

Synthesis and Characterization of High Energy Sheet Materials Based on HMX / RDX and Hydroxyl Terminated Polybutadiene

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Abstract. In this paper three types of thin sheets of highly energetic materials were prepared and characterized. The first based on 1,3,5,7-tetranitro-1,3,5,7-tetrazocane (HMX). The second type based on 1,3,5-trinitro-1,3,5-triazinane (RDX). Both types contain polyurethane (PU), formulated by hydroxyl terminated polybutadiene (HTPB) and Isophorondiisocyanate (IPDI). The third type based on (RDX) and polyisoprene (PI) as high elastomeric material. The first and second types of thin sheets were prepared by applying the casting technique while the third type was prepared by slurry technique then followed by rolling of the prepared beads of the RDX coated by PI. These high energy sheet materials were cured in oven at 60°C. The measured explosive properties of the prepared sheets were discussed and showed that the sensitivity to impact and friction of the prepared sheets explosives materials were markedly decreased when compared to pure HMX or pure RDX, but the sensitivity to heat was close to that of pure RDX. In spite of the markedly decrease in the sensitivity of these sheets, the explosive characteristics were nearly not affected the sheets have very good stress-strain values.

1. Introduction

Sheet explosive materials are plastic bonded explosives (PBXs) in sheet form which comprised of flexible materials including of explosives/energetic materials which are distributed in a polymer matrix based on polyurethane or highly flexible elastomeric binder as polyisoprene [1-4]. Thin sheets of high energetic materials (HEMs) afford the high energy to achieve the goals of the system [5].

The flexibility of these formulations is utilized in wide important fields (civil and military applications) as in explosive reactive armors (ERA). ERA consisting of sandwiched sheet explosive between metal casings offers effective protection to the armored tanks by defeating kinetic energy projectiles and the shaped charge warheads [6-9]. Many researches were focused on the synthesis, characterization and applications of PBXs including sheet explosive materials to accomplish high mechanical, physical properties and lower sensitivity without losing explosive properties of these formulations [10-16].

In the present investigation RDX and HMX were selected to be the explosive filler. Polyurethane was selected as the first binder type due to its flexibility wide range which depends mainly on the type and content of DOZ, IPDI, filler and HTPB. Polyisoprene PI was selected as the second high flexible binder because it, either natural or synthetic, forms after mastication process and sulfur vulcanization, the model for the ideal elastomeric properties including rapid extensibility to great elongation, high



stiffness and strength when stretched and also rapid and complete retraction on release of external stress [17].

2. Experimental work

2.1. Materials

In this research the entire chemical used are of high purity materials as; filler (HMX, RDX), binder (PI, PU based on HTPB), crosslinking agent (IPDI), plasticizer (DOZ), Bonding agent (MAPO), solvent (dichloroethane (DCE)) and solid lubricant (Teflon (PTFE)).

2.2. Preparation of PBX sheet based on HMX or RDX and PU (HTPB)

The calculated amounts of explosive, HTPB, IPDI, RDX, DOZ and MAPO were accurately weighed. These PBXs sheets based on PU were prepared by using the casting technique [18]. HTPB was then placed in a mixing kettle with two third of DOZ weight and mixed together. HMX or RDX was then added in small portions during mixing for 30 minutes. Thoroughly mixing was conducted for 10 minutes after complete addition of HMX or RDX to ensure complete coating. The residual amount of IPDI, DOZ and MAPO calculated, on basis of NCO/OH= 1.1, were added to the mixture and mixing continued for about 15 minutes. The prepared matrix (paste) was then pressed into a mold of Teflon and cured for 10 days at about 55-60°C. The obtained sheet was 6 mm thickness and its final composition by weight percentage was 88% HMX or RDX, 9.2% PU and 2.8% DOZ.

2.3. Preparation of PBX sheet based on RDX and PI

That PBX sheet based on PDX and PI was prepared by using the slurry technique followed by rolling and curing processes [19]. The first step is to dissolve the PI completely in DCE and then RDX was slowly added to the laquer. After 30 minutes about 500(ml), more than the volume of DCE, of distilled water was poured drop-wise and continue stirring for 30 minutes. Then increase the temperature to evaporate DCE, after that the formed beads were filtered off, washed with water and dried at 70°C. Teflon as a solid lubricant, DOZ as plasticizer and small amount of distilled water as wetting agent were added and thoroughly mixed with the RDX beads coated with PI to be ready for the rolling process. Finally using two heavy duties calendars and put the explosive beads between them to produce a sheet of thickness 4 mm and the rolling process was repeated 10 times at 25°C. We used Sulfur as vulcanizing agent in the first run which was added with some minor additives as activator and accelerator. Finally the produced sheet was cured at 55-60°C for about 48 hours.

2.4. Evaluation of PBXs sheets formulations

2.4.1. Sensitivity tests. The sensitivity to heat was obtained by measuring the ignition temperature for the prepared PBXs sheets using Chilworth deflagration test apparatus [20]. To determine the ignition temperature, the temperature was uniformly increased [5 °C/min] until the explosion conversion occurred. Sensitivity to impact was determined by using IkaMaschinenbau apparatus, using 5 Kg falling weight [21]. Sensitivity to friction was determined using BAM test apparatus. The test was conducted by the percentage of initiation by changing the loading of the pistil [20].

2.4.2. Detonation velocity. The Exploment -Fo-2000- Multi Channel test apparatus were used to determine the detonation velocity. For the sheet explosives formulations based on PU binder; the detonation velocities were obtained by measuring the time interval for a detonation wave to travel a known distance between the two fiber optic probes in microseconds which was displayed with the calculated detonation velocity in (m/s). The prepared PBX samples were pressed in a PVC mould tubes of 190 (mm) length and 22 (mm) inside diameter at a density 1.6 (g/cm³). For the sheet explosive based on PI binder, we used compressed pure PDX as a booster and three sheets of the prepared PBXs sheets formulations to form a sheet of 12 (mm) thickness.

2.4.3. Stress-strain characteristics. The universal testing machine WDW-100 which supplied by Fanguri technology company, China was used to measure the stress-strain characteristics of the PBXs sheet samples before and after curing.

3. Results and discussion

The results of sensitivity tests and detonation velocity test of all the prepared PBXs sheets formulations were compared to pure HMX and pure RDX as shown in table 1.

Table 1. Results of different explosive characteristics for the prepared sheet explosives based on PU and PI compared with pure HMX and pure RDX

Explosive Characteristics	Pure HMX	Pure RDX	Sheet Explosive Based on HMX / PU	Sheet Explosive Based on RDX / PU	Sheet Explosive Based on RDX / PI
Sensitivity to Impact (J)	7.4	7.5	14.1	14.5	45
Sensitivity to friction (N)	120	120	>360	>360	324
Sensitivity to heat (Ignition temp. °C)	287	222	252	209	235
Detonation velocity (m/sec)	9100	8750	7689	7180	8100

It is clear from table 1 that the sensitivity to impact was markedly decreased when the RDX crystals were coated by the polyisoprene thin layers. The sensitivity to impact of the sheet explosive based on RDX/PI was decreased by 600% when compared with that of pure RDX. For the sheet explosives formulations based on HMX and RDX was show also much less sensitivity than that of pure HMX and RDX.

The sensitivity to friction of the prepared sheets of explosives based on RDX/ PU and HMX/PU showed no initiation even when applying the maximum friction force (360 N), while for the sheet explosive based on PI was significantly less than pure HMX and pure RDX.

The sensitivity to heat expressed by the values of the ignition temperature of the prepared sheets explosives when compared with that of pure RDX are found to be close to each other.

From the obtained sensitivity results of the prepared sheets of explosives we can conclude that the prepared sheets of explosives satisfy low vulnerability explosives which are highly safe during storage, rolling and applications.

The obtained 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 HMX and pure RDX by a slight decrease. The slight decrease in the value of the detonation velocity of the prepared sheets of explosives means that in spite of the markedly decrease in the sensitivity of these sheets, the explosive characteristics were nearly not affected.

The stress-strain characteristics results are shown in table 2. The results emphasize the high mechanical properties, ductility and flexibility after curing. It is clear from the table the values of the stress and strain were greatly improved for the sheet explosive depends on PI after curing and the obtained sheet has excellent flexibility and ductility properties. The stress-strain values of the sheets explosives depend on HMX or RDX with PU binder are also accepted.

Table 2. Stress Strain Characteristics of the Prepared Sheets Explosives

Sheet explosive	Characteristics	Before Curing	After Curing
Sheet Explosive Based on HMX / PU	Maximum Stress (N/cm ²)	--	5.8
	Maximum Strain (%)	--	8.8
Sheet Explosive Based on RDX / PU	Maximum Stress (N/cm ²)	--	5.5
	Maximum Strain (%)	--	8.3
Sheet Explosive Based on RDX / PI	Maximum Stress (N/cm ²)	5.87	8.58
	Maximum Strain (%)	43	144

4. Conclusion

In the present study, three thin sheets of explosives of highly energetic materials based on RDX / polyisoprene or polyurethane as polymeric binders and HMX or RDX as high energetic explosive were successfully prepared and showed high ductility and excellent flexibility properties after curing. The stress-strain values of the sheets explosives depend on HMX or RDX with PU binder are also accepted. In the same time these sheets have high energetic properties which are close to that of pure RDX, detonation velocity of 8100(m/s) for the sheet explosive based on PI, also the sheet explosive based on HMX and PU showed high detonation velocity of 7689 (m/s) which is greater than that based on RDX and PU by 7.1%. The sensitivity to heat was also decrease but with a less extend than that of pure RDX and are found to be close to each other, while the sensitivity to impact and friction of the prepared sheets were markedly decreased when compared with that of pure HMX and pure RDX which decrease the vulnerability so these sheets are highly safe during storage, rolling and applications.

References

- [1] Noguez B, Mahe B and Vignaud P 2009 Cast PBX related technologies for IM shells and warheads *Sci. & Tech. Energetic. Materials* **70(5)** 135-139.
- [2] Suresh K, Mahadev B and Mrityunjay K 2016 Experimental studies on advanced sheet explosive formulations based on 2,4,6,8,10,12-Hexanitro- 2,4,6,8,10,12-hexaazaisowurtzitane (CL-20) and Hydroxyl Terminated Polybutadiene (HTPB), and comparison with a RDX-based system *Central European Journal of Energetic Materials* **13(1)** 135-147.
- [3] Ekhlas A 2002 Preparation and characterization of explosive sheets used in reactive armours M.Sc. Thesis MTC, Cairo, Egypt.
- [4] Brousseau P, Thiboutot S and Diaz E 2001 New melt-cast explosives based on energetic thermoplastic elastomers *32nd International Annual Conference of ICT* Karlsruhe, Germany.

- [5] Suresh K, Mrityunjay K and Vasant J 2016 Experimental studies on a high energy sheet explosive based on RDX and Bis (2,2-dinitropropyl) Formal/Acetal (BDNPF/A) *Central European Journal of Energetic Materials* **13(3)** 557-566.
- [6] Yadav H, Bohra B M, Joshi G D, Sundaram S G, Kamat P V 1995 Study on basic mechanism of reactive armour *Def. Sci. Journal* **45(3)** 207-212.
- [7] Held M 2001 Disturbance of shaped charge jets by bulging armour *Propellants Explos. Pyrotech.* **26** 191-195.
- [8] Warford J M 1988 Reactive armour-new life for soviet tanks *Armor* **97(1)** 6.
- [9] Yadav H 1988 Flyer plate motion by thin sheet of explosive *Propellants Explos. Pyrotech.* **13** 17-20.
- [10] Radwan M, Mostafa H and Elsharkawy K 2006 Preparation and characterization of thin sheets of energetic materials based on polyisoprene *3rd International Conference on Chemical & Environmental Engineering* Cairo, Egypt 449-455.
- [11] Radwan M 2001 Sensitivity and brisance of PBXs based on HMX and fluorel *32nd International Annual Conference of ICT* Karlsruhe, Germany.
- [12] Sjoberg P, Hytti H, Strandberg R, Kariniemi A and Muilu M 2002 PBX with insensitive RDX, a new EIDS. substance for under water use *33rd International Annual Conference of ICT* Karlsruhe, Germany.
- [13] Kaye S 1978 Encyclopedia of explosives and related items Part 2700 **8**.
- [14] Radwan M 2001 Explosive characteristics of aluminized PBXs based on HMX and polyurethane binder *32nd International Annual Conference of ICT* Karlsruhe, Germany.
- [15] Gerber P, Hubner C and Menke K 2000 Characterization of the Matrix filler properties of the GAP/RDX propellant system *31st International Annual Conference of ICT* Karlsruhe, Germany.
- [16] Bunyan P, Cunliffe B, Torry A and Bult H 1997 Stability studies on end modifications poly GLYN *Insensitive Munitions and Energetic Materials Technology Symposium* Orlando.
- [17] Brandrup J and Immergut E H 1989 *Polymer Handbook* Third edition, John Wiley & Sons, New York.
- [18] Talawar M B, Jangid S K, Nath T, Sinha R K, Asthana S N 2015 New directions in the science and technology of advanced sheet explosive formulations and the key energetic materials used in the processing of sheet explosives: Emerging trends *Central European Journal of Energetic Materials* **300** 509-528.
- [19] Kasprzyk D J, Bell D A, Flesner R L and Larson S A 1999 Characterization of a slurry process used to make a plastic bonded explosive *Propellants, Explosives, Pyrotechnics* **24** 333-338.
- [20] Suceska M 1995 *Test methods for explosives* Springer, ISBN 0-387-94555-5.
- [21] United Nations 1999 *Recommendations on the transportation of dangerous goods, manual of tests and criteria* Third edition, United Nations, New York and Geneva.