CALCULATION OF LINEAR ATTENUATION COEFFICIENTS OF A FLY ASH-BASED GEOPOLYMER MIXTURE WITH BARIUM SULPHATE USED FOR X-RAY SHIELDING PROTECTION

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ABSTRACT

This work was conducted to study the properties of fly ash geopolymer (FAGP) in order to use as an alternative cement mortar (OPC) material as shielding material by adding barium sulfate (BaSO4) as additional material. The fabrication of the FAGP involved the dissolution of aluminosilicate material in a highly alkaline solution and subsequent combination with sand. The shielding properties of FAGP were enhanced with the addition of BaSO4. The FAGP was dried in an oven for one day at 60 - 70 ℃ and then cooled at room temperature for 28 days. The fabricated FAGP was subjected to elemental composition analysis using Narrow beam geometry was used to measure transmission does, the μ and attenuation percentages of the samples To obtaining the thickness of FAGP which equivalent in attenuation to the 1mm thickness of lead. The linear attenuation values were calculated from the slope for each sample. Then, the design shielding boxes were fabricated as an application for diagnostic x-ray from FAGP with (0, 5, 10, and 15% BaSO4). X-ray was used as a radiation source with 60 keV. The results showed that the attenuation coefficient with the box of FAGP with 15% BaSO4 at 60 keV has decreased the radiation to 0.4.

Keywords: fly-ash based geopolymer, shielding materials.

1. INTRODUCTION

Fly ash material is available for researchers and can be used to construct the shielding instead of some high-cost materials such as Lead and concrete. Since a larger quantity of shielding material is required for purposes of radiation shielding, examining the propagation of radiation flux in shielding materials is an essential requirement for better shield design [1]. Furthermore, geopolymer have many excellent properties such as resistance, low shrinkage, and high compressive strength [2]. Geopolymers were fabricated from fly ash which is a solid residue arising from coal burning thermal power stations. Thus, it is very beneficial in terms of environmental impacts [2]. The magnitude of linear attenuation coefficients depends on a number of factors that include incident photon energy, atomic number, and density of the shielding materials. Given that the linear attenuation coefficients depend on the density (ρ), it is expressed as a mass attenuation coefficient (μ/ρ) which is the linear attenuation coefficient per unit mass of the material [3].

Taking linear attenuation coefficients into consideration, Davidovits developed amorphous to semi-crystalline aluminosilicate inorganic polymers in the 1980s, now referred to as geopolymers. Geopolymers are inorganic cementitious binding gel formed from the polymeric reaction between an alumino silica rich material and an alkali metal hydroxide/silicate liquid, which can be used to encapsulate fine and coarse aggregates to produce concrete [4-8]. Davidovits [7] reported that geopolymers possess high early strength, enhanced durability and pose no danger. Fly ash based geopolymers have garnered interest since the 1990s because of their excellent performance when exposed to different acids with varying concentrations and exposure durations as well as their higher compressive strength [9].

Fly ash based geopolymer, a modified version of geopolymers, has improved adhesion properties and is denser than OPC. Geopolymers have reduced the emission of harmful gases, produced in manufacturing of OPC to a significant extent [10, 11]. Barium sulphte with the chemical formula (BaSO4), fly ash-based geopolymer has good properties that allow it to be used as the shield, adding other materials such as barium sulphate to fly ash-based geopolymer in order to increase density and improve the attenuation characteristics. Barium Sulphate BaSO4 is used in this work to test its ability in radiation absorption in order to make radiation protection by mixing Barium Sulphate with fly ash geopolymer mortar. [12]. The novelty of this work is related to the use of fly ash-based geopolymer as shielding material with 15% Barium Sulphate as a design shielding box .The measurement of the dose by calculating the mass attenuation coefficient using narrow beam geometry.

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2. METHODOLOGY

2.1 Am point radiation source to measure μ (linear attenuation coefficient).

In this work, the linear attenuation coefficient was measured via narrow beam geometry using a 241Am point source which possessed a PE peak at 59.54 keV. In this measurement, the (Io/I) of FAGP with (0, 5, 10, and 15%) of BaSO4 as a function of the thicknesses of samples. Furthermore, calculate the μ values from the slope of the figures for all samples.

2.2 The design shielding box as application of FAGP and investigation setup

2.2.1 Design shieling boxes preparation

The shielding box was designed from the 5cm thickness of FAGP with (0, 5, 10, and 15%) BaSO4 used for radiation protection at low energies. The shielding box was undergone evaluation by diagnostic X-ray.

The design-shielding boxes were fabricated using the Perspex layers as two different boxes, the first box is the internal box with a dimension of 20 cm, and the second box is the external box with a dimension of 30 cm figure 1.(a and b).

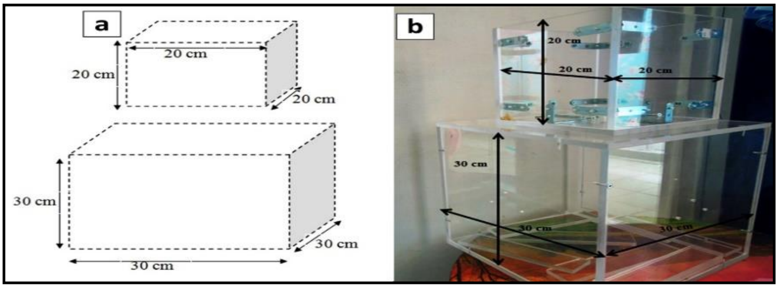

Figure 1 (a) Schematic drawing of Designed shielding box, (b) Image of actual Perspex box with its dimensions

When the internal box put inside the external box the distance between them is 5 cm for each side shown in figure 1 (a). This 5 cm distance was filled with the FAGP with (5, 10, and 15%) BaSO4. The internal and second boxes were detached from the material. The design shielding boxes were kept at room temperature until dry and then maintained at 60-70 ℃ for one day in the oven. After this, the design shielding boxes ready for investigation, as shown in(figure 2).

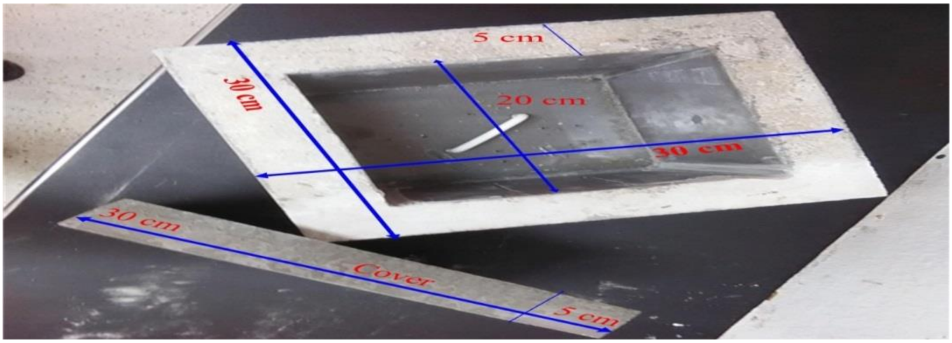

Figure (2) Design shielding box of FAGP with (0, 5, 10, and 15%) BaSO4 with the cover.

2.2.2 The design shielding boxes setup

The setup of this experiment established to investigate the performance ability of the design shielding box application for radiation attenuation. this set up consists of the x-ray as a radiation source, the distance between the source and the design shielding box is 100 cm, as the field size is 10 x10 cm. (Figure 3-a) the ion chamber put onto the box (without sample) while (Figure 3-b) the ion chamber was put inside the design-shielding box (with a sample) at 80kV. Five design shielding boxes were fabricated from FAGP with different percentages of BaSO4 (0, 5, 10, and 15%) and underwent radiation dose calculated by using Equation (1).

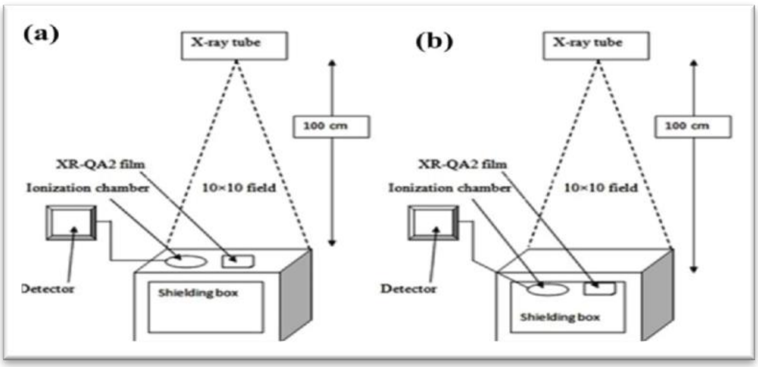

Figure (3) Setup X-ray experiment and calculate the dose radiation by ion chamber.

$$D_{air} = \frac{Q}{m_{air}} \left[\frac{W_{air}}{e} \right] (1)$$

where Q is charge and air of mass (mair) is related to absorbed dose (Wair/e) is the mean energy required to produce an ion pair in air per unit charge (the current value for dry air is 33.97 eV/ion pair or 33.97 J/C), with ρair = 1.25x10-3 g/cm3, vair = 3.46 cm3, mair = ρ x v = 4.33 x 10-6 kg.

3. RESULTS AND DISCUSSION

*3.1 The attenuation measurement of FAGP with different **BaSO4***percentages

The results show for the particular thickness, radiation attenuation increase with increasing the percentages of BaSO4 in FAGP shield (Figure 4). The effect of increasing the percentages of BaSO4 in FAGP was evaluated by fabricating various FAGP shields with (0, 5, 10, and 15%) percentages of BaSO4 and then evaluating their attenuation by narrow beam geometry. The results show that μ value increases with increasing BaSO4 percentages in FAGP shields (0, 5,10, and 15%) to obtain an attenuation of (0.598, 0.766, 1.02, and 1.21) respectively. Thus, FAGP with 15% of BaSO4 exhibited the best μ for all thicknesses. This phenomenon can attribute to the fact that the Zeff of shield material increased with the increase of BaSO4 percentage in FAGP shields, which increase the attenuation.

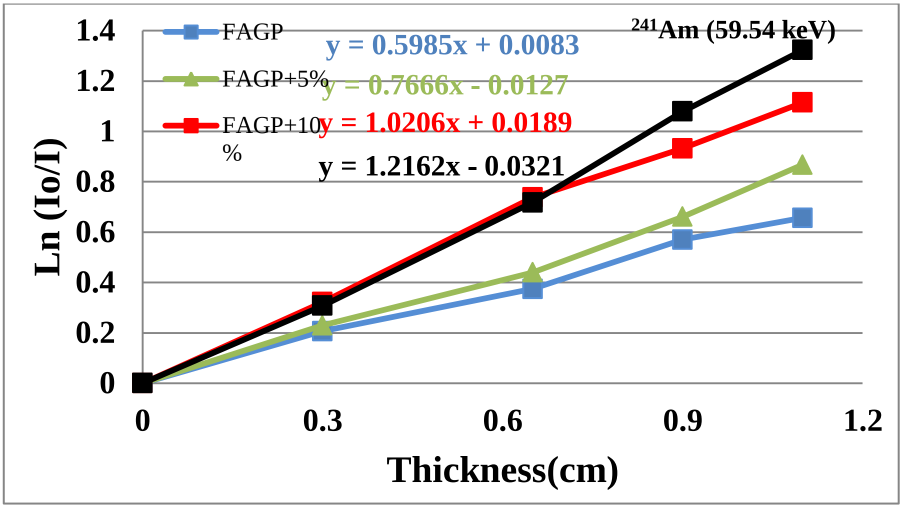

Figure (0) The μ for FAGP with (0, 5, 10 and 15%) of BaSO4

This varying steepness of slope can be attributed to the increase in shield attenuation value which recorded between 0.656 and 1.365 due to the addition of 15% of BaSO4 in the FAGP shield at 1.1cm thick. Furthermore, the linearity of the plot of radiation attenuation against shield thickness (R2) increased from 0.9944 and reached 0.9985 with increasing the percentages of BaSO4 in the FAGP from 0% to 15% which hint at more correlation between the result points. In summary, the addition of BaSO4 to the FAGP shield improves its radiation attenuation capability.

The Zeff of the samples calculated from the Equation (2)

$$Z_{eff} = [a_1 Z_1^{2.94} + a_2 Z_2^{2.94} + \cdots + a_n Z_n^{2.94}]^{\frac{1}{2.94}} \quad (2)$$

As shows in (Figure 5) the FAGP with 5% BaSO4 is better than FAGP in μ 0.7666, 0.5995 cm-1 respectively, because it's Zeff is higher than FAGP 15.355, 12.903 respectively, now after adding more BaSO4 to FAGP the Zeff start to increase with 10 and 15% which increases the Zeff of FAGP, in turn, increase the μ. In other words, FAGP is an effective material can be used in shielding after improvement with 15% BaSO4 to achieve a 1.2162cm-1 linear attenuation coefficient.

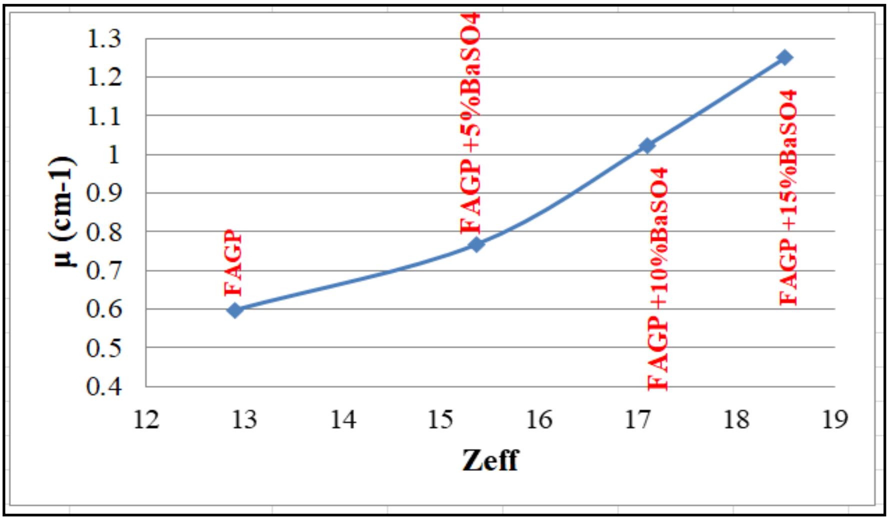

Figure (5) the relation between μ and Zeff

This work stopped the addition of BaSO4 at 15% because this ratio added to the FAGP make it is effective to decrease the radiation dose to 0.4 μGy. This happened because the FAGP has become a high effective atomic number value after adding 15% BaSO4.

3.2 Design shielding box radiation dose

Next, we study the design shielding boxes' performance and the ability to protect the radiation at 60kV of diagnostic x-ray. Four boxes of FAGP with (0, 5, 10, and 15%) BaSO4 have been fabricated and evaluated. As it is shown in (figure 6) that the radiation was decreased from 11.75-9.33 μGy with the FAGP shielding box without BaSO4. As the radiation was decreased to the value of 5.2 μGy with the FAGP and 5% BaSO4 shielding .

box. The 10%BaSO4 in the third shielding box decreased the radiation to 2.08 μGy, as the radiation decreased to 0.4 μGy with the fourth shielding box fabricated from FAGP with 15% BaSO4 which hint at the best resultrecorded in this investigation for the design shielding box application.

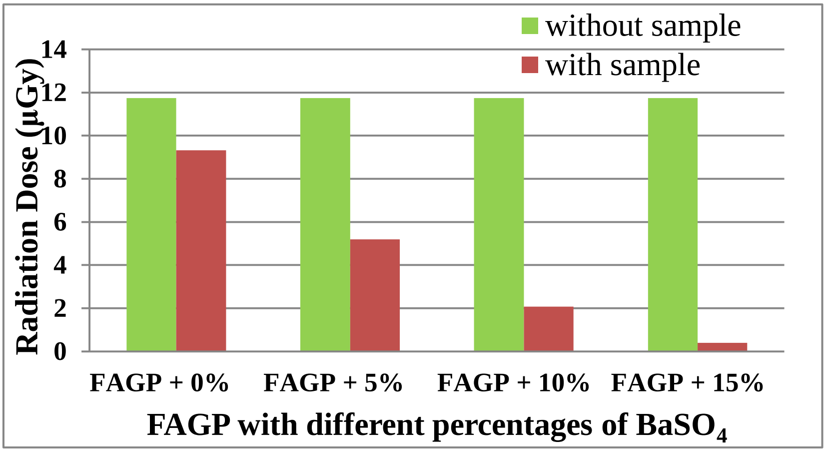

Figure (6) FAGP with different percentages of BaSO4 as a function in radiation dose

4. CONCLUSION

This work concluded that FAGP as a waste material can be converted into a useful shielding material. This can be achieved when barium sulphite is added to FAGP, because barium sulphate is a high-density material 4.5 g/cm3 that increases the value of the effective atomic number (Zeff) of the material, making the mixture attenuate the radiation passing through it. This study demonstrated that the FAGP with 15% Barium sulphate as an additive material increases the linear attenuation coefficient from 0.6 to 1.2162. This value is sufficient to attenuate the radiation at 60 kV (the energy used in most of diagnostic radiations). Here, this study provides evidences that the usage of the novel mixture in future could reduce the impact of radiation on workers in the radiology departments.

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