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1,1-Diamino-2,2-Dinitroethene (FOX-7) Based Sheet Explosive Material with Glycidyl Azide Polymer in Comparison with RDX Based System

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***Abstract*— In this research paper the synthesis and characterization of the advanced modern high energy sheet materials formulations based on 1,1-diamino-2,2-dinitroethene (FOX-7) and polyurethane (PU) based on glycidyl azide polymer (GAP) as an energetic binder in comparison with the high energy sheet materials which is based on 1,3,5-trinitro-1,3,5-triazinane (RDX) and PU based on GAP were described. Both of the formulations were prepared by the cast-cured method then followed by the rolling process technique. These formulations are evaluated for the performance, sensitivity (sensitivity to friction, heat and impact) and mechanical properties (stress-strain characteristics). The sensitivity tests results showed that the FOX-7 based sheet material has sensitivity to impact value of 48.3 J, which is about 33.8 J more than of the sheet material based on RDX. The sensitivity to friction study showed that there is no reaction or initiation for both formulations even when using the maximum friction force (360 N) of the test apparatus. It can be concluded that the results bring out that these formulations are promising and satisfying a low vulnerability which are highly safe during production, rolling, storage and can offer advanced modern high energy sheet materials for using in ERA (effective reactive armor) and other applications.**

Keywords*— Advanced materials, Polyurethane, FOX-7, RDX, GAP, ERA, Performance, Mechanical evaluation, Sensitivity.

I. INTRODUCTION

Advanced high energy sheet materials are thin sheets of explosives particles fillers which composed of energetic materials distributed in a polymeric matrix [1]. Those formulations are also called plastic bonded explosives (PBXs) and composite materials which prepared by casting or slurry technique followed by calendaring process using extrusion or rolling technique [2-5].

During recent periods, advanced high energy sheet materials have showed great importance in the military applications as component of explosive reactive armors (ERA). They also have showed good importance in the civil fields as in underwater demolition and in metal cutting field because of the good flexibility properties of these formulations [6]. ERA is composed of thin sheet explosive material between double layers of two metal plates which provide active shield to the armored vehicles as tanks against different types of attacking warheads, light combat vehicles and projectiles attack which based on shaped charges [7-12].

In the present research the insensitive high energetic explosive FOX-7 was selected as a partial replacement of RDX to be the high energetic material / explosive filler and PU was selected because of the wide range on its flexibility as a binder which based on GAP as an energetic binder and Isophoron diisocyanate (IPDI) as a curing agent.

II. EXPERIMENTAL

A. Materials

All the chemicals used in this work; FOX-7, RDX, GAP and IPDI were of high purity.

B. Preparation of High Energy Sheet Material Based on FOX-7 / RDX and PU (GAP)

The preparation was carried out using the casting technique [13]. The casting process was conducted in 2500 ml stainless steel bowel provided with double wall jacket, where a circulating liquid could be either heated or cooled. Stainless steel bowel is equipped with a vertical mixer with three blades rotating in an orbital motion. All mixing facilities including mixers are air-conditioned, while mixers themselves are closed with a tight-fitting lid, which is equipped with a vacuum device, used to secure low residual pressure of about 10 mm Hg. Water, volatile components, and air trapped in the slurry are easily removed in the course of the kneading process.

The prepolymer used in this work is GAP (1.433 mg equivalent OH/g GAP) was precisely weighted and dropped into the reactor followed by the mixing with the explosive filler (FOX-7 or RDX). The curing agent IPDI (9 mg equivalent NCO/g IPDI) was added and thoroughly mixing was continued. The mixing process was carried out at 55-60 ºC and on the basis of NCO/OH= 1.1. Pouring in suitable mould of Teflon and polyvinyl chloride (PVC) tubes to measure the mechanical and performance characteristics respectively. Finally two heavy duties calendars were used to produce the sheet materials and the rolling process was repeated 10 times.

The curing process was carried out at 55-60 ºC for 10 days. The compositions and summary formula of the formulations are listed in Table I.

TABLE I. The Compositions and Summary Formula of the Prepared Formulations

		FOX-7	RDX	High energy sheet materials based on PU (GAP)	
				PBX based on FOX-7	*PBX based on RDX*
Composition wt%	*FOX-7*	100	-	88	-
	RDX	-	100	-	88
	GAP	-	-	9.5	9.5
	IPDI	-	-	2.5	2.5
Summary	*C*	2	3	2.2	3.21
	H	4	6	4.24	6.18
	O	4	6	3.89	5.68
	N	4	6	3.55	5.18

III. PERFORMANCE AND MECHANICAL EVALUATION OF THE PREPARED FORMULATIONS

A. *Detonation Velocity of the Prepared Formulations*

The prepared PBXs formulations were pressed in PVC mold tubes of 22 mm inside diameter, 190 mm length and about 2 mm thickness at 1.6 g/cm^3 as shown in Figure 1. The Explorment -Fo- Multi Channel apparatus (Swiss made) were used to measure the detonation velocity of the formulations.

The measured time interval for a detonation wave to travel between the two fibers optic probes of a known distance in microseconds was displayed with the measured detonation velocity in m/s.

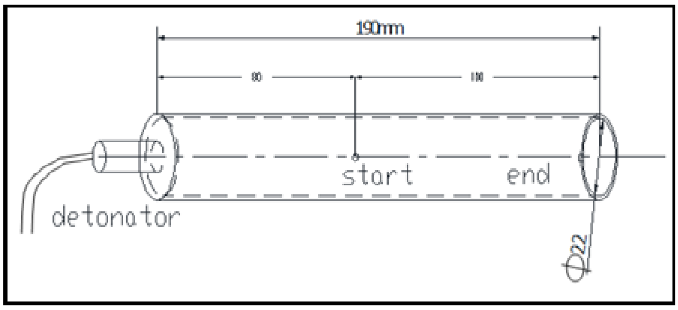

Fig.1. Standard Cartridge Dimensions for Measuring Detonation Velocity

B. *Brisance of the Prepared Formulations*

Brisance of an explosive is a very important characteristic which represents the ability of explosives to break the solid target surrounding the explosive charge and create fragments from this object. The brisance of an explosive depends mainly on explosive density and detonation velocity [14].

The brisance of the prepared PBXs formulations was measured according to the Kast method [15], where 2.5 g of the formulation was prepared by pressing it to 1.6 g/cm^3 into an aluminium tube of 4 mm wall thickness, 30 mm length and 12 mm inside diameter. Copper cylinder crusher of standard dimensions (6 mm diameter and 9.8 mm height) was used. After initiation of the charge; the deformation of the copper crusher was measured and converted into force units according to the calibration table of the copper crusher static compression force test [16].

C. *Sensitivity of The Prepared Formulations*

Sensitivity to friction was determined by employing BAM FSKM-10friction test apparatus. The test was conducted in such a way that by increasing the loading on the pistil then the percentage of initiation was measured. The force in Newton could be determined at 100% initiation by a certain load [16].

The sensitivity to heat was determined by using The AET 402 (automatic explosion temperature tester) test apparatus by measuring the ignition temperature for the prepared PBXs formulations. To determine the ignition temperature, the temperature was uniformly increased [5 ºC/min] until the deflagration of the sample occurs [16].

Sensitivity to impact was determined by employing OZM ball fall hammer BFH-12A apparatus, using 2 and 5 Kg falling weight according to the standard technique [16].

D. *Stress-Strain of the Prepared Formulations*

Stress-strain characteristics of the PBXs sheet samples were determined after curing process by using the universal testing machine WDW-100 (China made). The stress- strain is an important term representing the resistance of the sheet explosives materials to deformation and different stresses.

The test specimens are produced according to Joint Army-Navy-NASA-Air Force Propulsion Committee (JANNAF) standard [17], which having the dimensions shown in Figure 2, using a special cut press as shown in with standard cut form as shown in Figure 3.

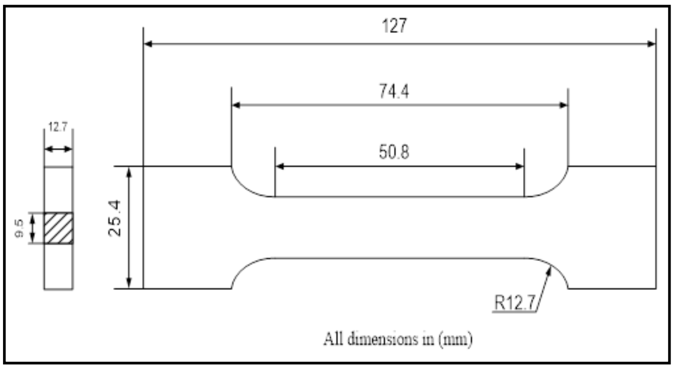

Fig.2. Standard Dimensions of the Tensile Test Specimen

Fig.3. Special Cutting Press

Then the produced specimens shown in Figure 4 for the prepared formulations are checked for voids (e.g. cracks, air bubbles, foreign matter) by X-Ray. After that, the accepted specimens are stored at ambient temperature in dry place.

Fig.4. Specimens of the Prepared Formulations According to JANNAF Standard

Every experimental test was carried out on 3 specimens and the average value of these 3 results is used for the analysis. Also, for every test the specimens were pre-conditioned at least for 3 hours in external conditioning chamber with humidity (20 - 25) %. Also, all tests were performed at constant temperature provided by the machine test chamber.

IV. RESULTS AND DISCUSSION

The results of detonation velocity, brisance and sensitivity tests of all the prepared PBXs sheets formulations were compared to FOX-7 and RDX as shown in Table II.

TABLE II. Performance Properties of the Prepared PBXs Sheets Formulations Compared to FOX-7 and RDX

Explosive Characteristics	FOX-7	RDX	Sheet Explosive Based on FOX-7 / GAP	Sheet Explosive Based on RDX / GAP
Detonation velocity (m/sec)	8870	8750	8410	8330
Brisance (kp)	1302	1298	1232	1208
Sensitivity to friction (N)	>360	120	>360	>360
Sensitivity to heat (Ignition temp. ºC)	226	222	215	209
Sensitivity to Impact (J)	24.7	7.5	48.3	14.5

A. *Detonation Velocity*

It is obvious from Table II and Figure 5 that the results of the detonation velocity for the prepared sheets of explosives which represent the explosive performance were slightly decreased than the value obtained for pure FOX-7 and RDX by a slight decrease. For sheets based on FOX-7, detonation velocity decreased by 5.18% but decreased by 4.8% for that based on RDX when compared with that of pure FOX-7 and RDX respectively.

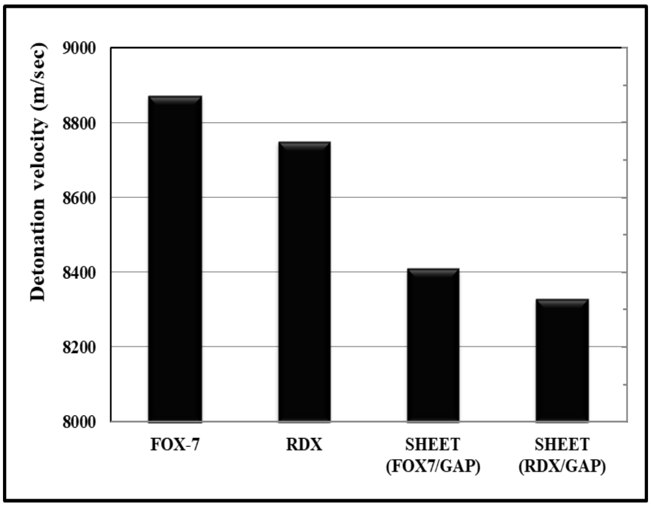

Fig.5. Detonation Velocity of FOX-7, RDX and the Prepared High Energy Sheet Materials Formulations

B. *Brisance*

It is clear from Table II and Figure 6 that the brisance value for PBX formulations based on FOX-7 is close to that of than that of based on RDX. Both values were slightly decreased than the value obtained from pure FOX-7 and RDX by slight decrease respectively. This slight decrease may be attributed to the high density of GAP and to GAP energetic groups (Azide groups, oxygen atoms).

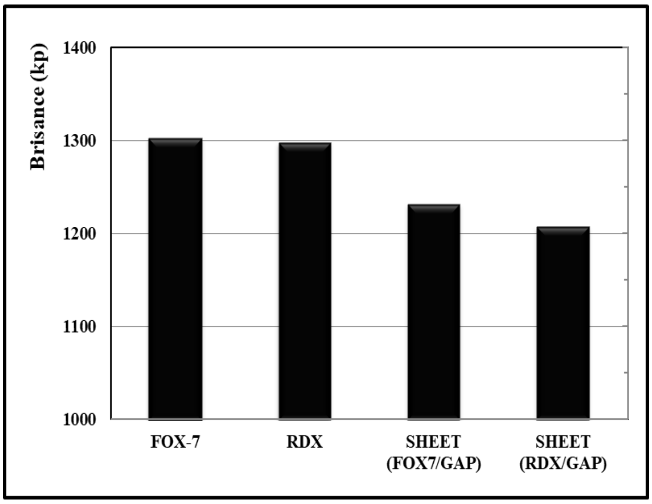

Fig.6. Brisance of FOX-7, RDX and the Prepared High Energy Sheet Materials Formulations

C. *Sensitivity Tests*

It is clear from Table II that the sensitivity to friction of the prepared sheets based on FOX-7 or RDX showed that there is no initiation even when using the maximum friction force (360 N) of the test apparatus.

The sensitivity to heat of the prepared sheets expressed by the ignition temperature values showed slightly lower values than that of pure FOX-7 and RDX respectively. This can be because that the coating of PU based on GAP acts as heat sensitizing medium due to its softening temperature is less than 152 ºC.

The sensitivity to impact was significantly decreased for the sheet based on FOX-7 by 69.9% when compared with that based on RDX. This highly decreases because of using FOX-7 which is insensitive high energetic material.

D. Stress-Strain

It is obvious from Table III, Figure 7 and Figure 8 that the results of the stress-strain characteristics which represent the mechanical properties of the prepared sheets of explosives. The results showed good mechanical properties, flexibility and ductility after curing.

TABLE III. Mechanical Properties of the Prepared PBXs Sheets Formulations

Characteristics	Sheet Explosive Based on FOX-7 / GAP	Sheet Explosive Based on RDX / GAP
Maximum Stress (N/cm^2)	5.1	5.4
Maximum Strain (%)	7.8	8.2

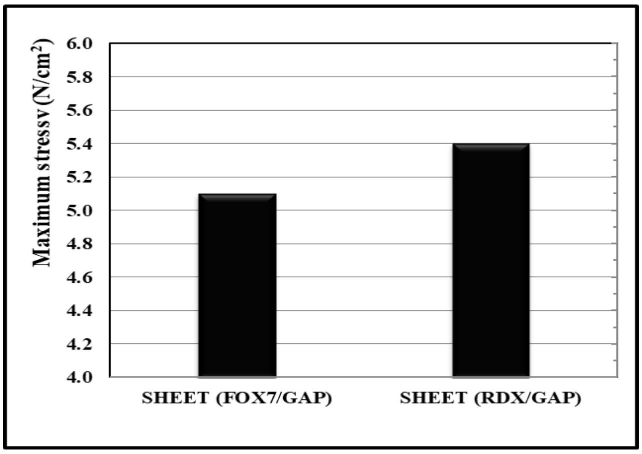

Fig.7. Maximum Stress Results of FOX-7, RDX and the Prepared High Energy Sheet Materials Formulations

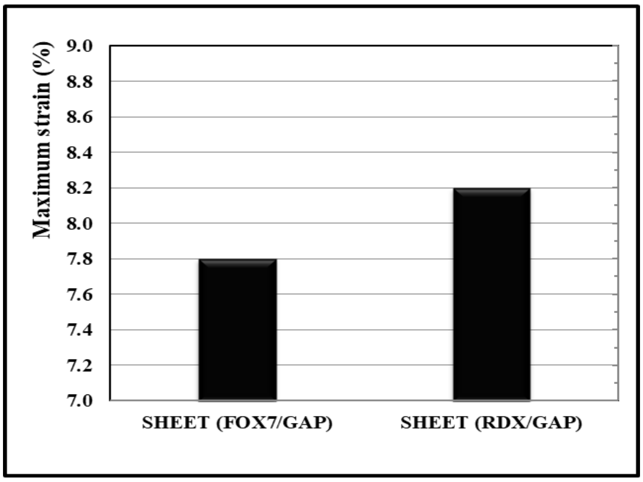

Fig.8. Maximum Strain Results of FOX-7, RDX and the Prepared High Energy Sheet Materials Formulations

V. CONCLUSION

In the present study, PBXs sheet materials based on polyurethane containing GAP and FOX-7 or RDX have been formulated and investigated for the performance, sensitivity and mechanical properties. The sheet explosive material formulation based on 88% FOX-7 and 12% PU containing GAP showed excellent flexibility characteristics and high ductility after curing, high performance values (brisance and detonation velocity), low sensitivity values especially sensitivity to impact which decreased by 69.9% when compared with that of formulation based on RDX. , it can be concluded that the results bring out that these formulations are promising and satisfying low vulnerability explosives which are highly safe during production, rolling, storage and can offer advanced modern high energy sheet materials for using in ERA and other applications.

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