

Characterization and Performance Evaluation of Aluminized Polymer Bonded Explosives Formulations

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Abstract

This study presents the preparation and evaluation of Aluminized Polymer Bonded Explosives (ABXs) formulations comprising RDX (Cyclotrimethylenetrinitramine), AL powder, and Isoprene Rubber (IR). The formulations were carefully prepared in a laboratory setting, with efficient mixing observed at 70°C and subsequent curing at 80°C for five days. Analysis of scanning electron microscope images revealed well-coated crystals, while density measurements ranged from (1.386 to 1.65)g/cm³ indicating a direct correlation between AL powder content and density. Impact sensitivity testing ranged from (20.5 to 31.85) Joule demonstrated decreased sensitivity with higher AL powder percentages and reduced RDX content. The formulated ABXs exhibited favorable attributes, including ease of production, reduced sensitivity to impact, appropriate sensitivity to heat range from (231 to 236)°C, and commendable performance coupled with enhanced safety and long-term thermal stability. Hence, the findings suggest promising applications for ABXs formulations in ammunition projectiles and rocket warheads, Explosive Reactive Armor, and underwater weapons.

Key words-Aluminized Polymer Bonded Explosives, RDX, Sulfur Vulcanization System, Impact Sensitivity, AL Powder, Fuel Metal, Ignition Temperature

I. INTRODUCTION

The enhancement of energetic materials through the addition of metal particles is a widely recognized strategy to augment their efficiency[1]. Various metallic powders, including aluminum (AL Powder), magnesium (Mg), copper (Cu), iron (Fe), and beryllium (Be), are esteemed for their high density and combustion heat release[2]. Among these, aluminum powder emerges as a particularly accessible and cost-effective option, extensively utilized across military and civil industries to augment high explosives of diverse configurations[3]. One notable advancement in this domain is the development of aluminized polymer-bonded explosives (ABXs). These composite materials integrate solid explosive particles dispersed within a polymer matrix, comprising three primary components: a polymeric binder, metal fuel, and filler (typically a nitramine explosive). ABXs systems are characterized by their robust mechanical strength, reduced vulnerability, exceptional thermal stability, and high energy output[4].

The selection of the polymeric binder is a critical aspect of ABXs compositions. Various polymers, including polyvinyl chloride (PVC), polyethylene (PE), polystyrene (PS), poly(methyl methacrylate) (PMMA), and copolymers such as hexafluoropropylene (HFP), vinylidene fluoride (Viton), and hydroxyl-terminated polybutadiene (HTPB), can be utilized to tailor the properties of the explosive formulation to specific requirements[5].

The incorporation of a metal fuel component is vital in ABXs formulations. This component, typically aluminum powder, contributes to the explosive's effectiveness, imparting high density, smoky characteristics, and enhanced blasting effect and impulse. Moreover, the sensitivity to impact dimin-

ishes with increasing aluminum powder content and decreasing percentages of nitramine explosives (e.g., RDX), resulting in improved mechanical properties and reduced vulnerability[6].

In general, values below 25 cm (0.25 m) usually indicate relative sensitivity to impact. Values of 25 cm to 70 cm (0.25 to 0.7 m) indicate a material of moderate sensitivity to impact. Values above 70 cm (0.7 m) indicate relative insensitivity to impact by using 5 kg [7]. The ignition temperature was found using a deflagration test apparatus. The ignition temperature can be experimentally determined by heating at a constant rate an explosive sample of a given mass until ignition occurs[8].

Critical additives such as bonding agents, plasticizers, cross-linking agents, and fillers play crucial roles in optimizing the performance and processing characteristics of ABXs. These additives enhance adhesion between the binder and solids, improve particle dispersion for uniform performance, facilitate process ability and low-temperature properties, and promote cross-linking to ensure structural integrity [1].

The sulfur vulcanization system serves as a fundamental process in ABXs formulations, facilitating the crosslinking of rubber molecules to form an elastic three-dimensional network. Isoprene rubber vulcanized via the sulfur process emerges as a preferred choice due to its cost-effectiveness and superior longevity compared to HTPB systems[7]. In sulfur-vulcanization, a mixture of Isoprene rubber and free sulfur is heated up, most probably free radicals are formed as a result of the ring opening of the eight-membered sulfur rings. Sulfur is a natural material and melts at 80 - 90°C temperatures[9]. Accelerators are necessary ingredients for all sulfur-curing systems. They increase the curing ratio and efficiency of the sulfur bonding to rubber macromolecules in the form of

cross-links, allowing vulcanization [10] to proceed at lower temperatures and with greater efficiency. Tetramethyl-thiuram-disulfide (TMTD) is used as an accelerator[9]. Activators are required for the optimum influence of sulfur vulcanization systems, with the most widely known activator being ZnO[11].

Transformer oil, or tan oils, directly obtained from crude oil refining, is used to reduce the viscosity of Isoprene rubber and improve the process ability of mixing as a plasticizer. Stearic acid, with the IUPAC name octadecanoic acid[12], is a waxy solid with its chemical formula $C_{18}H_{36}O_2$. It is used as an activator.

II. PREVIOUS STUDIES

Thom et al. studied the influence of Aluminum on the performance of PBX formulation of RDX/AL Powder /AP/GAP. In this formulation, the binder used was GAP the plasticizer was BDNPA/BDNPF (1:1 mix), and the curing agent of the binder system was Desmodur N100. The study showed that charges with the same mass exhibited the same peak pressure for the formulations containing AL Powder from 15% to 35%. Only formulations with higher Aluminum Powder contents supplied decreasing peak pressures. The impulse results were similar to the peak pressure, which meant the impulse for AL Powder contents from 15% up to 35% was nearly constant. Increasing AL Powder content above 40% decreased impulse output. With different AL Powder particle sizes from 5 μ m to 150 μ m, similar bubble energies were observed. They concluded that during the detonation reaction. During consecutive reaction processes, Aluminum Powder had the highest affinity to oxygen in the explosive formulation. AL Powder increased the bubble energy with a minimum of 40%-50% AL Powder contents. Pressure and impulse were not influenced by AL Powder contents up to 30%. This point is surprising and the authors suggested it should be checked in test arrangements with more pressure gauges close to the charges[5].

Vinay Prakash et al. performed a study of the influence of Aluminum on the performance of HTPB-based Aluminized PBXs. The PBXs were processed as per standard procedures. Compositions with different formulations were prepared by varying the percentages of Aluminum Powder and RDX, and their explosive properties, including the velocity of detonation, peak pressure, duration, impulse, and sensitivity to different types of stimuli, were studied. The experimental and theoretical values of the velocity of detonation were compared. It was concluded that about 15% Aluminum Powder content is suitable for achieving the optimum explosion effect by the blast wave in the air. At about 15% AL Powder content in the composition, the optimum velocity of detonation, peak pressure, and impulse were achieved[6].

For aluminized explosives, it is important to investigate the effect of the active aluminum content on their detonation performance. Ten formulations of plastic-bonded explosives (PBXs) containing (AL Powder /RDX/binder system) were prepared, where their active AL Powder contents were varied. Measurements of detonation velocity for these formulations were done by a 430 g cylindrical charge. It was shown that there is a strong linear relationship between the measured

detonation velocities and active AL Powder contents in different samples. The measured detonation velocities of the formulations with a higher content of active AL Powder were greater than the other compositions. Thus, it can be expected that the contribution of AL Powder in the reaction zone is higher for the formulations with a higher content of active AL Powder. The results of this work show that the coating of the surface of submicron-sized AL Powder reduces the oxidation rate and increases their service life [13].

III. OBJECTIVES OF THE STUDY

This work aimed to prepare four samples of Aluminized Polymer Bonded Explosives (ABXs) with various percent of Isoprene Rubber (IR) and Cyclotrimethylenetrinitramine (RDX), Aluminum powder (AL Powder) (RDX /AL/IR), based on Sulfur Vulcanization process. The objectives were:

- 1) To determine the chemical, physical, and explosive properties of the prepared samples.
- 2) To investigate the process conditions for processing castable ABXs to achieve the optimum solid loading.
- 3) To fill/charge sample warheads with the prepared ABXs paste using a water bath mixer.

IV. EXPERIMENTAL WORK

The objective of this study was to prepare various samples of Aluminized Polymer Bonded Explosives (ABXs) with different proportions of Isoprene Rubber (IR) and RDX, utilizing AL Powder based on the Sulfur Vulcanization process. Subsequently, the sensitivity of the prepared Aluminized Polymer Bonded Explosive to initial impulses was determined, and various explosive performance characteristics were evaluated. All experiments were conducted in a laboratory setting.

A. Lab Scale Product

The composition of the ABXs samples was standardized with a constant 15% polymeric binder, varying AL powder content from zero to 35%, and RDX from 50% to 85% shown in Table (I). The precise amounts of Isoprene Rubber, RDX, AL Powder, Sulfur, TMTD, ZnO, Stearic acid, and Trans oil were accurately weighed and mixed in a 2-liter water bath mixer at 70 °C shown in Fig (1). The compositions were then cured for 5 days at 70-80 °C in an oven. outlines the compositions of ABXs prepared at a lab scale.

TABLE I
THE COMPOSITION OF THE ABXs SAMPLES

Compound	ABXs-0	ABXs-15	ABXs-25	ABXs-35
RDX	85 %	70 %	60 %	50 %
AL Powder	0	15 %	25 %	35 %
Vulcanization System	15 %	15 %	15 %	15 %
Temperature (oC)	70	70	70	70



Fig. 1. 2-liter water bath mixer

TABLE II
RAW MATERIALS SPECIFICATION

No	Materials	Properties	Function
1	Sulfur	Melting point 120°C	Cross-linking agent
2	Isoprene rubber	Molecular Weight: 31000	Polymer
3	TMTD	Melting point 120°C	Accelerator
4	RDX	Decomposition at 204°C	Explosive
5	ZnO	Melting point 120°C	Activator
6	Stearic acid	Melting point 69.3°C	Activator
7	Trans oil	Improve the mixing	Plasticizer
8	AL Powder	Density: 2.7 g/cm ³ , Particle size: 27-28 μm	Reactive metal

B. laboratory tests

Density, impact sensitivity, and ignition temperature are the main characteristics of the explosive materials that were taken from three points in the warhead section shown in Fig (2). Therefore, the five samples were sent for these tests. Density was found using a Density meter and automatically calculated. Impact sensitivity test also experiment has been determined using Ika-Maschinenbau. The impact energy of dropping weight at each height was calculated according to Eq. 1

$$I.E = m * H * g \quad (1)$$

Where: I.E is Impact energy (Joule), m is the mass of the falling hammer (kg), H is drop height (m), and g is the acceleration due to gravity = $9.8m/s^2$.

C. Casting of warhead samples

The raw materials used in this study are detailed in Table (II) including their properties and respective functions.

32kg of Aluminized polymer-bonded explosives formulations were processed in a 5-liter capacity mixer water bath shown in Fig (3), varying the AL powder content from 15% to 35% and RDX from 50% to 85%, RDX was added incrementally during mixing, with 10 minutes of mixing after each addition are detailed in Table (III)

The filling process was carried out using casting methods shown in Fig (4) gradually adding 1/4 of ABXs each time and compressing. The C-8 warheads were then cured in an electric oven shown in Fig (5) for five days at temperatures ranging from 70 °C to 80 °C. This section provides a comprehensive overview of the experimental procedures undertaken to prepare

TABLE III
PROCESS USED TO FILLING WARHEAD

N	Work Content	Time (Minute)	Rotating speed (rpm)
1	Add premixing materials (AL Powder, IR, TMTD, Sulfur, Trans oil, stearic acid, ZnO)	10	30
2	Add RDX about 1/4 of the total amount.	10	30
3	Stop the mixer, Add RDX about 1/4 of the total amount.	10	30
4	Stop the mixer, Add RDX about 1/4 of the total amount.	10	30
5	Stop the mixer, Add residual RDX	10	30
6	stop mixer	10	30
7	Take out materials.		

and evaluate the ABXs samples. varying ratios of RDX, AL powder, and the vulcanization system. These samples were processed in a 2-liter water bath mixer at a temperature of 70 °C and subsequently cured in an electric oven at 80 °C for five days. Following the curing process, key characteristics of the explosive substances, including density, impact sensitivity, and ignition temperature, were evaluated. Additionally, a crystal morphology study was conducted for the samples. samples, providing valuable insights into their performance characteristics.



Fig. 2. warhead section



Fig. 3. 5-liter capacity mixer water

V. RESULTS AND DISCUSSIONS

This section presents comprehensive findings and discussions regarding the density, impact sensitivity, ignition temperature, and crystal morphology of the prepared ABXs samples, providing valuable insights into their performance characteristics. Four laboratory samples of ABXs were prepared with varying ratios of RDX, AL powder, and the vulcanization system. These samples were processed in a 2-liter water bath mixer at a temperature of 70°C and subsequently cured in an electric oven at 80°C for five days. Following the curing process, key characteristics of the explosive substances, including density, impact sensitivity, and ignition temperature, were evaluated. Additionally, a crystal morphology study was conducted for the samples. The densities of the four laboratory samples were measured using a density meter, revealing a gradual increase as the percentage of AL powder in the samples increased. These results were close to the density of Comp-B (RDX 60%, TNT 40%)[14]. The results are summarized in Table (IV). Impact sensitivity was determined using Ika-Maschinenbau, indicating a decrease in sensitivity with higher percentages of AL Powder in the samples. It was better by about 71.8% than Comp-B Impact sensitivity[15]. The results are presented in Table (IV). The ignition temperature was determined using a Deflagration Test Apparatus, showing consistent temperature ranges (230 to 236°C) across all four samples. It was also close to the ignition temperature of Comp-B [16]. Table (IV) summarizes the ignition temperature findings.



Fig. 4. Casting methods

TABLE IV
RESULTS IN EXPERIMENTAL

Compound	Density (g/cm ³)	Impact Sensitivity (Joule)	Ignition Temperature(°C)
ABXs-0	1.386	20.5	236
ABXs-15	1.521	24.5	231
ABXs-25	1.533	29.4	234
ABXs-35	1.65	31.85	235

A scanning electron microscope (SEM) was utilized to examine the morphology of the crystals and the quality of the coating[17]. SEM photographs of both RDX crystals and the prepared ABXs were captured. The images revealed that RDX



Fig. 5. Electric oven

crystals exhibited varying sizes, irregular shapes, edges, and corners, as shown in Fig.(6). However, SEM photographs of ABXs, shown in Fig.(7), demonstrated the complete coating of RDX crystals by the polymeric matrix, with no crystals appearing outside the matrix. These results confirmed the efficacy of the new polymeric matrix in bonding the crystals and adequately coating their surfaces.

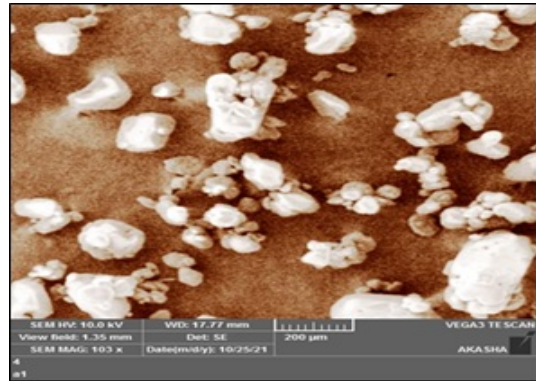


Fig. 6. SEM photographs RDX crystals

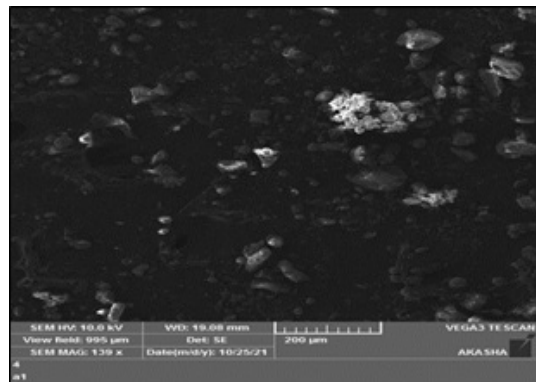


Fig. 7. SEM photographs of ABXs

VI. CONCLUSION

In conclusion, this study successfully prepared Aluminized Polymer Bonded Explosives (ABXs) formulations comprising

RDX, AL powder, and Isoprene Rubber (IR) in the laboratory setting. The production process exhibited efficient mixing of materials at 70°C, followed by curing at 80°C for five days, ensuring optimal formulation integrity. Analysis of scanning electron microscope images revealed a well-executed coating process, corroborated by results indicating satisfactory impact sensitivity. Furthermore, observations of density variations across the four samples underscored the direct relationship between AL powder content and density, alongside the inverse correlation between AL powder and RDX proportions. The higher percentages of AL Powder and the corresponding reduction in RDX content correlated with diminished impact sensitivity across all samples, indicative of improved safety characteristics. Moreover, the prepared explosive formulations exhibited favorable attributes, including ease of production, reduced sensitivity to impact and friction, appropriate sensitivity to heat, and commendable performance coupled with enhanced safety and long-term thermal stability. In light of these findings, it can be inferred that the formulated ABXs compositions hold promise for applications in filling ammunition projectiles, rocket warheads, Explosive Reactive Armor, and underwater weapons. The demonstrated advantages, combined with the observed performance characteristics, underscore the potential utility and effectiveness of these formulations in practical military and civil applications.

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