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Characteristics of a paste explosive (EPX-P20) used in explosive bolts for spacecraft's applications

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Abstract: An explosive charge, located within a machined cavity in a bolt, provides the energetic stimulus required for cleanly bolt fracture. The shock wave produced fom the explosion causes tensile fracture along the bolt itself with minumum fragmentation and helps to control the separation process of the satellite from its rocket. In this study, EPX-P20 is a paste explosive in the research stage. EPX-P20 is based on PETN (pentaerythritol tetranitrate) bonded by polydimethyl-siloxane binder matrix. A computerizing mixer plastograph was used for the production of EPX-P20. The internal energy of combustion was measured and used to determine the enthalpy of formation. Sensitivity against both friction and impact stimuli were determined. The detonation properties were calculated theoretically using the EXPLO 5 soft code, while the detonation velocity was determined experimentally. For comparison, several commercial available explosives such as; Sprängdeg m/46, Formex P1, Semtex 10 and EPX-1 were investigated. It was proven that EPX-P20 possesses the lowest velocity of detonation while maintaining its very low sensitivity. Interesting inversely proportion relationship amongst the measured internal energy of combustion and the calculated heat of detonation was observed. The produced paste explosive might be used in explosive bolt for space craft's applications.

Keywords: plastic explosives, sensitivity, combustion, detonation.

1. Introduction

In space craft's applications, Explosive bolts are usually used as explosive device for the separation of satellites from the long range rockets [1]. An explosive bolt consists of a bolt with a cavity filled by an explosive charge [2]. Satellites are normally fixed on the rockets using separating device including the explosive bolts [3]. On the time of separation, electrical signal causes the detonation of the explosive which produces gaseous products with high energy that are able to break the connection joints and causes the separation of the satellites [4]. Special types of plastic explosives could be used for filling the explosive bolts. The plastic explosive consists mainly of energetic material as filler bonded by selected rubbery material in order to reduce the sensitivity of the explosive and improve its mechanical properties [5, 6]. The main key in the fabrication of the plastic explosive is the polymeric matrix. This matrix in addition to the mixing process has a significant impact on the characteristics of the produced plastic explosive [7-9]. Several publications presented the different categories of plastic explosives and compared the sensitivity and the performance of the commercially available plastic explosives [10,

11]. The composition of the polymeric matrix has also a significant influence on the energetic materials thermal stability [12]. Many types of research discussed the decomposition kinetics of plastic explosives produced by different countries and their impact on the shelf life and the stability of the different products using variable techniques [13-18]. Semtex 10 is a Czech plastic explosive which is used for underwater blasting and demolition of rocks. It contains Pentaerythritol tetranitrate (PETN) as filler mixed by plasticized nitrile rubber [19]. Formex P1 is a Frensh plastic explosive contains a polymeric matrix of styrene butadiene rubber bond PETN explosive [20]. EPX-1 is an Egyptian plastic explosive contains PETN explosive bonded by a non-energetic binder, it has been used in blasting techniques for civil applications [21]. The Sweden explosive, Sprängdeg m/46, contains a mixture of viscous liquid bonded the energetic material, PETN [22].

In this work, the production method of a paste explosive named EPX-P20 was presented. The explosive properties of the new EPX-P20 in comparison with several commercial explosives; Sprängdeg m/46, EPX-1, Formex P1, and Semtex 10 were determined and discussed. The detonation properties of the studied materials were calculated using the EXPLO5 software. The internal energy of combustion and the heat of detonation were discussed. Sensitivities of the samples to different stimuli were compared. The performance represented by the detonation velocity and detonation pressure of each sample was discussed. The effect of the energy content on the performance of the plastic explosive was also observed.

2. Experimental

2.1. Preparation of EPX-P20

The production of EPX-P20 is performed in Heliopolis Company for Chemical Industries, Egypt. Penetrite (PETN) with a mean particle size of 38 and 284 µm respectively is produced by the company. Polydimethyl siloxane (MS) was obtained from Germany.

The preparation of the polymeric matrix is based on the mixing of different MS with different viscosities to obtain a viscous polymeric matrix. The production of the plastic explosive is performed in a programming mixer plastograph BRABENDER. The process based on the mixing of PETN with MS at two stages; 80 wt% of PETN was placed in the plastograph and mixed with 20 wt% of MS for 60 min. at normal temperature. The product was extruded to fill a cylinder of paste explosive.

2.2. Elemental analysis

Perkin Elmer 2400 CHNS/O elemental analyzer was utilized to conclude the elemental percentage of carbon “C”, hydrogen “H”, and nitrogen “N” in the produced explosive. The obtained elemental analysis was recalculated in order to contest the N content of the specific explosive and reported in Table (1). This calculated summary formula was used as a demonstrative of particular explosive and so it can be used as a formula in EXPLO5 code to determine the detonation parameters of EPX-P20.

2.3. The internal energy of combustion

The internal energy of combustion was calculated using a Programmed Combustion Calorimeter known as MS10A. The process constructed on ignition of the prepared sample in a bomb packed with an excess of oxygen [23]. The acquired result was reported in Table 1. The internal energy of combustion was used to calculate the heat of formation which is required to determine the detonation parameters.

2.4. Impact sensitivity measurements

The impact energy required for initiation was determined using BAM impact sensitivity instrument. The measurement was achieved using a commutable drop weight [22]. 50 mm^3 of the sample tested using 2 kg and 5 kg drop hammers. The possible initiation levels were forecasted using the probit analysis method [23]. The accepted levels of initiated which achieved a 50% possible initiation or more are informed in Table 2.

Table 1. The data required for the calculation of detonation characteristics

No.	Explosive type	Formula	Mol. Weight ($g \cdot mol^{-1}$)	Internal energy of combustion ($J \cdot g^{-1}$)	Heat of formation ($kJ \cdot mol^{-1}$)
1	EPX-1 [21]	$C_{7.88}H_{12.36}N_4O_{12.59}$	364.58	11528	-666.5
2	Semtex 10 [19]	$C_{8.05}H_{12.64}N_4O_{12.37}$	363.38	11942	-646.8
3	Formex P1 [24]	$C_{8.26}H_{13.98}N_4O_{11.85}$	358.93	12943	-613.2
4	Sprängdeg m/46 [25]	$C_{8.10}H_{12.81}N_4O_{10.90}$	340.63	13179	-539.2
5	EPX-P20	$C_{7.11}H_{11.76}N_4O_{12.67}Si_{0.89}$	379.92	12284	-487.3

2.5. Friction sensitivity measurements

The sensitivity to friction was measured using the BAM friction test device and the experiments have been performed under the typical test conditions [26]. 0.01g of the investigated sample was placed carefully on a porcelain plate surface. The experiment took place using different loads in order to alter the normal force induced between the plate and the porcelain pistil. The initiation of the investigated sample was counted if any of the characteristic features appeared such as; sound, smoke, or smell. Applying the Probit analysis method [27], the friction force necessary to achieve a 50% successful initiation is reported in Table 2.

2.6. Detonation velocity measurements

Detonation velocity of EPX-P20 explosive was measured using the EXPLOMET-FO-2000 (created by KONTINITRO AG). In this experiment, a cylinder with a 21 mm diameter and a 200 mm length was prepared. Three optical sensors were used where an optical sensor has been placed in each charge. Initially, the first sensor was located away from the initiator edge by a distance of 50 mm, while the other sensors were positioned at a 50 mm away from each previous sensor. Detonator no. 8 was utilized for the initiation process and the average value out of the three measurements was recorded as given in Table 2.

Table 2. The measured characteristics of the investigated explosives

No.	Explosive type	Impact energy (J)	Friction sensitivity (N)	Density ($g \cdot cm^{-3}$)	Detonation velocity *measured* ($m \cdot s^{-1}$)
1	EPX-1 [21]	13.9	176	1.55	7636
2	Semtex 10 [19]	15.7	204	1.52	7486
3	Formex P1 [24]	13.5	194	1.53	7544
4	Sprängdeg-m/46 [25]	14.2	183	1.52	7520
5	EPX-P20	26.4	332	1.48	7212

2.7. Detonation characteristics determination methodology.

The calculated detonation parameters (detonation velocity (D), detonation pressure (P), and the heat of detonation (Q) of EPX-P20 and the traditional plastic explosives characteristics were assessed using the EXPLO5 soft code [28]. The Becker-Kistiakowsky-Wilson equation of state (BKW EOS) was

used after setting the Becker-Kistiakowsky-Wilson (BKWN) constants; α = 0.5, β = 0.298, k = 10.50, Θ = 6620. The measured detonation features obtained from these experiments were reported in Table 3.

Table 3. The acquired detonation characteristics of the investigated explosive samples

No.	Explosive type	Density ($g \cdot cm^{-3}$)	EXPLO5			
			detonation velocity ($m \cdot s^{-1}$)	$\frac{D_{calc}-D_{exp}}{D_{exp}/100}$ (%)	detonation pressure (GPa)	detonation Heat ($J \cdot g^{-1}$)
1	EPX-1 [21]	1.55	7398	-3.1	21.17	5742
2	Semtex 10 [19]	1.52	7370	-1.5	20.89	5708
3	Formex P1 [24]	1.53	7346	-2.6	20.03	5411
4	Sprängdeg-m/46 [11]	1.52	7232	-3.8	19.28	5345
5	EPX-P20	1.48	7078	-1.9	18.46	5124

3. Results and Discussion

In the experimental part, when discussing the preparation procedure of the EPX-P20, it was observed that the conditions of mixing the ingredients affect the characteristics of the final product [29]. The torque value was decreased until it reached a stable range where the sample had a high homogeneity and the air-gaps were removed. The results acquired for the sensitivity values against the impact and friction stimuli scheme in Figure 1 for comparison. A group of plastic explosives was observed including all the commercial plastic explosives. While EPX-P20 has impact and friction sensitivities relatively very low if compared with the examined plastic explosives. It means that the paste explosive EPX-P20 has very low sensitivity and suitable for special applications required high safety. Even that all the studied samples are filled by PETN but the siloxane matrix and its percentage in EPX-P20 completely decreased the mechanical sensitivity regardless of the explosive type.

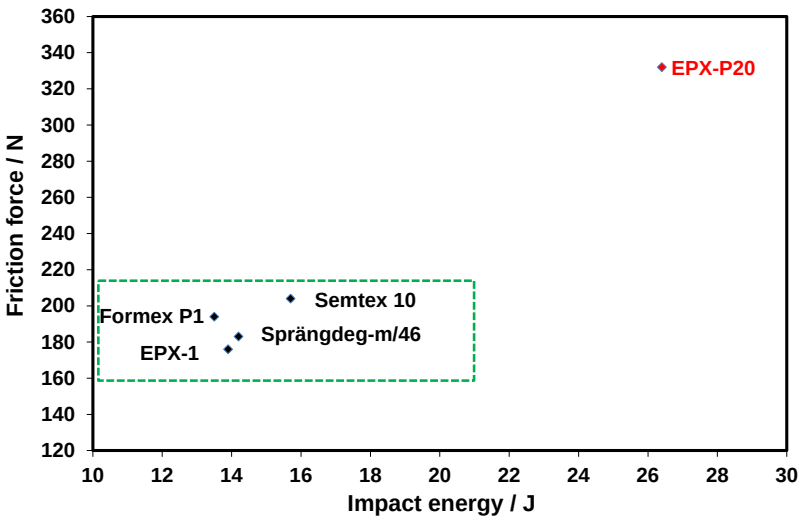

Figure 1. The impact and friction sensitivities EPX-P20 in comparison with the studied samples.

The detonation velocities measured were plotted in Figure 2 versus the loading density of the prepared samples. This relation is well known according to the theory of explosion. The results proved that the paste explosive EPX-P20 owns the lowest detonation velocity relatively to the corresponding values obtained for all the other investigated samples. This result is logic because the explosive filler in EPX-P20 is 80 wt% which is the least of all the studied samples. In addition, the highly energetic plastic explosive EPX-1 has the uppermost detonation velocity value compared with the commercially available plastic explosives studied. The results verify the predicted relationship with high accuracy R^2 = 0.9712. It also authorizes the compatibility of this work results with the references results. The calculated detonation parameters also proved that EPX-P20 has the lowest detonation parameters than all the studied plastic explosives.

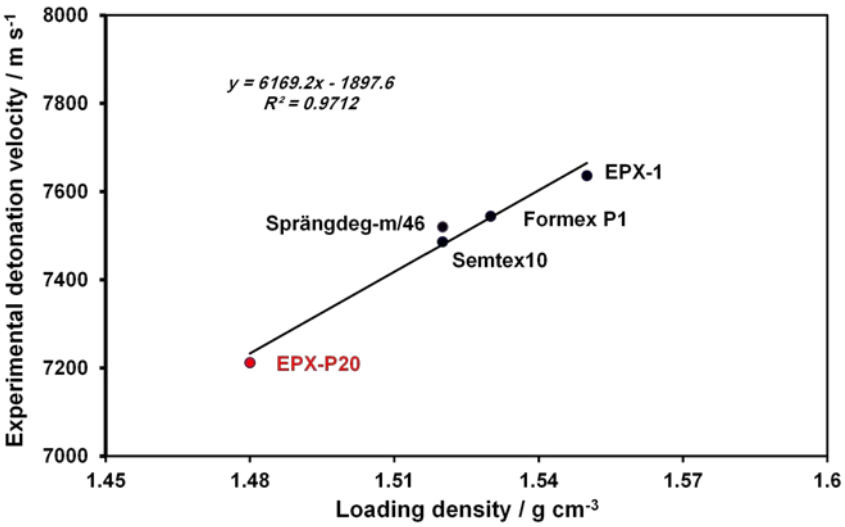

Figure 2. A Relationship of the loading densities versus the experimental detonation velocities

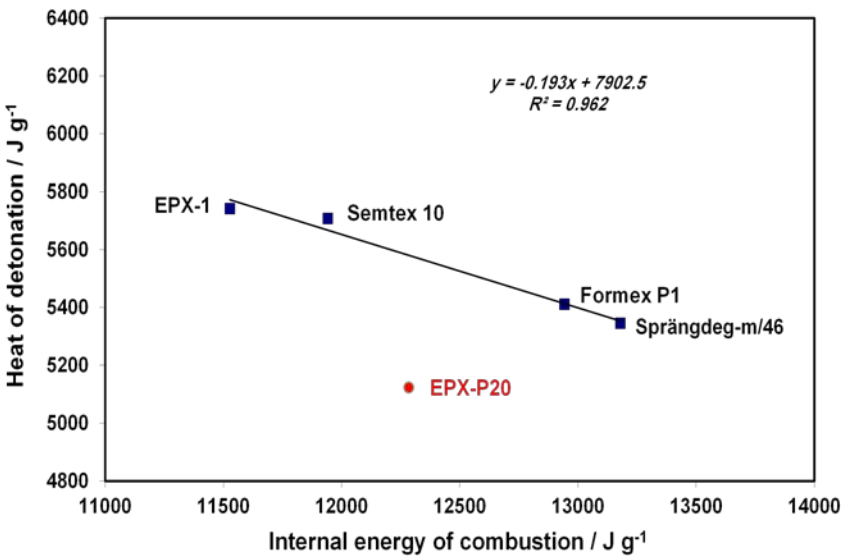

Figure 3. Inversely proportion relationship between the measured internal energy of combustion and the calculated heat of detonation.

Another inverse linear relationship was detected between the calculated heat of detonation obtained by EXPLO5 code and the measured internal energy of combustion as exposed in Figure 3. The increase in the polymer weight percentage in the sample caused an increase of the internal energy of combustion and decreased the heat of detonation (due to decreasing of the explosive wt%). In case of EPX-P20, the relation does not exist, this might be due to the polysiloxane matrix which is inert and has lower heat of combustion compared with the fuel oil presented in the other plastic explosives. The results seem logic according to the physics of explosion; it is known that increasing the weight percentage of explosives causes increasing of the detonation parameters (including heat of detonation). EPX-P20 has the lowest heat of detonation (as predicted) but its internal energy of combustion is also lower than Sprangdeg-m/46 and Formex P1. It is well known that Sprangdeg-m/46 contains only highly viscous oil which has a high heat of combustion. In addition, Formex P1 has only 20 wt% binder and 80 wt% oil. That is the main reason for increasing the heat of combustion of Formex P1 and Sprangdeg-m/46.

4. Conclusion

EPX-P20 is an interesting plastic explosive; the conditions of its production affect its characteristics. Its sensitivities to different stimuli were the lowest when compared with all the investigated traditional plastic explosives. EPX-P20 has lower detonation parameters than the studied traditional explosives. The Egyptian plastic explosive (EPX-1) still possesses the highest performance among all the well-known plastic explosives. The heat of detonation of EPX-P20 is also the lowest. In addition, an inverse proportional connection was observed between the measured internal energy of combustion and the calculated heat of detonation. EPX-P20 is an energetic plastic explosive which could be used in explosive bolts for space craft's applications.

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