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Light Pyrotechnics Using Gunpowder Derived from Fly Ash Bottom Ash (FABA) Waste and Activated Carbon

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Abstract—Pyrotechnic materials are a category of materials that are often used in various applications, including military activities, lighting, signaling, and combat effects. In this study, an experiment was conducted to create a light pyrotechnic material using gunpowder, which is a mixture of potassium nitrate, sulfur, and activated carbon. The manufacturing process involved the activation of carbon from fly ash bottom ash (FABA) waste and the composition of different pyrotechnic materials. The experiment involved testing pyrotechnic compositions with varying ratios of KNO_3 : carbon : sulfur. The results showed that the composition with a ratio of 15 : 7.5 : 7.5 produced the highest light intensity, reaching 104 lux, and provided optimal visual effects. In addition, the relative proportions of oxidizer, carbon and sulfur affected the type of pyrotechnic effect produced. Pyrotechnic light generation from gunpowder could be considered successful, and the best composition for spectacular visual effects was a ratio of 15 : 7.5 : 7.5. However, sufficient caution and knowledge were required in the use of pyrotechnic materials to ensure safety and compliance with applicable regulations.

Keywords—*Activated carbon; FABA; Gunpowder; Light intensity; Light pyrotechnic*

1. INTRODUCTION

Pyrotechnics are materials containing fuel and oxidizers that produce heat, flame, sound, colored light, smoke, and several of gases upon ignition. These materials are frequently used in military activities, illumination, signaling, sound simulation and combat effects, and communication [1]. Fuels and oxidants, traditionally used in pyrotechnics, come as the form of fine powders. Fuels can be metals (like aluminum, magnesium and iron) or nonmetals (such as silicon, carbon, sulfur and certain organic compounds). Oxidizers, typically salts or metal oxides, are chemically metastable, meaning they are unstable and readily react. They exhibit low reaction rates but produce significant energy during combustion [2]. Common oxidants include oxides, peroxides, and oxysalt. To improve specific properties essential for manufacturing or application, various additives can be incorporated into pyrotechnic compositions. Pyrotechnics can be divided into heat, light, sound, smoke, and delay pyrotechnics. Light pyrotechnics fall into two categories: flash powder and flares. Flash powder is usually a mixture of metal and salt, while flares consist of a mixture of binders with metal and salt. The light produced by pyrotechnics is due to the physical processes. The heat energy absorbed by the metal electrons excites the outermost electrons to a higher energy level. Then the electrons will experience deexcitation so that they return to the grounding level.

In pyrotechnics, hundreds of chemicals can be used, each serving a specific function in the combustion reactions. Typical pyrotechnic mixtures include oxidizers, fuels, carbon sources, and various additives. Carbon, a key component in black powder fireworks, acts as the primary fuel source. Common forms include carbon black, sugar, and starch. Gunpowder, also known as black powder, is a chemical explosive mixture of potassium nitrate (KNO_3), sulfur, and carbon. The ratio of these three components determines the final effects [3]. Carbon, fuelled by potassium nitrate (the oxidizer), burns readily due to sulfur's flammability, allowing combustion to spread throughout the mixture [4]. This combination results in deflagration, a rapid but short-lived combustion. This experiment utilized carbon obtained from bottom ash waste, the fine particles

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remaining after combustion. This study aimed to design a light-emitting pyrotechnic composition using gunpowder, focusing on maximizing light output (lux) and visual effects. The composition design was then analyzed and tested for optimal results.

2. EXPERIMENTAL SECTION

2.1. Materials

The tools used in the research were mortar, grinder, beaker glass, hot plate, filter paper, and a set of light testing tools. The materials used in this study were 500 g of FABA (Fly Ash Bottom Ash) samples, 50 g of NaOH, 85 mL of HCl 37%, sulfur, KNO_3, cellulose, sugar, fireworks fuse, and 2 L of distilled water.

2.2. Activated Carbon Production for Fly Ash Bottom Ash (FABA)

The production of activated carbon powder typically involves several steps, including a preparation stage, a carbonization stage, and an activated stage. However, in this study, the activated carbon sample only underwent the activation stage because the sample used had already been processed through the preparation and carbonization stages. The activation process was carried out in two stages. First, the sample was soaked and heated in chemical activators (HCl and NaOH for 2 h). Then, the charcoal was separated from the activator solution by filtration and dried by heating at 350 °C for 1 h. The charcoal sample used was 500 g of FABA charcoal. In the first activation step, 42 mL of 37% HCl was added, followed by water to make a total volume of 500 mL. The mixture of FABA charcoal and the HCl activator was then heated to accelerate the activation process. The resulting acid-activated carbon was filtered, washed, and dried. Subsequently, a second activation was carried out using NaOH, where 25 g of NaOH was added to the activated carbon, dissolved in water up to 500 mL, and then heated for 2 h. Finally, the activated carbon from the second activation was filtered, washed, and dried.

2.3. Making Gunpowder

Gunpowder production was conducted based on Verbovytskyy & Harrison (2022) [3]. First, raw materials such as potassium nitrate (KNO_3), sulfur, and carbon (charcoal) were prepared. These materials were typically mixed in a specific ratio of 74,8% KNO_3, 11,9% sulfur, and 13,3% activated carbon. Next step, through experimental comparison, KNO_3 : carbon: sulfur were made with a composition ratio of A (15 : 7.5 : 7.5), B (7.5 : 7.5 : 15), C (7.5 : 15 : 7.5), D (18 : 9 : 9), E (9 : 9 : 18), F (9 : 18 : 9), and G (22.5 : 4.2 : 3.6). To achieve a uniform mixture, each raw material was individually ground using a mortar to create a fine powder. Importantly, these materials were ground separately, not together. The resulting powders were then stored at a controlled humidity level before mixing. Then, all components were combined in a mortar and ground together for 10 min or more. The gunpowder was sifted using a sieve to break it into small grains, and then dried under sunlight on a sheet of paper. Once dry, the gunpowder was pressed into a mold to achieve a compact form. This compact gunpowder was then removed from the mold, and a fuse was inserted into one side. Finally, a light-intensity test was conducted using a flux meter on the gunpowder to assess its properties.

3. RESULT AND DISCUSSION

Pyrotechnics are materials commonly used in various military applications [5]. They also have commercial applications, such as in fireworks production [6]. In this study, we made a pyrotechnic light material using gunpowder, which is often used in filling bullets, with raw materials consisting of FABA (Fly Ash Bottom Ash) waste utilized to form activated carbon by acid (HCl) and base (KOH). The activated carbon was then mixed with sulfur and KNO_3 derived from KNO_3 fertilizer [7].

Fig. 1. Pyrotechnics burning experiment with composition as reference

A 500 g sample of FABA waste was processed with 500 mL of 1M HCl solution to modify its surface properties, making it more suitable for further carbonization. The reaction was carried out under controlled conditions at 150 °C for 2 h. The mixture was then left for a day to facilitate further chemical reactions and enhance the activation process. Next, the FABA waste was thoroughly washed with distilled water until it reached a neutral pH of 7, removing acid residues and by-products. Once the desired pH level was reached, the rinse water was discarded to prepare for the next activation stage. To initiate the base activation process, 500 mL of 1 M KOH solution was added to the FABA waste. Similar to the acid activation, the reaction was carried out at 150 °C for 2 h, facilitating the development of a porous structure in the FABA matrix. After base activation, the material underwent another round of washing to remove any remaining impurities and residue from the activation process. Finally, the resulting product was dried and characterized, producing 150 gr of activated carbon derived from the initial 500 gr of FABA waste.

Following the method described in the paper [8], we conducted an initial experiment to assess the suitability of Gunpowder as a pyrotechnic light material source. The results demonstrated a satisfactory level of brightness as displayed in **Fig. 1**.

After obtaining successful results yielding a sufficiently bright light visibly, we procced to modify the compositions of the mixture to observe the effects of each compound. This aimed to identify the key ingredients for achieving optimal light emission.

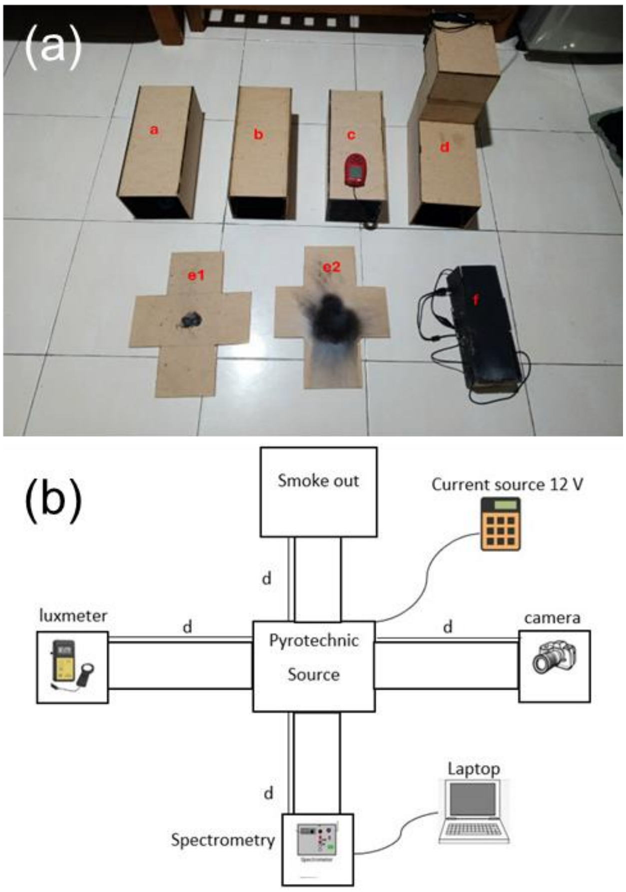

Fig. 2. (a) Part of light testing equipment, (b) Scheme of test equipment assembly

Using the testing equipment (**Fig. 2a**), assembled as shown in **Fig. 2b**, the box labelled f is inserted into box a, which functions to record emission traces using analysis software. Then, the USB on box f is connected to a laptop to record emission traces. Box b is parallel to box d and is used for visual recording using a smartphone camera, while box c functions to record the light values produced with a light meter. The part shaped like a plus sign is used as a connector for the four boxes, where e1 at the bottom and e2 at the top. Box d is used for the smoke outlet, as there is a baffle there to absorb smoke for emission. However, due to an incorrect camera placement during spectrum capture, the resulting spectrum was not appeared on the PC.

Our experiments consistently showed that composition code A (KNO_3: carbon : sulfur ratio of 15 : 7.5 : 7.5) achieved the highest lux value. Conversely, composition D (18 : 9 : 9) resulted in a lower lux value. These findings suggest that the materials that make up light pyrotechnics must be in optimum composition. The optimum stoichiometric composition can only be obtained if thermal reaction experiments is carried out [9-11]. Higher carbon content, such as 7.5 : 15 : 7.5 (C) or 9 : 18 : 9 (F), resulted in the least lux, as this composition is more suitable for producing gas or smoke than pyrotechnics. However, when a composition with more sulfur is used, such as 7.5 : 7.5 : 15 (B) or 9 : 9 : 18 (E), a reasonably high lux is obtained but still inferior than compositions A and D. If the composition is according to the paper, a relatively high lux is obtained but still lower than code A and D, approximately around 49 lux. The ratio of the amount of sulfur in the light pyrotechnic composition has a positive correlation with the light intensity value, but only within a certain range of values [10,12]. If the sulfur ratio is changed instead of a 1 : 1 ratio, there will be a change in the colour of the smoke produced and the amount of smoke. If carbon is propagated it will cause dark or black smoke, while if sulfur is propagated it will produce white smoke colour. Ideally, an optimum composition would maximize light produced while minimizing smoke production.

Based on the results, a higher oxidizer content (like KNO_3) appears to be beneficial for light pyrotechnics. However, a higher carbon or sulfur content is preferable in producing smoke pyrotechnics. This aligns with the literature that specific metals can be used to create different and brighter colors. This is because metal atoms can undergo excitation and produce energy that gives light and colors to pyrotechnics [11,13-15].

Table 1. Pyrotechnic experiment composition

Code	KNO_3 (g)	Carbon (g)	Sulfur (g)	Max lux
A	15.0	7.5	7.5	104.0
B	7.5	7.5	15.0	65.0
C	7.5	15.0	7.5	5.0
D	18.0	9.0	9.0	63.0
E	9.0	9.0	18.0	30.0
F	9.0	18.0	9.0	3.0
G	22.5	4.2	3.6	49.0

The visualization results of determining the maximum lux values for various compositions, from A to G, are depicted with quality in **Fig. 3**. **Table 1** shows that composition A has the highest flux, reaching 104.

This finding is confirmed by the visualization in Figure Code A, which clearly confirms the brightness of the light. Conversely, compositions F and C produce minimal light, consistent with the low-intensity visualizations. This phenomenon can be attributed to incomplete combustion in composition F, resulting in increased smoke production more than its light [16,17]. Compositions B and D show relatively similar maximum flux values, at 65 and 63, respectively. This similarity in brightness level is evident in the visualizations of Figures B and D.

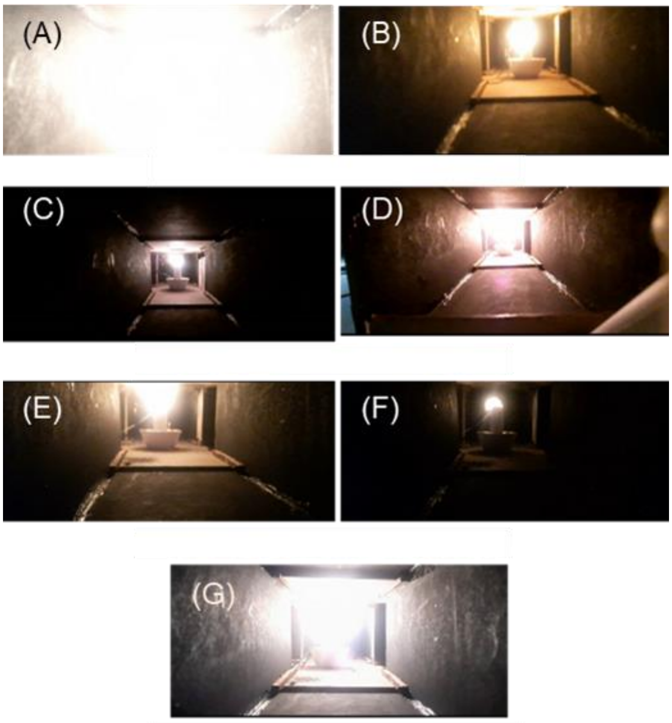

Fig. 3. Visualization results of pyrotechnics experiment in testing equipment

Finally, the use of the compositions, according to the literature by Fordham S., results in dimmer light, as shown by the less intense visualization compared to composition A [8]. With striking visualization results, composition A is the best choice for producing optimal light pyrotechnics. The highest flux in this composition, reaching 104, and its visual brightness is evident in Figure Code A. Therefore, composition A is strongly recommended for creating spectacular and captivating light pyrotechnic effects.

CONCLUSION

This study explored the potential of utilizing a combination of gunpowder and Fly Ash Bottom Ash (FABA) waste to create light pyrotechnic materials, Experimental results consistently showed that a specific composition of KNO_3 : cabon : sulfur = 15 : 7.5 : 7.5 produced optimal light emission, reaching a flux value of up to 104, superior to various other composition variations. These findings were confirmed through experimental visualizations illustrating the significant brightness of the specific composition. Therefore, this study had made significant strides in developing optimal light pyrotechnics. This success could be attributed to two key factors: the utilization of FABA waste to produce activated carbon, and the identification of the ideal 15 : 7.5 : 7.5 ratio for KNO_3 : carbon : sulfur. A strong recommendation was given to adopt the 15 : 7.5 : 7.5 composition as the main foundation for producing light pyrotechnic products. This approach not only produces spectacular visual effects but also support environmental sustainability by effectively utilizing waste materials.

SUPPORTING INFORMATION

There is no supporting information in this paper. The data that support the findings of this study are available on request from the corresponding author (STJ).

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CONFLICT OF INTEREST

The authors have no conflict of interest in this publication.

AUTHOR CONTRIBUTIONS

FIS and AEP performed the experiment and wrote the early manuscript. FIS, AEP, STJ, DRYA, and MG collaborated on data calculations, writing, and revising the manuscript . All authors agreed the final version of the manuscript.

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