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Performance characteristics of modified HMX-gun propellants

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Abstract: Nitramines explosive, HMX, was used for preparation of gun propellant formulations based on slurry technique. Acrylonitrile butadiene rubber (NBR) was used as a polymer for coating HMX crystals in addition to the traditional Nitrocellulose matrix. Ballistic performance of the compositions was evaluated on the basis of closed vessel test. Heat of combustion was also measured using a calorimetric bomb. Impact and friction sensitivities of the prepared compositions in addition to the ignition temperature were also determined. The obtained results reveal that gun propellant compositions based on approximately 50 percent HMX could provide relatively high performance and relatively suitable sensitivity for its application as gun propellant.

Keywords: Propellants, HMX, NBR, Performance, Sensitivity.

1. Introduction

In order to enhance the performance of several gun propellants, nitramine explosives have been suggested to replace the traditional double base propellants in selected gun ammunition. RDX and HMX are interesting nitramines, because they can be prepared by well-known methods, where the raw materials used for the preparation are available and cheap compared with advanced energetic materials [1]. Mainly RDX and HMX have several applications in the field of explosives and warheads. On the other side, these nitramines can improve the performance of gun propellants and also they can enhance the thermal stability and the cost of double base propellants [2-4]. In literature, several modified gun propellants have been studied so far. Addition of different percentages of RDX to nitrocellulose (NC) has been studied as gun propellants and the results proved that addition of 65 wt% of RDX to NC increased the force constant [1]. Also Acetyl Triethyl Citrate (ATEC) was studied as plasticizer for selected LOVA gun propellant formulation. ATEC is an excellent plasticizer and imparts desirable vulnerability properties. However, it is a very inert Plasticizer [5]. On the other side, HMX has been studied as LOVA gun propellant containing glyciyl azide polymer (GAP) as a replacement of inert binders [6].

LOVA gun propellant with GAP (Glyciyl Azide Polymer) binder instead of inert binder (CAB) offers better burning characteristics [7]. 87% RDX and 13% GAP gives impetus more than 200 J/g higher compared with the conventional JA-2 propellant [8]. A new propellant was designed with CL-20 as main energetic component has powder force 1253 J/g [9]. Acrylonitrile butadiene rubber (NBR) has several applications in the plastic explosives [10]. The effect of NBR on the performance, stability and sensitivity of the explosives has been presented in literature [11-14].

In this paper, sensitivity and performance of advanced gun propellants were studied. Several gun propellant compositions based on HMX, Nitrocellulose and NBR binder were prepared using slurry technique. Ignition temperature of the prepared samples was measured, impact and friction sensitivities were determined and the ballistic performance was evaluated using closed bomb vessel. In addition, the heat of combustion was measured.

2. Experimental

2.1. Preparation of gun propellant compositions

Four different gun propellant compositions based on cyclotetramethylene tetranitramine (HMX), acrylonitrile butadiene rubber (NBR) (analyzed in faculty of Pharmacy, Cairo university) and nitrocellulose (12.5% Nitrogen content) were prepared using slurry technique [15, 16]. Acrylonitrile butadiene rubber was dissolved in methyl ethyl ketone using mechanical stirrer at 50 °C. HMX of average grain size of 64 μm was placed in distilled water and stirred at 80 °C. Nitrocellulose solution with centralite I (CI) and diphenylamine (DPA) were added in small portions to the reactor. Stirring was continued for 30 minutes after complete addition of nitrocellulose solution to ensure good mixing. After complete addition of HMX slurry and nitrocellulose solution, the temperature was increased to 90 °C to evaporate the solvent. The mixture was then cooled, filtered and washed several times with distilled water. The obtained beads were dried at 60 °C and then pressed to the required shape for testing. The compositions of the prepared modern gun propellants are listed in Table (1).

Table 1. Composition of the prepared gun propellants

Materials	F1	F2	F3	F4
HMX (wt%)	65	60	55	50
NBR (wt%)	10	10	10	10
NC* (wt%)	25	30	35	40

* Centralite I (CI) and diphenylamine (DPA) are included.

2.2. Sensitivity determination

BAM falling hammer test (T 316 SS) was used to determine the impact sensitivity (IS) according to STANAG 4489 [17]. The probit analysis method was used to determine the 50% probability of initiation of the studied samples. BAM friction tester (ODG 632 GmbH) for the determination of the friction sensitivity (FS) according to STANAG 4487 [17]. Also the probit analysis method was used to determine the 50% probability of initiation of the studied samples.

2.3. Ignition temperature determination

Deflagration apparatus with heating rate 5 °C.min⁻¹ was used to determine the ignition temperature of the studied samples.

2.4. Heat of combustion

Automatic Combustion Calorimeter MS10A was used for measuring the heat of combustion of the samples. The sample was prepared and placed in a calorific bomb filled by excess of oxygen [18], where the data obtained from the measurements was reported in Table 2. This data was used for calculation of the heat of formation of the samples, which was used for the calculation of the detonation parameters

2.5. Closed bomb vessel
In 102.85 cm^3 ballistic bomb, 15 g of the studied compositions were burned at 10 MPa ignition pressure. The p-t curves of the studied compositions propellants were determined.

3. Results and discussion
The obtained values from the impact test are presented in Table (2). It is obvious that the sensitivity of the prepared formulations to impact generally increases by increasing the percentage of HMX in the composition as illustrated in the comparison between the impact and friction sensitivities as shown in Figure (1). The same criterion of the impact sensitivity with the HMX percentage is the same for friction sensitivity, where the friction sensitivity of the studied samples increases by increasing the percentage of HMX in the sample. Simply, the friction sensitivity of the pure HMX explosive is 88 N [19], this takes part in increasing the sensitivity in the propellant mixture; i.e. the higher the HMX ratio, the higher the friction sensitivity. In addition, NBR was generally able to decrease the sensitivity of the mixtures to limit lower than the traditional double base gun propellants.

Table 2. Experimental results

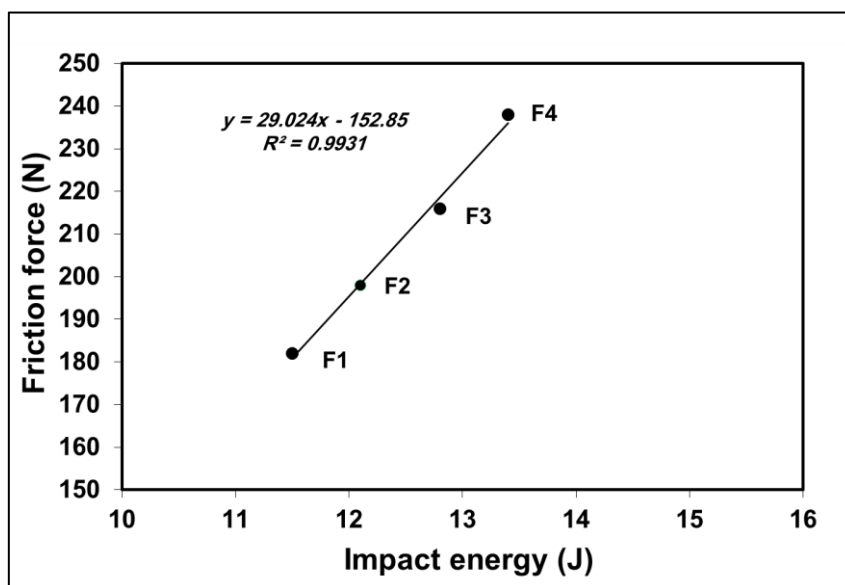| Tests	F1	F2	F3	F4
Impact energy (J)	11.5	12.1	12.8	13.4
Friction force (N)	182	198	216	238
Ignition temperature (°C)	248	242	236	229
Heat of Combustion (Cal/g)	1184	1142	1095	1058

Figure 1. Relation between friction force and impact energy for the studied HMX-based gun propellant formulations.

From Figure 1, it is clear that the impact and friction sensitivities increase as the percentage of HMX in the composition increase. It means that, from the safety point, it is preferable to decrease the percentage of HMX in the sample.

Regarding to the ignition temperature, significant decrease in the ignition temperature of the propellant as the percentage of HMX decreased in the composition. The percentage of HMX has obvious effect on the compositions. Also, all the samples have higher ignition temperature than the traditional double base gun propellant.
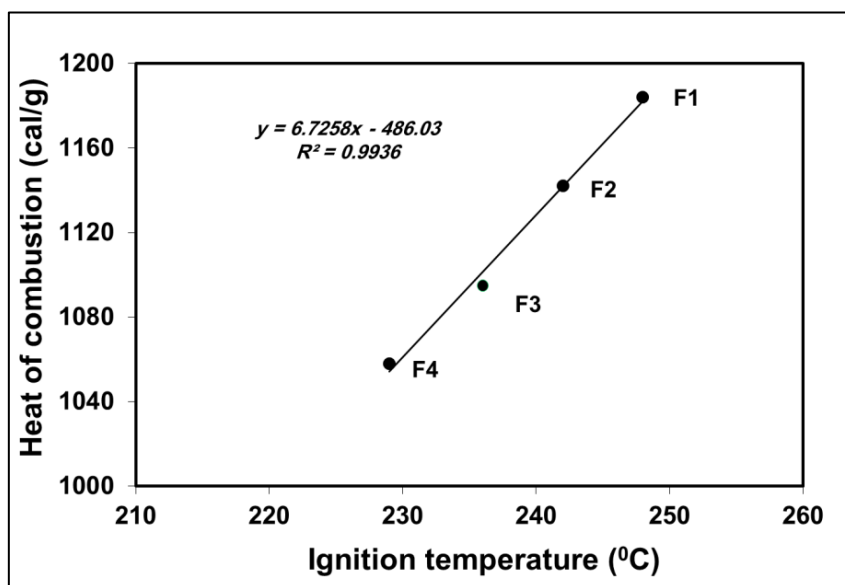
Figure 2. Dependence of heat of combustion on the ignition
temperature of HMX-based gun propellant formulations

The heat of combustion increases as the percentage of HMX in the gun propellant formulations increases. It means that the presence of HMX improve the output energy of the studied samples due to its relatively high heat of formation of -17.93 kCal/mol. In addition, NBR has positive effect on the combustion heat, which may be attributed to the presence of nitrogen in the binder itself, which takes part in the combustion of the samples and increased the combustion heat. Regarding to the closed vessel measurements, the data obtained are presented in Table 3.

Table 3. Combustion parameters at constant volume

Formulation	r (cm.s^{-1})	N	P_{max} (MPa)
F1	7.63	1.036	332
F2	8.89	1.021	323
F3	9.77	1.009	311
F4	10.45	0.994	302

It is obvious that increasing the percentage of HMX causes decreasing of the burning rate of the propellant compositions at the studied temperature. Also the pressure index increases as the percentage of HMX increase in the composition. The burning rate pressure index is less than 1 in case of composition F4. The pressure index increases as the percentage of HMX increases. Simply, the HMX-based propellant is expected to have high performance due to its superior heat of formation (17 kcal/mol) even when compared to RDX-based propellants (14 kcal/mol) [20].
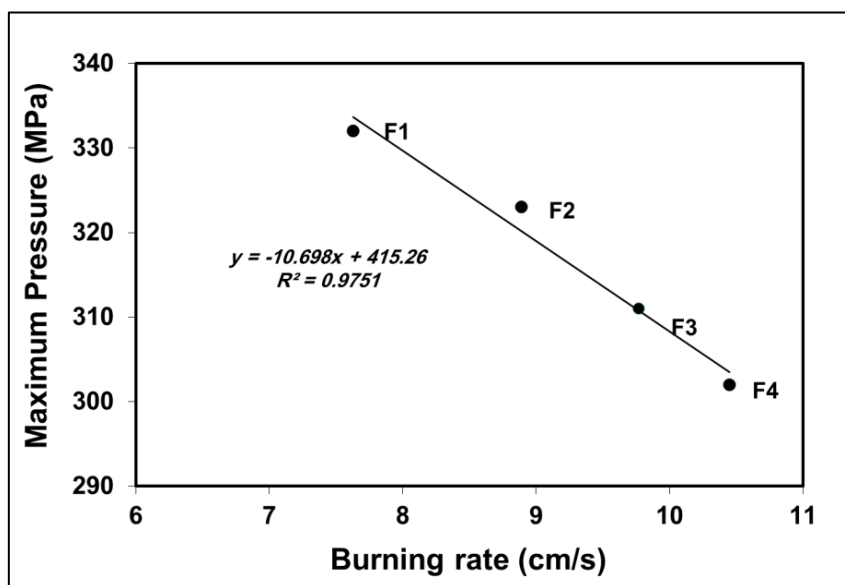
Figure 3. Relation between maximum pressure and the burning rate
of the HMX-based gun propellant formulations

Figure 3 presents an interesting relationship between the maximum pressure obtained for the studied samples and their burning rate. Inversely proportion relationship was observed. Increasing of the percentage of HMX in the sample caused decreasing of the burning rate and increasing of the maximum pressure. This result is compatible with the results of the heat of combustion. As the heat of combustion increases, the maximum pressure increases.

4. Conclusion

Successfully a new gun propellant based on HMX coated by NBR and NC has been prepared as beads using slurry technique. All the prepared compositions have sensitivity lower than that of the traditional gun double base propellant. The heat of combustion and the maximum pressure have been increased by increasing the percentage of HMX in the composition. On the other side, the burning rate of the propellant composition decreased as the percentage of HMX increased in the compositions. It is recommended to continue the studying of HMX based gun propellant with 50% HMX. Moreover, NBR is interesting binder to be used in gun propellant applications. Eventually, Both HMX and NBR combinations are recommended for usage as large caliber tank gun ammunition for their enhanced performance.

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