Study of Zirconium and Ammonium Perchlorate Based Igniter for Composite Solid Base Bleed Propellant

Amir Mukhtar, Habib Nasir, and Badar Rashid

***Abstract*—Ammonium perchlorate and hydroxyl-terminated polybutadiene (AP/HTPB) based solid composite base bleed (BB) propellant is used in BB units of modern artillery projectiles. An igniter is very vital part of BB unit for ignition and reignition of BB grain of projectile after muzzle exit. Very high energy igniter compositions based on Ammonium perchlorate (AP) and Zirconium (Zr) were developed with and without gum arabic as binder. Different ratios of Zr/AP were studied for pressure-time (P-t) curve, pressure maximum (P_{max}), rate of change of pressure (dP/dt), time to reach P_{max} (t_{Pmax}), calorific value, and burning rate. It was observed that composition Z-7 with 50 wt. % of Zr and 50 wt. % AP having 6.5 wt. % of binder (additional) gave good burning rate, P_{max}, dP/dt and heat of reaction. Selected composition was filled in igniter cups and of igniter bodied developed for BB unit of 155 mm Extended Range Base Bleed (ERBB) artillery projectile. Several igniters were fired by electronic ignition to recording burning time, igniter mass burning rate and ignition consistency.**

***Index Terms*—Ammonium perchlorate, closed vessel, base bleed, zirconium.**

I. Introduction

Pyrotechnic are used for several military and civilian systems all around the globe [1]. These formulations are made of homogenous mixtures of various metal fuels and oxidizers [2]. Ammonium perchlorate, potassium nitrate and potassium perchlorate are oxidizers being used in compositions that are less sensitive to unwanted stimuli and are very stable [3]-[5]. Energetic pyrotechnic mixtures with high energy density utilize fuels (metal) with high enthalpies of combustion. Commonly used fuels are Zirconium (Zr), Aluminum, and Magnesium. These are considered as good reducers with good energy content.

Extended Range Base Bleed (ERBB) artillery projectile has a base bleed (BB) unit to reduce base drag acting on the projectile during its flight and extend range by 30% [6], [7]. BB unit has an ammonium perchlorate (AP) and hydroxyl-terminated polybutadiene (HTPB) based BB grain housed in metallic chamber which release hot combustion products at projectile base thereby increasing the base pressure. Artillery projectile is subjected to high acceleration, chamber pressure and rate of rotation and sudden pressure drop at its base on muzzle exit. This pressure drop can cause quenching of BB propellant. To enable it to reignite a highly reliable igniter with very energetic pyrotechnic composition is made available in BB unit. This igniter is considerably strong to undergo high acceleration, gun chamber pressure, very high set back and projectile rotation. Igniter must ensure reignition of BB propellant and consistency in projectile range. The following main properties are a must for a good BB unit igniter: -

1) It must be properly waterproofed.
2) It must be compact and strong enough to undergo extreme temperature, pressure and high velocity in gun chamber.
3) It must be sensitive enough to be ignited in gun chamber.
4) It must withstand the sudden pressure drop on muzzle exit and must not get quenched
5) It must ensure BB propellant ignition until it attains stable burning.
6) It must not interfere with the BB unit performance during flight.

Magnesium-Teflon-Viton known as MTV are igniter mixtures used for rocket motors and systems with BB propellant [8]-[13]. MTV mixtures undergo aging at higher rates cue to reaction of Magnesium with moisture at elevated temperature conditions weakening the mechanical strength and energy [14]-[17]. Zr is widely used fuel in composition for consistent ignition property, high energy content and good burning rates. It reacts with oxidizer and undergoes fast combustion reaction producing good ignition force. Zr/ $KClO_4$ mixtures having suitable binder have been used as initiators and are reported in literature [18], [19]. 1 A/1 W no-fire EEDs (electro explosive devices) use Zr/ $KClO_4$ pyrotechnic mixture [5]. Zr/AP based igniter composition with gum arabic as binder has not been reported for AP/HTPB composite solid BB propellant.

Therefore, the main aim of this research work was to study Zr/AP based compositions for development of a reliable igniter composition. It was also ensured that the developed igniter composition must give desired performance under endure extreme mechanical stresses, heat and pressure produced by gun propellant while being fired as a part of BB unit in artillery projectile.

II. Experimental

A. Materials

Zr powder, AP powder and gum arabic were provided by Pakistan Ordnance Factories. All chemicals were of research

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grade and 99% pure.

B. Igniter Composition Preparation

Zr and AP powders were dried in an oven at 50 °C for 3 hours. The compositions were prepared my mixing in mortar and pestle. Fuel and oxidizer were homogenized, and additional content of gum Arabic was added under mixing. The mixing is performed until the composition is properly homogenized and can be filling in solid strands in shape of pipes for burning rate analysis, high pressure Closed Vessel (CV) tests and heat of reaction in bomb calorimeter. Gum arabic provided effective binding of solid particles of igniter compositions. The prepared samples dried in oven at 40 °C for 48 hours to ensured proper solidification.

TABLE I: IGNITER COMPOSITIONS

Composition	Zr wt. %	AP wt. %	Gum arabic wt. %
Z-1	30	70	-
Z-2	40	60	-
Z-3	50	50	-
Z-4	60	40	-
Z-5	30	70	6.5 (Additional)
Z-6	40	60	6.5 (Additional)
Z-7	50	50	6.5 (Additional)
Z-8	60	40	6.5 (Additional)

Four compositions Z-1 to Z-4 were prepared by changing Zr/AP ratio without binder and Z-5 to Z-8 were prepared by adding 6.5 % additional binder as given in "Table I". Prepared samples characterized for pressure-time (P-t) data, maximum pressure (P_{max}), differential pressure (dP/dt), rate of burning and calorific value. Selected composition was prepared in a 0.4-liter horizontal mixing machine and press filled in steel igniter cups of igniter assembly. Filled cups were press fitted in igniter bodies and test fired for studying ignition behavior and burning time. The preparation process followed from composition to filing and assembling igniter is shown in Fig. 1.

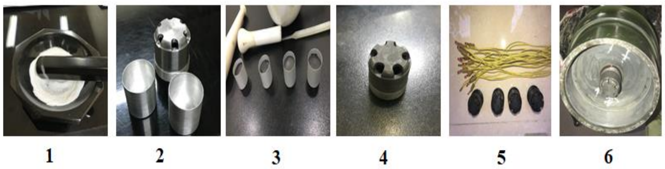


Fig. 1. Preparation, filling and assembling the igniter.

III. CHARACTERIZATION TECHNIQUES

A. Bomb Calorimeter

An oxygen bomb calorimeter Parr 6200 with oxygen bomb 1104 was used for the measurement of the calorific value of all the igniter compositions. Samples were tested several times to obtain mean results. The sample mass of ~0.75 g was used for each firing.

B. CV

CV is used to determine combustion performance of propellants. It is a safer, less expensive and quick method than field firing with gun research and development on energetic materials is involved [20]. A known sample mass as per loading density is used in CV for ballistic performance investigation. CV used in this work has 100 cm^3 of chamber volume with pressure range of 5000 bars. Firing block has a firing mechanism with ignition bag having 1.5 g of black powder and a pressure block equipped with quartz pressure transducer type 6203. Kistler charge amplifier type 5018 and data acquisition module provides P-t data. A schematic diagram of CV is shown in Fig. 2.

1-CV; 2-Firing block with igniter bag; 3-Pressure transducer
Fig. 2. CV system.

C. Fuse Wire Technique

For reliable and desired burning of a pyrotechnic composition, processes occurring inside the burning mass are required to be balanced for achieving maximum desired output. A controlled rate of burning is the one of the most vital mechanisms responsible for producing desired effect. It determines the rate of release of hot gases and energy. Therefore, the adjusting of a proper and controlled burning rate is of paramount importance to improve performance and safety of a BB unit igniter. Burning rate of a pyrotechnic mixture is primarily influenced by choice of fuel and oxidizer, an optimum value for ratio of fuel to oxidizer, homogeneous mixing of main ingredients, shape and particle size and additives including any catalysts.

Burning rate was measured by fuse wire technique by passing two fuse wires through solid strands at measured length as shown in Fig. 3. Burning time was recorded by electronic timer. Solid strand for burning tests were made with compositions having binder.

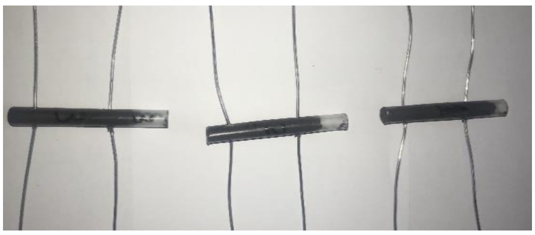


Fig. 3. Solid strands for burning rate.

IV. RESULTS AND DISCUSSION

AP and Zr react to release hot combustion products in as exothermic fast reaction. Bomb calorimeter measurements showed that the heat of combustion of igniter compositions reduced with increasing Zr wt. %. This resulted from increased Zr wt. % leading to access of fuel content, more than the stoichiometric value. Homogenous mixtures Z-1 to Z-4 were tested in powdered form and composition Z-5 to Z-8 with additional 6.5 wt. % gum arabic. Calorific value of

7439.94 J/g was recorded for Z-1 without binder and with binder value of 6711.44 J/g was recorded for Z-5.

CV testing of each composition was performed several times and mean results were obtained. 5 g of sample mass was tested for P-t data for all compositions. Basic data recorded is P-t and comparative P-t profiles are plotted in Fig. 4&5. The differential pressure is obtained by using P-t data which has been plotted vs P in Fig. 6&7. P_{max} and dP/dt decreased with rise in Zr for all compositions under investigation. The mean experimental results are given in "Table II".

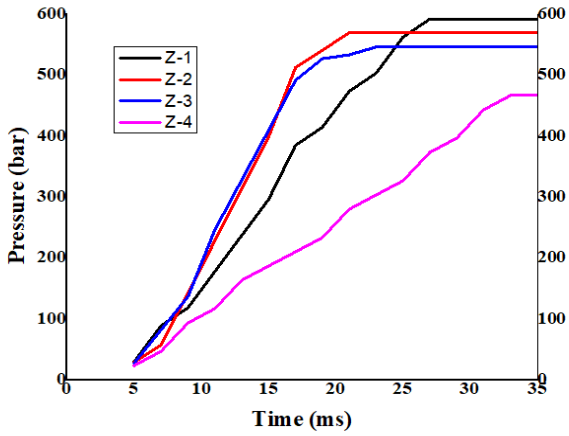


Fig. 4. Comparative P-t profile for composition Z-1 to Z-4.

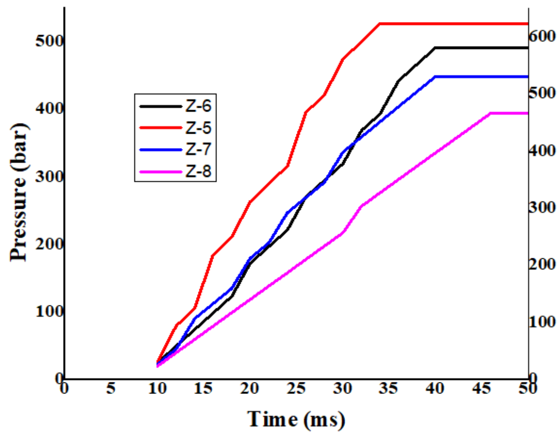


Fig. 5. Comparative P-t profile for composition Z-5 to Z-8.

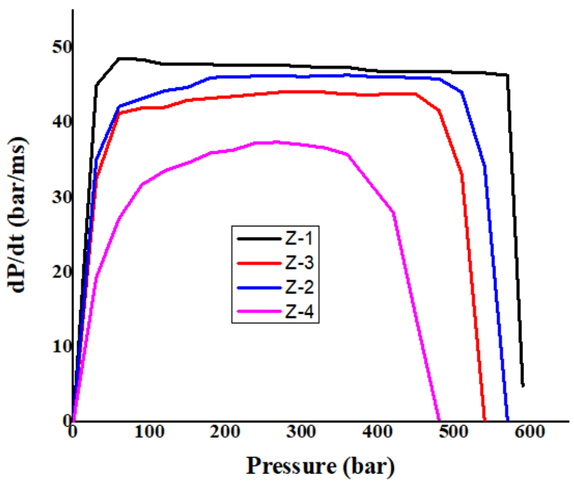


Fig. 6. Comparative dP/dt against P for composition Z-1 to Z-4.

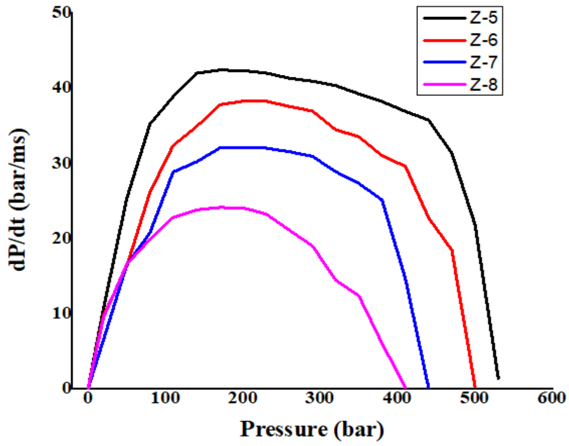


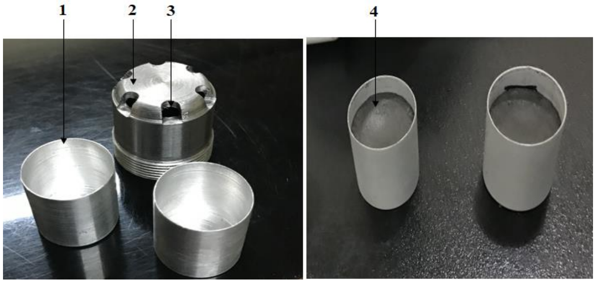
Fig. 7. Comparative dP/dt against P for composition Z-5 to Z-8.

TABLE II: CV RESULTS

Composition	P_{max} (bar)	t_{Pmax} (ms)	$(dP/dt)_{max}$ (bar/ms)	Calorific value (J/g)	Burning Rate (mm/s)
Z-1	591.62	26.00	48.56	7439.94	-
Z-2	569.16	21.50	46.33	7259.91	-
Z-3	545.88	23.50	44.14	6770.06	-
Z-4	466.30	33.50	37.46	6451.86	-
Z-5	526.34	34.00	42.38	6711.44	2.51
Z-6	490.91	40.00	38.24	6259.27	4.70
Z-7	448.37	40.50	32.11	5735.92	6.50
Z-8	394.35	45.00	24.10	5354.92	7.30

P-t and dP/dt profiles show the combustion behavior of the compositions under investigation. Fuel/oxidizer ratio increasing and P_{max} is also decreasing as mean calorific value is also reducing as confirmed in recorded results. P_{max} and dP/dt show that the higher wt. % of oxidizer gives higher pressure and differential pressure is also higher for less fuel and more oxidizer content. Oxidizer releases oxygen and fuel combines with oxygen forming strong chemical bonds and releasing combustion energy. Maximum pressure and differential pressure of compositions Z-1 to Z-4 are higher as compared to Z-5 to Z-8. Binder apparently caused the lowering of heat of reaction. Solid inhibited strands in form of straw pipes of 30 mm length and 4 mm diameter were made with compositions Z-5 to Z-8. These strands were for tested for burning rates in ambient conditions. When there is a deviation from an optimum fuel/oxidizer ratio, the burning rate is reduced due to reduced heat of reaction as there is an extra amount of oxidizer or fuel not participating in the reaction giving no input in overall composition burning performance.

Composition Z-7 with the burning rate of 6.50 mm/s, P_{max} (448.37 bars) and a mean time of 40.50 ms to achieve P_{max} and mean calculated value of 32.11 for dP/dt was selected as composition for igniter for AP/HTPB based composite BB propellant. For performance evaluation of igniter composition "Z-7", it was tested in igniter assembly consisting of a steel cup and steel igniter body with six holes through which the hot gun propellant gases ignite the compositions and let the hot igniter combustion products flow out that provide ignition to the BB propellant as shown in Fig. 8. The composition (22 g) was pressed in igniter cups with the help a hydraulic press. A specific pressure was applied for 15 seconds at ambient conditions for filling each igniter cup. Igniter composition cups were then fitted in main igniter bodies. Igniters were tested by initiating with electric squib Fig. 9.



1-Igniter cup; 2-Igniter body; 3-Igniter holes; 4- Zr/AP composition
Fig. 8. Igniter assembly.

1-Dummy shell base; 2-Igniter assembly; 3-Igniter flame
Fig. 9. Igniter firing.

No significant ignition delay was observed, and good burning performance was achieved. The average igniter mass burning rate was recorded at 6.28 g/s. Average igniter burning time was recorded at 3.5 seconds.

V. Conclusion

Zr/AP based igniter for AP/HTPB based propellant for BB system was studied in this work. It was found that with the wt. % of Zr and reduction in wt. % of AP the heat of combustion decreased. Same decreasing trend was recorded in P_{max} and $(dP/dt)_{max}$ in CV firing results. The heat of explosion can increase by a higher wt. % of Zr. But this resulted in slow ignition behavior and low burning rates effecting the burning time of igniter. Experimental results showed that the composition Z-7 was found as a suitable composition for BB unit igniter. Static examination of igniter performance was performed successfully. Therefore, this composition is recommended to be further investigated for application in BB unit for performance analysis at static as well as dynamic filed trials for successful ignition or reignition of a BB grain.

Conflict of Interest

The authors declare no conflict of interest.

Authors Contributions

Amir Mukhtar studied and synthesized the igniter compositions followed by characterization for results and analysis. He wrote the complete paper. Habib Nasir provided lab facilities to carry out the synthesis and helped in data analysis for paper write up. Badar Rashid provided complete chemicals, characterization instruments and igniter firing facilities. All authors had approved the final version of this research article.

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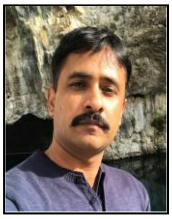

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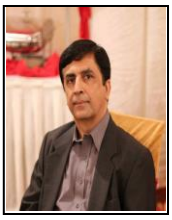

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