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Effect of body material and temperature variation on the performance of the time delay pyrotechnic compositions

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ABSTRACT

Significance of body material and temperature variation on burning time and burning rate of Si/PbO/Pb_3O_4/FG and B/$BaCrO_4$/FG pyrotechnic delay compositions were experimentally studied. Brass and stainless steel were used as delay body materials. High resolution oscilloscope and a customized chronometer were simultaneously used for the measurement of burning time and burning rate. Results reveal that brass material with controlled column dimensions reduced the variation in burning time of Si/PbO/Pb_3O_4/FG delay mixture from 7.43% to 4.17% and that of B/$BaCrO_4$/FG mixture from 16.83% to 9.39%. Similarly the variation in burning rate was reduced from 7.57% to 4.12% and from 17% to 9.69% for Si/PbO/Pb_3O_4/FG and B/$BaCrO_4$/FG mixtures respectively. Si/PbO/Pb_3O_4/FG delay mixture was also subjected to temperature ranging from $-54\,^{\circ}C$ up to $+100\,^{\circ}C$. The burning rate of this composition varied linearly with temperature. Burning rate increased from 28.01 mm/s to 34.38 mm/s when the temperature was varied from $-54\,^{\circ}C$ to $+100\,^{\circ}C$.

1. Introduction

End result of a pyrotechnic delay device demands that it must function reliably and produce consistent burning time [1–4]. Silicon and Boron fuels based pyrotechnic compositions attracted interest for delay devices and detonators due to their excellent end results [5–9]. The material of the delay body affects the burning rate of pyrotechnic delay composition. The rigid delay body acts as a heat sink during burning of the delay composition. Metals are generally better conductors of heat than the delay compositions [10]. The accuracy of pyrotechnic delay composition can be improved at given temperature by improving the design and controlling the dimensions of the delay column especially the length and diameter. Material in respect of the body of the delay material is also very important while designing a pyrotechnic delay device. Better accuracy is achieved by using brass delay body compared to stainless steel, aluminum and carbon steel. Main concern in pyrotechnic delay compositions is the accuracy that ranges between $\pm 10\%$ to $\pm 20\%$ of the mean value over the normally military operating temperature ranges of $-40\,^{\circ}C$ to $+70\,^{\circ}C$ [11]. In some pyrotechnic compositions, the time delay increased up to 25% from mean at low temperature of $-54\,^{\circ}C$ [12–15]. The development of pyrotechnic delay composition consists of mixing an oxidizer, fuel, binder and solvent to form slurry. It is then dried to remove the liquid to obtain solid product and then into desired grains sizes. Now a trend has been developed of replacing lead as a body material with delay body made of rigid metals such as aluminum, zinc, steel or brass. Delay body made of rigid metal can facilitate ease of loading the delay composition. Rigid delay body into which a pyrotechnic composition is loaded has higher thermal conductivity and act as a heat sink because of better conductors of heat than pyrotechnic delay compositions. There is a risk of failure of combustion propagation especially when the delay device is operating in low temperature environment. The pyrotechnic composition should produce more heat than the heat loss to the surrounding due to thermal conductivity of the delay body, to sustain combustion propagation [16,17]. Modern pyrotechnic delay devices require reliable initiation and to produce consistence burning time [18]. Pyrotechnic delay compositions due to controlled chemical reactions are also strongly affected by the ambient temperature. Change in the ambient temperature varies the burning time of a pyrotechnic composition. High ambient temperature normally produces smaller change in burning time than when a temperature change occurs at lower ambient temperature [19]. To the best of our knowledge not much data is available on the effect of ranges of

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ambient temperatures and body material on burning performance of these types of pyrotechnic delay compositions. The main objective of this research work was to study:

(a) The effect of body material on the burning time and burning rate of $Si/PbO/Pb_3O_4/FG$ and $B/BaCrO_4/FG$ pyrotechnic delay compositions.
(b) The effect of temperature variation on the burning time and burning rate of $Si/PbO/Pb_3O_4/FG$ pyrotechnic delay compositions.

2. Experimental part

2.1. Materials used

2.1.1. $Si/PbO/Pb_3O_4/FG$ delay mixture

High purity analytical grade silicon powder as fuel, lead (II) oxide (PbO) and lead oxide Pb_3O_4 as oxidizers and commercial grade fish glue as a binder were used during this research work. All these chemicals were procured from Sigma Aldrich Company. Purity of these ingredients was ≥99%. Particle sizes of silicon (Si), lead (II) oxide (PbO) and lead oxide Pb_3O_4 were ≤44 μm, 1–2 μm and <10 μm respectively.

2.1.2. $B/BaCrO_4/FG$ delay mixture

Boron was used as a fuel and barium chromate was used as oxidizer. The purity of the boron and barium chromate is between 95 and 98%. The fuel and oxidizer used were fine powder, whereas commercial grade fish glue as a binder was used during this study.

2.2. Formulation of pyrotechnic delay composition

2.2.1. Mixing of pyrotechnic delay compositions

Fuels and oxidizers were dried in heating oven at 80 °C for 2 h to remove the moisture content. The ingredients of the mixture were weighted according to the required percentages, and mixed the ingredients in the three dimensional (3-D) automatic Tumbler Mixing Machine. Small batches of 5–10 g each were further processed by mixing the chemicals in Mortar and Pestle in a mechanized mixing machine for 30 min to further homogenize the compositions. These operations were performed in a specially designed fuming hood. Binder solutions of 0.30 wt % and 1.0 wt % Fish Glue were prepared in distilled water for $Si/PbO/Pb_3O_4/FG$ and $B/BaCrO_4/FG$ delay composition respectively. Binder solutions were then mixed in delay compositions. A homogenous paste was prepared by using the spatula in agate container. The composition was semi dried in the Drying oven at 80 °C. To avoid the formation of lumps, the semi dried composition was broken carefully by spatula in an agate container. The composition was then sieved gently through 212 mesh to get grains sizes of ≤65 μm. Haver test shaker EML 200-89 digital was used for preparation of grains of required particle sizes [20,21]. Grains were dried for 8 h at 80 °C to remove the moisture content. The finished compositions were stored in special containers and placed in desiccators for 24 h to stabilize the compositions.

Binder was added to collect the particles to bind together in the form of free flowing grains. The binder protects the fuel and oxidizer from environment effect such as humidity. Additionally, binder also increase cohesion between particles of fuels and oxidizers to protect them from being segregated due to their density difference especially during storage. The grains also provide ease of loading of the composition in the cartridge body. Free flowing grains of the mixture have the ability to flow freely when poured from one container to another.

2.2.2. Safety precautions during mixing of compositions

These compositions are sensitive to friction, especially the processes of dry mixing and grains formation. The following safety precautions were observed during handling of these compositions.

(a) The exposure of a minimum number of operators was ensured during processing steps.
(b) The quantity of pyrotechnic composition for each batch was kept to 5–10 g.
(c) A mechanized mixing machine installed with Mortar and Pestle was used.
(d) A Blast proof screen was used while mixing the compositions.
(e) Fire proof goggles and gloves were used while handling and preparing these compositions.

2.2.3. Pressing of delay composition in delay tube

Finalized compositions were pressed into stainless steel and brass delay tubes of internal bore diameter of 4.0 mm. The bulk density of the $Si/PbO/Pb_3O_4/FG$ delay composition is more than that of $B/BaCrO_4/FG$ delay mixture; therefore, the $Si/PbO/Pb_3O_4/FG$ and $B/BaCrO_4/FG$ delay mixtures were loaded in six and four equal increments respectively. The weight of each increment was kept 100 mg. Each increment was weighted separately and pressed at 30000 psi in the delay tubes one by one. A hydraulic press machine installed with a calibrated pressure gauge was used to press the delay compositions in the delay tubes. The surface of the delay column was kept flushed with the end of the delay tube. Extra delay composition was removed by sliding the end of the delay tube. Delay device filled with delay composition is shown in Fig. 1.

2.2.4. Functional testing and data recording

Delay device used in this study consisted of rigid delay body, percussion primer, pyrotechnic delay composition and flame composition. These delay compositions were tested in mechanically initiated delay devices. Percussion cap of this mechanically initiated delay device was hit with a striking pin. The firing system consisted of electromechanical switch. Burning time started when the pin hit the percussion primer, and stopped when the Light Dependent Resistor (Sensor) detected the flame of the delay composition. To protect the senor from the slag, a Perspex disc was assembled in front of it. The burning time was measured with digital Oscilloscope. Measured results were in milliseconds, therefor the sensitivity of the instruments used were in micro second in order to avoid motion blur. A customize chronometer was also used for the measurement of the burning time simultaneously. Schematic diagram of the burning time measurement system is shown in Fig. 2. Five measurements for each composition were carried out and the results were averaged.

3. Results and discussion

In this study two pyrotechnic delay compositions $Si/PbO/Pb_3O_4/FG$ and $B/BaCrO_4/FG$ were experimentally investigated. Stainless

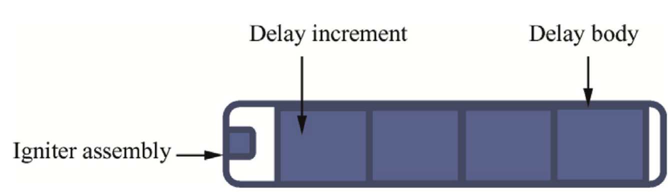

Fig. 1. Pyrotechnic delay device.