

# Cis-1,3,4,6-Tetranitrooctahydroimidazo-[4,5-d]imidazole (BCHMX) as a Part of Low Sensitive Compositions based on DATB or HNAB

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**Abstract:** A new focus in the fields of energetic materials is on preserving high performance while enhancing manipulation safety. In this work, a special type of plastic-bonded explosive (PBX) mixture has begun to be developed by combining a new nitramine, cis-1,3,4,6-tetranitrooctahydroimidazo-[4,5-d]imidazole (BCHMX), with the thermally stable explosives 1,3-diamino-2,4,6-trinitrobenzene (DATB) and 2,2',4,4',6,6'-hexanitroazobenzene (HNAB) bonded by a styrene-butadiene rubber (SBR) binder. The studied PBXs prepared are insensitive explosives. They have been compared with Czech plastic explosives (SEMTEX 10 and SEMTEX 1H), a new Egyptian plastic explosive (EPX-1), a Swedish plastic explosive (Sprängdeg m/46) and with analogous PBXs, filled by 1,3,5-trinitro-1,3,5-triazinane (RDX),  $\beta$ -1,3,5,7-tetranitro-1,3,5,7-tetrazocane ( $\beta$ -HMX), and cis-1,3,4,6-tetranitrooctahydroimidazo-[4,5-d]imidazole (BCHMX). The in-

dividual explosives, PETN, BCHMX,  $\beta$ -HMX and RDX, have been studied as well. Thermal behavior of the pure active components has been investigated. The impact and friction sensitivities have been obtained along with the measured detonation velocities. The detonation characteristics have also been calculated using the EXPLO5 code. The relationship between performance and sensitivity to mechanical impulses has been investigated. The results have shown that DATB has a significant influence on the reduction of the sensitivity of BCHMX to a level close to TNT and much lower than all the other studied plastic explosives. In addition, the new PBX based on BCHMX and DATB has higher detonation characteristics than the commercial PBXs and TNT. The influence of DATB on BCHMX is a promising topic requiring more research for its application.

**Keywords:** Nitramines · BCHMX · Sensitivities · Detonation properties · Performance

## 1 Introduction

An attractive cyclic nitramine, cis-1,3,4,6-tetranitrooctahydroimidazo-[4,5-d]imidazole (BCHMX), was originally synthesized in Russia in the 1980s [1], but its preparation and application were confidential until 2010. Approximately twenty-five years after the Russian industrial production of BCHMX began, a similar process of BCHMX synthesis was independently developed at University of Pardubice [2,3] and research into its application in plastic-bonded explosives (PBXs) was started there [4]. Due to its rigid molecular skeleton and deformed valence angles, BCHMX has a crowded molecule [3,4], resulting in its three times higher enthalpy of formation, but also a slightly lower crystal density than in the case of  $\beta$ -1,3,5,7-tetranitro-1,3,5,7-tetrazocane ( $\beta$ -HMX) [4]. The mentioned deformations of the BCHMX molecule also lead to higher impact sensitivity when compared to HMX (at the level of pentaerythritol tetranitrate) [3,4]. However, by incorporating BCHMX into a suitable polymeric matrix, this sensitivity can be significantly eliminated [4,5], and by adding another insensitive explosive, it is possible to prepare a ternary PBX with the character of low vulnerability ammunition (LOVA) and with good performance [4–6]. Several publications dis-

cussed the sensitivity and performance of different PBXs [4,7,8], which are derived from 1,3,5-trinitro-1,3,5-triazinane (RDX),  $\beta$ -1,3,5,7-tetranitro-1,3,5,7-tetrazocane ( $\beta$ -HMX) and BCHMX. In addition, different publications have presented the effect of several polymeric matrices such as Viton A 200 [9], polydimethylsiloxane [6,10], acrylonitrile-butadiene rubber (NBR) [11], polyisobutylene (PIB) [12] and poly-(methyl methacrylate) (PMMA) [13] on the performance of the explosives. Recently, a melt cast composition based on BCHMX and TNT was investigated [14,15]. Also several publications present insensitive explosives with high performance, but their production process is expensive and the raw materials are not commercially available [16–18]. On the other side, thermally stable compounds are required for several special civilian and military applications [19–23]. Based on our experience in the preparation and testing of the already-mentioned tertiary low-sensitivity PBXs [4–6],

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we have modified the BCHMX plastic explosives with the thermally stable 1,3-diamino-2,4,6-trinitrobenzene (DATB) and 2,2',4,4',6,6'-hexanitroazobenzene (HNAB); these tertiary PBXs are bonded by a styrene-butadiene rubber binder. In these ternary energetic compositions, the sensitivity and explosive characteristics have been determined and compared with the same data for Czech plastic explosives (SEMTEX 10 and SEMTEX 1H), a new Egyptian plastic explosive (EPX-1), a Swedish plastic explosive (Sprängdeg m/46) and for analogous PBXs, filled by RDX,  $\beta$ -HMX and BCHMX. In addition, the thermal stability of the pure active components of these PBXs has been determined by means of TG/DTG.

## 2 Experimental

### 2.1 Materials and the Preparation Method

BCHMX, whose chemical structure (see Figure 1a) is a white crystalline powder, was prepared at the Institute of Energetic Materials as reported in Refs. [2, 3] and it was recrystallized by acetone/heptane using the solvent/anti-solvent technique to obtain crystals with a uniform shape and a small particle size.

DATB (1,3-diamino-2,4,6-trinitrobenzene), whose chemical structure (see Figure 1b) is a yellowish green crystalline substance with a density of  $1.83 \text{ g cm}^{-3}$  [24], was prepared on a laboratory scale by treating 1,3-dichloro-2,4,6-trinitrobenzene with ammonia in methanol according to Ref. [25]. HNAB (2,2',4,4',6,6'-hexanitroazobenzene), whose chemical structure (see Figure 1c) is a brownish-red crystalline substance with a density of  $1.79 \text{ g cm}^{-3}$ , was prepared at a laboratory in two main steps [25] through the potassium salt of 2,2',4,4',6,6'-hexanitrohydrazobenzene, which is then oxidized by 97 % wt. of nitric acid.

A styrene-butadiene rubber binder (SBR-binder) was used as a polymeric matrix to bond the prepared explosive mixture. The styrene-butadiene rubber binder was prepared by swelling the rubber in a dioctyl sebacate plasticizer in 1:3 weight ratios. Using a Brabender Plastograph computerized mixer, the solid explosive ingredients (BCHMX 43.5 wt. % and DATB 43.5 wt %) were mixed together, after which the polymeric matrix (13 wt. %) was being added at  $25^\circ\text{C}$  for 90 min. The prepared plastic explosive was ex-

truded to form cylindrical explosives with a diameter of 21 mm. The same procedure was applied to prepare BCHMX/HNAB-SBR by adding HNAB instead of DATB using the same conditions.

### 2.2 Thermal Study

The thermal behavior of the prepared pure explosives (BCHMX, DATB and HNAB) was studied by Thermogravimetric analysis (TG; Netzsch 209F3 instrument, open  $\text{Al}_2\text{O}_3$  crucible) with the heating rate of  $2^\circ\text{C min}^{-1}$  (with the data collection rate of 40 points per Kelvin). The test temperature range for the TG was  $30\text{--}450^\circ\text{C}$ , with the sample mass of about 1.5–1.85 mg under a dynamic nitrogen atmosphere (at a flow rate of  $30 \text{ ml min}^{-1}$ ). The low heating rate was applied to clarify the decomposition peaks of the explosives [11].

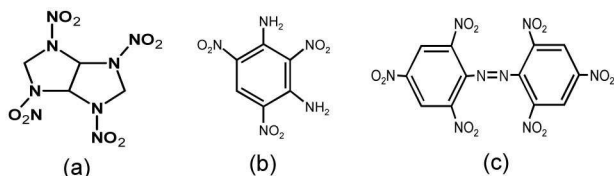
### 2.3 Sensitivity to Impact and Friction

The standard impact tester with a BAM impact sensitivity instrument with an exchangeable drop weight [26] was used; the amount of the substance tested was  $50 \text{ mm}^3$ . Probit analysis method was utilized to determine the probability levels of the initiation. Only the 50 % probability of initiation ( $H_{50}$  recalculated in Joules [27]) was used (see Table 1). A BAM friction test apparatus was used to determine the sensitivity to friction using the standard test conditions [26]. The sensitivity to friction was determined

**Table 1.** The results of the experimental measurements on the samples studied.

No	Code designation	Summary formula	Impact sensitivity [J]	Friction sensitivity [N]
1.	BCHMX	$\text{C}_4\text{H}_6\text{N}_8\text{O}_8$	3.2 <sup>[a]</sup>	88 <sup>[a]</sup>
2.	$\beta$ -HMX	$\text{C}_4\text{H}_8\text{N}_8\text{O}_8$	6.4 <sup>[a]</sup>	95 <sup>[a]</sup>
3.	RDX	$\text{C}_3\text{H}_6\text{N}_6\text{O}_6$	5.6 <sup>[a]</sup>	120 <sup>[a]</sup>
4.	DATB	$\text{C}_6\text{H}_5\text{N}_5\text{O}_6$	78.4	> 360
5.	HNAB	$\text{C}_{12}\text{H}_4\text{N}_8\text{O}_{12}$	7.8	302
6.	TNT	$\text{C}_7\text{H}_5\text{N}_3\text{O}_6$	34.8	354
7.	PETN	$\text{C}_5\text{H}_8\text{N}_4\text{O}_{12}$	2.9 <sup>[b]</sup>	46 <sup>[b]</sup>
8.	BCHMX-SBR	$\text{C}_{7.31}\text{H}_{11.72}\text{N}_{8.07}\text{O}_{7.96}$	15.8 <sup>[c]</sup>	228 <sup>[c]</sup>
9.	HMX-SBR	$\text{C}_{7.16}\text{H}_{13.63}\text{N}_{8.07}\text{O}_{7.94}$	18.2 <sup>[c]</sup>	236 <sup>[c]</sup>
10.	RDX-SBR	$\text{C}_{5.47}\text{H}_{10.1}\text{N}_{6.0}\text{O}_{5.94}$	21.4 <sup>[c]</sup>	258 <sup>[c]</sup>
11.	BCHMX/ DATB-SBR	$\text{C}_{8.64}\text{H}_{11.03}\text{N}_{7.2}\text{O}_{7.72}$	35.2	> 360
12.	BCHMX/ HNAB-SBR	$\text{C}_{9.75}\text{H}_{10.4}\text{N}_{7.2}\text{O}_{8.62}$	25.1	330
13.	EPX-1	$\text{C}_{7.88}\text{H}_{12.36}\text{N}_{4.0}\text{O}_{12.59}$	13.9 <sup>[d]</sup>	176 <sup>[d]</sup>
14.	SEMTEX10	$\text{C}_{8.05}\text{H}_{12.64}\text{N}_{4.0}\text{O}_{12.37}$	15.7 <sup>[b]</sup>	204 <sup>[b]</sup>
15.	SEMTEX 1H	$\text{C}_{6.39}\text{H}_{11.36}\text{N}_{5.34}\text{O}_{7.91}$	20.2 <sup>[e]</sup>	233 <sup>[e]</sup>
16.	Sprangdeg m/46	$\text{C}_{8.10}\text{H}_{12.81}\text{N}_{4.0}\text{O}_{10.90}$	14.2 <sup>[f]</sup>	183 <sup>[f]</sup>

<sup>[a]</sup>[28], <sup>[b]</sup>[29], <sup>[c]</sup>[30], <sup>[d]</sup>[31], <sup>[e]</sup>[32], <sup>[f]</sup>[8]



**Figure 1.** The structural formulas of a) BCHMX, b) DATB and c) HNAB.

by spreading approximately 0.01 g of the studied explosive on the surface of a 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, smoke appearance, or by the characteristic smell of the decomposition products. Using the Probit analysis method [27], only the normal force at which 50% of initiations occurred is reported in Table 1, namely as the friction sensitivity.

## 2.4 Detonation Velocity Measurements

The detonation velocity of the composition prepared was measured by an EXPLOMET-FO-2000 produced by KONTINIRO AG. The composition tested was prepared in the form of cylinders with a diameter of 21 mm and a length of 200 mm. Three optical sensors were placed in each charge, with the first sensor being placed at a distance of 50 mm from the surface containing the detonator. Each of the other two sensors was placed at a distance of 60 mm from the previous one. Charges were set off using detonator no. 8. For a good precision of the results, three measurements were performed for the each composition; the mean value (max.  $\pm 69 \text{ m s}^{-1}$ ) is reported in Table 2.

## 2.5 Calculation of the Detonation Characteristics

The theoretical detonation characteristics (detonation velocity,  $D$ , heat of detonation,  $Q$ , and detonation pressure,  $P$ )

of the prepared compositions as well as those of the individual explosives were calculated by the EXPLO5 code version 5.04 [33]. The following BKWN set of parameters was used:  $\alpha = 0.5$ ,  $\beta = 0.176$ ,  $\kappa = 14.71$ ,  $\Theta = 6620$  [33]. The heat of explosion is the heat released in a constant-volume explosion; it is determined by subtracting the heats of formation of the explosive (reactants) from the sum of the heats of formation of the detonation. The theoretical calculation and the error of the experimental results are listed in Table 2.

## 3 Results and Discussion

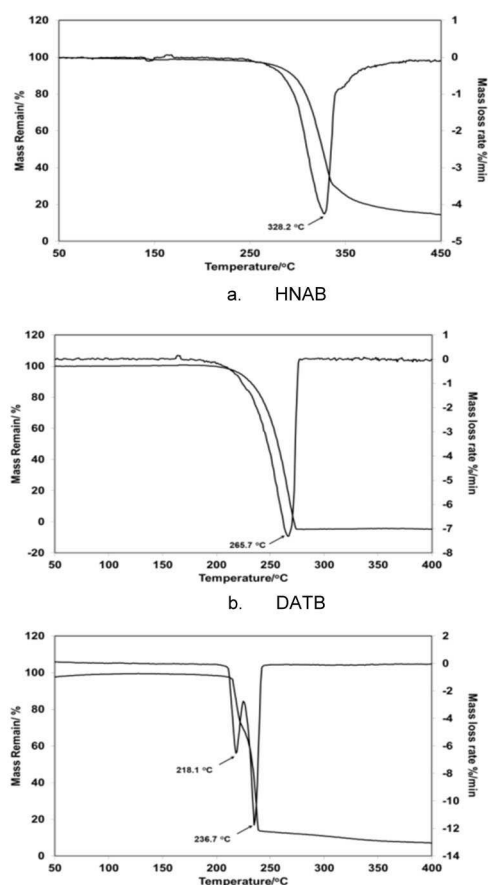
### 3.1 Thermal Data

The TG/DTG curves of the prepared pure HNAB, DATB and BCHMX obtained at the heating rates of  $2^\circ\text{C min}^{-1}$  are shown in Figure 2. In addition, the decomposition results of the studied samples are presented in Table 3. It is evident that only a single decomposition process has been observed for HNAB at the maximum peak temperature of  $328.2^\circ\text{C}$ . The decomposition process began at  $303^\circ\text{C}$  with steady mass loss until the end of the decomposition process at  $341.2^\circ\text{C}$ . It means that HNAB is a thermally stable explosive [20]. the decomposition process occurring at a higher temperature than in the case of the traditional explosives (onset decomposition temperatures of PETN at  $187^\circ\text{C}$ , RDX at  $198^\circ\text{C}$  and HMX at  $274^\circ\text{C}$  [3]). In addition, the thermal behavior of DATB showed a single decomposition peak with the onset decomposition temperature at  $243.3^\circ\text{C}$  and

**Table 2.** The detonation parameters of the samples studied.

No.	Studied sample Sample codes	Experimental measurement	Detonation parameters calculated by the Explo5 code				
		Density $\rho$ [g cm $^{-3}$ ]	Detonation velocity [m.s $^{-1}$ ] experimental $D_{\text{exp}}$	calculated $D_{\text{cal.}}$	Error %	Detonation pressure $P$ [GPa]	Heat of detonation $Q$ [kJ kg $^{-1}$ ]
1.	BCHMX	1.79 <sup>[a]</sup>	8650 <sup>[a]</sup>	8840	+2.2	33.9	6447
2.	$\beta$ -HMX	1.90 <sup>[a]</sup>	9100 <sup>[a]</sup>	9225	+1.4	38.0	6075
3.	RDX	1.76 <sup>[a]</sup>	8750 <sup>[a]</sup>	8718	-0.4	32.1	6085
4.	DATB	1.79	7520	7658	+1.8	24.3	4714
5.	HNAB	1.60	7310	7362	+0.7	21.6	5595
6.	TNT	1.60 <sup>[a]</sup>	6900 <sup>[a]</sup>	7126	+3.3	19.5	5101
7.	PETN	1.70 <sup>[a]</sup>	8400 <sup>[a]</sup>	8318	-1.0	28.5	6160
8.	BCHMX-SBR	1.59 <sup>[b]</sup>	7922 <sup>[b]</sup>	7755	-2.1	22.7	6245
9.	HMX-SBR	1.60 <sup>[b]</sup>	7986 <sup>[b]</sup>	7839	-1.8	23.2	5994
10.	RDX-SBR	1.56 <sup>[b]</sup>	7711 <sup>[b]</sup>	7601	-1.4	21.0	5958
11.	BCHMX/ DATB-SBR	1.56	7815	7660	-2.0	22.7	6049
12.	BCHMX/ HNAB-SBR	1.59	7874	7670	-2.6	23.2	6170
13.	EPX-1	1.55 <sup>[c]</sup>	7636 <sup>[c]</sup>	7398	-3.1	21.17	5742
14.	SEMTEX10	1.52 <sup>[d]</sup>	7486 <sup>[d]</sup>	7370	-1.5	20.89	5708
15.	SEMTEX 1H	1.53 <sup>[e]</sup>	7568 <sup>[e]</sup>	7463	-1.4	20.33	5475
16.	Sprangdeg m/46	1.52 <sup>[f]</sup>	7520 <sup>[f]</sup>	7232	-3.8	19.28	5345

<sup>[a]</sup>[34], <sup>[b]</sup>[30], <sup>[c]</sup>[31], <sup>[d]</sup>[29], <sup>[e]</sup>[32], <sup>[f]</sup>[8]



**Figure 2.** The TG/DTG of the studied sample; a) pure HNAB, b) pure DATB and c) pure BCHMX at the heating rate of  $2^{\circ}\text{C min}^{-1}$ .

**Table 3.** The results of the non-isothermal TG/DTG of the studied PBX formulation and pure explosives at the heating rate of  $2^{\circ}\text{C min}^{-1}$ .

Type		TG curve		DTG curve		
		T <sub>o</sub> (°C)	Mass loss (%)	L <sub>max</sub> (%min <sup>-1</sup> )	T <sub>p</sub> (°C)	T <sub>oe</sub> (°C)
HNAB		303.0	−82.29	−4.26	328.2	341.2
DATB		243.2	−99.8	−7.33	265.7	275.5
BCHMX	1 <sup>st</sup> peak	213.8	−29.57	−7.7	218.1	222.8
	2 <sup>nd</sup> peak	234.4	−56.02	−11.86	236.7	239.4

$T_o$ , the onset temperature of the decomposition;  $L_{max}$ , the maximum-mass loss rate;  $T_p$ , the peak temperature of the mass-loss rate for the DTG curve and the maximum peak temperature for the DTG curves;  $T_{er}$ , the onset temperature of the end decomposition.

the maximum peak temperature at  $265.7^{\circ}\text{C}$ . The mass loss during the decomposition process was 99.8% and the decomposition finished completely at  $275.5^{\circ}\text{C}$ . On the other hand, the behavior of BCHMX was different from that of DATB and HNAB. BCHMX had two consecutive decomposition peaks. The onset decomposition peak of the first

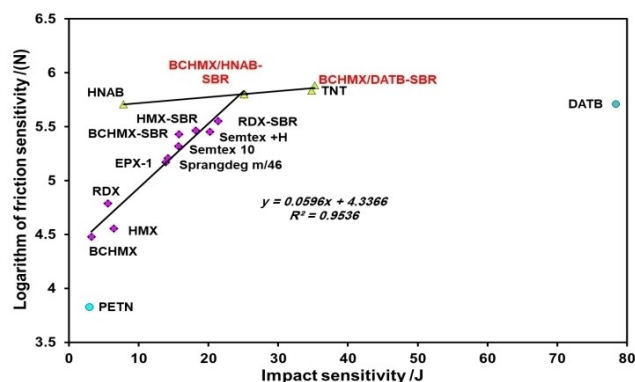
stage started at  $213.8^{\circ}\text{C}$  and reached its maximum at  $218.1^{\circ}\text{C}$ . The mass loss during the first stage was 29.57% and finished at  $222.8^{\circ}\text{C}$ . The second decomposition stage started at  $234.4^{\circ}\text{C}$  and the decomposition reached its maximum peak at  $236.7^{\circ}\text{C}$ , where the mass loss during this stage was 56.02%. This may have been caused by the effect of both the accumulated heat and the autocatalytic reaction. According to Refs. [4,35], the longest N-NO<sub>2</sub> bond in the rigid molecule of BCHMX has been broken and caused the first thermolysis at the surface of the molecule, which forms an active medium for the continuation of the decomposition reaction during the second stage of decomposition.

It has also been discussed that BCHMX has only one decomposition peak at the high heating rate because of the overlap of the two peaks at the high heating rate [36,37]. Finally, it is obvious that BCHMX has lower thermal stability than DATB and HNAB.

### 3.2 Sensitivity and Performance

The performance of an explosive material significantly affects its impact and friction sensitivity, which corroborates the recently accepted presumption that the high performance of an explosive is usually accompanied by an increase in explosive sensitivity [38].

However, modern techniques are used to combine increasing the performance with reducing the sensitivity. One of the methods is the plastic explosive compositions. In order to study the sensitivity of the studied samples, Zeman et al. [38,39] have described the mutual relationship between the initiation by impact (uniaxial compression) and initiation by friction (shear slide with a fixed volume). The difference between them might be caused by the difference in the transfer mode of the initiation impulse from the mentioned kinds of initiation into the reaction center of the studied nitramine molecules. In this connection, a semi-logarithmic relationship between friction and impact sensitivity has been derived for the studied explosives in Figure 3. It



**Figure 3.** The semi-logarithmic relationship between friction and impact sensitivity.

has been observed that DATB has very low impact sensitivity in comparison with all the studied samples. Moreover, it considerably influences the sensitivity of BCHMX, as shown in the figure, where BCHMX/DATB-SBR has the impact sensitivity close to the pure TNT and lower than all the studied samples. Regarding the friction sensitivity, an interesting observation was made where the pure explosives HNAB, TNT and their mixtures lay on the same straight line, representing the group of the lowest friction sensitivity of all the samples studied. The results of DATB in Figure 3 are entirely different from those of these two groups; in the crystalline state, DATB molecules do not form 2D planar networks, although they are linked together into a 1D continuous chain by intermolecular hydrogen bonds [40]. These hydrogen bonds play an important role in stabilizing the energy change of the crystal system [41].

This arrangement in the crystal lattice of DATB should not have much influence on the shear (friction sensitivity), but it stabilizes DATB against impact (a change of volume). On the other hand, pure nitramines (RDX, HMX and BCHMX) and the samples based on SBR lay on the same straight line with the commercially available plastic explosives based on PETN. In addition, HNAB improves the sensitivity of BCHMX in the polymeric matrix to a level lower than all the commercial plastic explosives, but it is less effective than DATB. In addition, the presence of the SBR matrix obviously improves the sensitivity. This is clearly shown by the significant decrease of the impact sensitivity of the pure nitramines, which was observed after the addition of the SBR matrix.

A comparison of the impact sensitivity of BCHMX-SBR (15.8 J) and BCHMX/DATB-SBR (35.2 J) clearly shows the great influence of DATB on BCHMX. When all the plastic explosives are compared, the Czech Semtex 1H has the lowest sensitivity; this is caused by the presence of RDX as an explosive filler, which has lower sensitivity than PETN.

For the assessment of the influence of thermally stable explosives and the polymeric matrix on the performance of the explosives studied, an interesting relation between the volume heat of detonation (the product of loading density and the volume explosion heat  $\rho Q/\text{MJ}\cdot\text{m}^{-3}$ ) and the logarithm of impact sensitivity is presented in Figure 4 (for more on the nature of this relation in general, see Ref. [38]). This figure contains three line groups. The first group includes HMX, both the ternary PBXs and DATB. The second one comprises BCHMX, RDX and PBXs based on SBR.

The compositions of these groups are not accidental – a certain molecular-structural relationship between the active components is evident. The third group represents PETN/explosives with the exception of Sprängdeg m/46 (desensitized by mineral oil without polymer). Sprängdeg m/46 has the lowest performance of all the samples studied, which might be due to the absence of the polymeric binder in its composition. The new explosives, BCHMX/DATB-SBR and BCHMX/HNAB-SBR, belong to the first group, where their performance is higher than that of RDX-SBR. As presented in the previous

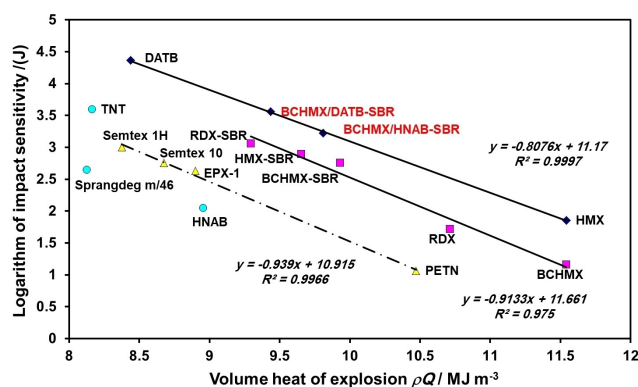


Figure 4. The semi-logarithmic relationship between impact sensitivity and the volume heat of explosion.

section, BCHMX/DATB-SBR has the lowest impact sensitivity of all the studied plastic explosives, which is very close to that of TNT. Also EPX-1 has the highest performance of the commercial plastic explosives. Figure 4 confirms the general finding that an increase in the performance (volume heat of detonation) is usually accompanied by an increase in the sensitivity of explosives [38].

A well-known relationship between the density of the explosives and their detonation velocity has been studied in several publications [8]. In this study, the authors discuss this relationship in the presence of thermally stable explosives and their new compositions as shown in Figure 5. It was observed that the pure explosives, DATB, HNAB and TNT, do not verify this relationship (the primary fission chemistry in their detonation is markedly different from that of the other explosives studied [42]). These pure polynitroarenes have relatively low detonation velocity in comparison with their density. On the other hand, a linear relationship has been observed between the density and the detonation velocity of all the studied plastic explosives and

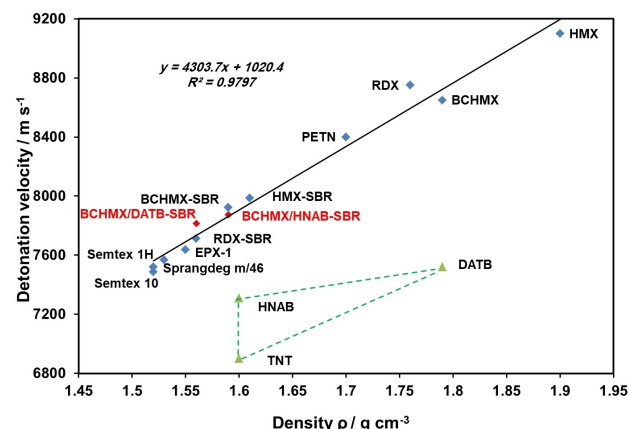


Figure 5. The relationship between the density of the explosives and their experimental detonation velocity.

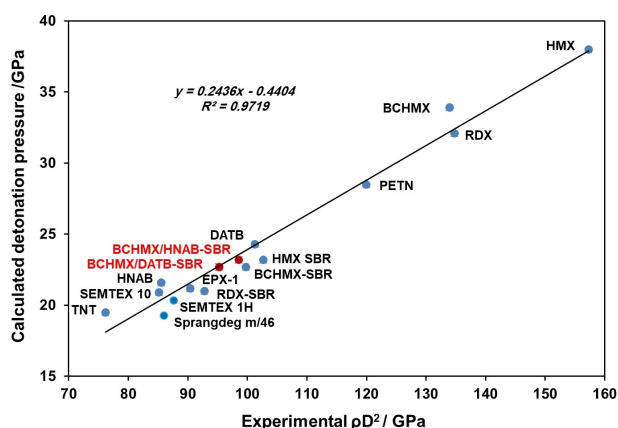


the pure nitramines. As observed in Figure 5, the pure HMX has the highest detonation velocity of all the studied samples and its plastic explosive HMX-SBR has the highest detonation velocity of all the plastic explosives studied.

Here, the detonation velocity of BCHMX-SBR is higher than the new composition BCHMX/DATB-SBR by nearly  $100 \text{ ms}^{-1}$ . This result confirms that the addition of DATB slightly decreases the performance of BCHMX but greatly decreases its sensitivity to a level close to TNT. In spite of that, the detonation velocity of BCHMX/DATB-SBR is higher than that of all the commercial plastic explosives studied.

Regarding the physics of explosion, the detonation pressure of the explosives could be represented by the products of the square of the detonation velocity and the loading density.

Figure 6 presents a comparison of the calculated detonation pressure (by the EXPLO5 code) with the product of the square of the experimental detonation velocity and the loading density, where the compatibility of the calculated results with the experimental measurements has been confirmed. It is also clear that the detonation characteristics of BCHMX/DATB-SBR are higher than those of RDX-SBR and all the commercial explosives studied, whereas the detonation pressure of BCHMX/HNAB-SBR is on the same level as both BCHMX-SBR and HMX-SBR. This confirms the efficiency of HNAB to maintain the performance of BCHMX. The results of the sensitivity and performance of the studied samples have proven that the new PBXs based on DATB and HNAB are interesting plastic explosives with lower impact sensitivity and higher performance than the commercially available plastic explosives. In addition, when the results are optimized, BCHMX-DATB-SBR seems to be a promising plastic explosive with some potential application in the future, requiring further study.



**Figure 6.** The relationship between the calculated detonation pressure and the square of the experimental detonation velocity multiplied by the loading density.

## 4 Conclusion

The prepared ternary plastic explosive based on BCHMX with an admixture of DATB or HNAB, bonded by styrene-butadiene rubber (SBR), has lower sensitivity to impact and friction than all the studied pure cyclic nitramines and industrial PETN plastic explosives. The evaluation of these nitramine explosives has confirmed the semi-logarithmic relationship between the impact and friction sensitivity. It has been concluded that the presence of the low sensitive explosives DATB and HNAB significantly reduces the sensitivity of the BCHMX explosive mixtures. The interesting relationship between performance and sensitivity shows the relatively high performance of the new BCHMX/HNAB-SBR and BCHMX/DATB-SBR with low sensitivity to impact in comparison with the commercial plastic explosives studied. However, the new ternary PBX containing HNAB has slightly higher performance while its DATB-containing analogue has lower sensitivity. These new ternary PBXs are considered promising compositions optimizing high performance and low sensitivity, which might have applications in the future.

## Data Availability Statement

Data available on request from the authors.

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