6,8,10,12-hexanitro-2,4,6,8,10,12-hexaazaisowurtzitane, *ε*-CL-20), bonded by the selected polymeric matrices were prepared. Sensitivity to impact of all of the plastic explosives prepared as well as of the pure explosives, was measured using the fall hammer test. Sensitivity to friction was determined using the BAM friction test. The performance was studied using the ballistic mortar test and the results were recorded relative to TNT (trinitrotoluene) as reference. By comparing the results of impact and friction sensitivities, it is obvious that the mechanism of transfer of the friction force to the reaction center of the nitramine molecule should be different from that of impact energy transfer. The silicone binder appeared to be the best polymer for decreasing the sensitivity of explosives. The results of the ballistic mortar proved that the performance of the plastic explosives prepared is affected by the type and weight percentage of the binder in each sample.

Keywords: HNIW, BCHMX, RDX, HMX, sensitivity, performance

Introduction

The sensitivity of high energy materials (HEMs) represents a very important characteristic of these materials from the standpoint of safety during manufacturing and handling. This sensitivity is primarily due to the chemical character of these materials; this means that the term "initiation reactivity" can be used in this case [1]. *cis*-1,3,4,6-tetranitrooctahydroimidazo-[4,5-*d*] imidazole (bicyclo-HMX or BCHMX) is a new attractive nitramine which had been prepared at the Institute of Energetic Materials (IEM) by a 2 stage method (unpublished) [2] − it has high detonation parameters but it is more sensitive than the other common nitramines. The detonation characteristics of BCHMX and other nitramines as plastic explosives and plastic bonded explosives have been published [3-6]. Therefore, this present paper represents a study of the friction and impact sensitivities of polymer bonded explosives incorporating BCHMX, in comparison with other attractive explosives, such as 1,3,5-trinitro-1,3,5-tiazacyclohexane (RDX), *β*-1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane (*ε*-HMX) and *ε*-2,4,6,8,10,12-hexanitro-2,4,6,8,10,12-hexaazaisowurtzitane (*ε*-HNIW). These nitramines were studied in the crystalline state as well as in the form of plastic explosives bonded with different kinds of binders; Styrene-butadiene rubber, polymethyl methacrylate and silicone matrix. The relative strength of the plastic explosives prepared was determined using the ballistic mortar.

Experimental

Nitramines

The RDX used was from Dyno Nobel (mixture of Classes 2 and 5 according to the standard [7]), *ε*-HMX was imported from Russia (its particle size was close to Class 3 according to the standard [8]), technical-grade *ε*-HNIW was a product of the Explosia pilot plant, and BCHMX was prepared by a two step continuous laboratory synthesis at the IEM.

Polymeric matrices

Three different polymeric matrices were used in the study. The styrene-butadiene rubber (25 wt%) was plasticized by HM-46 oil (75 wt%) and heated for 7 days at 80 °C to form a polymeric matrix named formex matrix. The silicone matrix of the desired average molecular mass and viscosity (unpublished) was obtained from polydimethyl-siloxane. Polymethyl-methacrylate polymer

(25 wt%) was plasticized with dioctyl adipate (75%) to form a polymeric matrix named acrylate matrix.

Preparation of the plastic explosives

All of the samples were prepared in the *Explosia Company* (Research Institute of Industrial Chemistry) Pardubice, Czech Republic. The preparation method was based on mixing the explosive crystals with the polymeric matrix using a computerized mixer Plastograph *Brabender*. In the case of the plastic explosives based on the formex matrix, 87 wt% of each individual explosive was mixed with 13 wt% of formex matrix and the resulting explosives were designated as RDX-form, HMX-form, BCHMX-form and HNIW-form. In the case of the plastic explosives based on the silicone matrix, 88 wt% of each individual explosive was mixed with 12 wt% silicone and the resulting explosives were designated as RDX-sil, HMX-sil, BCHMX-sil and HNIW-sil. The plastic explosives based on the acrylate matrix were prepared by using the slurry technique, where the compositions prepared contain 91 wt% of explosive and 9 wt% of acrylate matrix [9]. The resulting explosives were designated as RDX-PA, HMX-PA, BCHMX-PA and HNIW-PA.

Fabrication of the samples

The samples prepared were extruded by means of a 40 mm screw extruder at 80 °C to obtain long cylindrical charges of plastic explosives with 16 mm diameter and 200 mm length.

Friction sensitivity measurements

A BAM friction test apparatus was used to determine the sensitivity to friction by applying the standard test conditions [10]. Sensitivity to friction was determined by spreading about 0.01 g of the plastic explosive onto the surface of the porcelain plate in the form of a thin layer. Different loads were used to change the normal force between the porcelain pistil and the plate. Sample initiation was observed through sound, appearance of smoke, or by the characteristic smell of the decomposition products. Using the probit analysis [11], only the normal force at which 50% of initiations occur is reported as the friction sensitivity in Table 1.

Impact sensitivity measurements

The standard impact tester with exchangeable anvil (Julius Peters [10]) was used; the amount of substance tested was 50 mm^3, and drop hammers of 2 and 5 kg weight were used. The probit analysis [11] was used to determine the probability levels of the initiation. The sensitivity obtained was expressed as the drop energy, E_{dr}, versus percentage of initiation. Only the 50% probability of initiation is used in this article and is reported in Table 1.

Ballistic mortar measurements

The ballistic mortar is a heavy steel mortar attached to a pendulum. A fixed amount of explosive (10 g) was inserted into the mortar, enclosed by a steel projectile and then fired using a non-electric detonator. The maximal swing of the pendulum is a measure of the explosive strength [10, 12]. The performance of the explosive tested was expressed as a relative strength using TNT as a reference standard. For each measurement, part of a non-electric detonator is inserted into 10 g of the plastic explosive sample and fired by match. Three tests were performed for each sample; the averaged values are summarized and reported as a relative strength with respect to TNT in Table 1.

Table 1. Results of the experimental measurements on the samples studied

No.	Code designation*	Impact sensitivity [J]	Friction sensitivity [N]	Relative strength [%TNT]
1	RDX cryst.	5.6	120	-
2	RDX-form	21.4	258	132.4
3	RDX-sil	31.90	254	136
4	RDX-PA	11.8	240	137.8
5	HMX cryst.	6.4	95	-
6	HMX-form	18.2	236	131.2
7	HMX-sil	27.6	228	136.4
8	HMX-PA	12.7	211	137.6
9	BCHMX cryst.	3.2	88	-
10	BCHMX-form	15.8	228	134.2
11	BCHMX-sil	24.3	232	137.5
12	BCHMX-PA	6.1	192	139.2
13	ε-HNIW cryst.	4.1	64	-
14	ε-HNIW-form	16.2	198	136.1
15	ε-HNIW-sil	26.0	192	141.1
16	ε-HNIW-PA	8.2	164	142.6

* Each code designation is defined in the Experimental part under the heading „Preparation of the plastic explosives”.

Figure 1. Photo of plastic explosives prepared.

Figure 2. Photo of the ballistic mortar during firing.

Results and Discussion

It is obvious from Table 1 that the presence of polymeric matrices mixed with the explosive crystals decreases the sensitivity to mechanical stimuli. The effect of each type of polymeric matrix on the explosives sensitivities can be readily represented as shown in Figure 3. A comparison between the results of impact and friction sensitivities divides the explosives studied into two groups as shown in Figure 3. The first group (1) is including the pure explosives and both HNIW-PA and BCHMX-PA. This group has high sensitivity to impact (lower than 10 J), while the friction sensitivity changed from 64 N for pure HNIW to 192 N for BCHMX-PA. This group shows that the acrylate matrix enhances the friction sensitivity of both HNIW and BCHMX whilst it has a very little effect on the impact sensitivity of these explosives.

The second group (2) includes the rest of the plastic explosives prepared. The results in this group show that the friction sensitivity of all of the samples included is higher than 200 N and less than 260 N. This means that these samples have friction sensitivities close to each other. Meanwhile the impact sensitivity is changed from sensitive materials, such as RDX-PA (11.8 J) to low sensitivity materials such as RDX-sil (31.9 J). These results demonstrate the large effect of the type of the polymeric matrix on the impact sensitivity of the explosives. The silicone matrix decreased the impact sensitivity of each individual explosive to a safe level, whilst the new BCHMX-sil has an impact sensitivity lower than that of RDX-form and HMX-form.

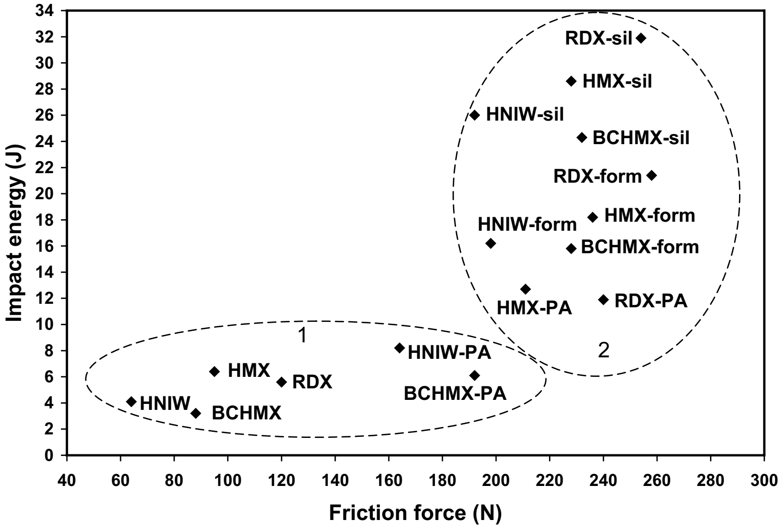

Figure 3. Results of impact sensitivity compared with friction sensitivity for all the samples studied.

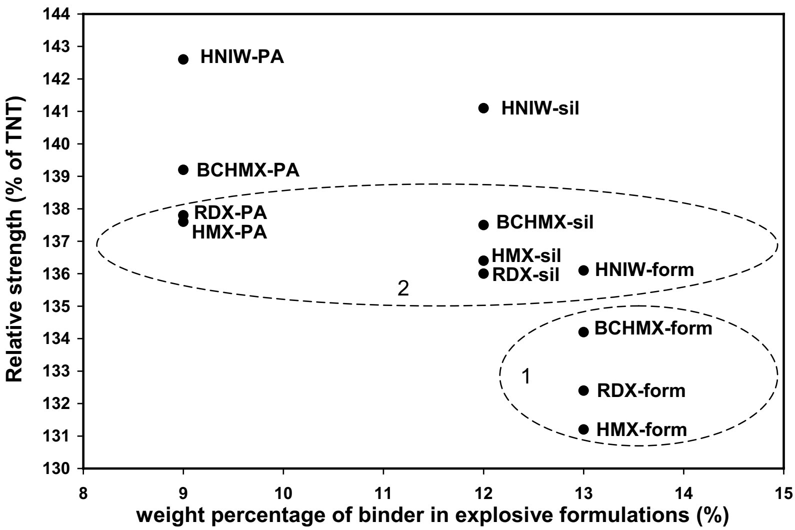

Figure 4. Results of relative strength compared with the percentage of binder in each sample studied.

Figure 4 shows the results of the ballistic mortar tests represented by the relative strength of the plastic explosives prepared compared with the percentage of binder in each sample. This figure contains three groups; the first group (1) contains the samples based on the formex matrix (13 wt%) except for HNIW-form, this group has relative strength lower than 135. The second group (2) has relative strength between 136 and 138. It includes HNIW-form, all samples based on the silicone matrix (12 wt%) except for HNIW-sil and samples based on acrylate matrix (9 wt%) except BCHMX-PA and HNIW-PA. The last group has relative strength higher than 139.

It is clear that samples based on HNIW have the highest relative strength for each individual binder. For each individual explosive, the relative strength decreases as the percentage of the binder increases. Although samples based on the silicone matrix and formex matrix have similar compositions (12 and 13% polymer, respectively), there is a significant increase in performance when the formex matrix is replaced by a silicone matrix. Samples based on the acrylate matrix have the highest relative strength for each individual explosive.

Conclusion

A silicone matrix has the greatest influence on decreasing the impact sensitivity of the explosives studied. All of the polymeric matrices studied were able to decrease the friction sensitivity of the explosives to a safe level. Samples based on the acrylate matrix showed the highest relative strength (highest performance) compared with the other polymeric matrices for each individual explosive but acrylate based samples have high sensitivity to impact. The new plastic BCHMX-sil is a promising plastic explosive, has low sensitivity to impact and friction and has a relatively high relative strength (high performance), comparable to that of HMX-PA.

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