Analysis of Absorption Properties of a Composite FlyAsh and Fe$_2$O$_3$ for X-ray Radiation Shielding Applications

M A Budiawan$^1$, S Suryani$^2$, B Abdullah$^3$, D Tahir$^4$

Department of physics, Hasanuddin University, Makassar, 90245 Indonesia

*Email: suryani@fmipa.unhas.ac.id

Abstract. X-ray radiation shielding materials are generally made of lead. The inconvenience of using lead is heavy and expensive. Therefore, research has been conducted on X-ray radiation shielding materials made from a mixture of fly ash and Fe$_2$O$_3$, which is lighter, and cheaper, because the material is easily obtained. The results showed that radiation shielding material made from a mixture of fly ash and Fe$_2$O$_3$ had good X-ray radiation energy absorption for material thickness of 2 cm and for low X-ray radiation energy.

1. Introduction

X-ray is one of the radiation which has the ability to ionize like gamma and ultraviolet radiation. X-rays have a frequency region of $3 \times 10^{16}$ Hz to $3 \times 10^{19}$ Hz, so X-rays have energy from 100 eV to 100 KeV. The use of X-rays in the health sector is a necessity, therefore X-ray instruments can be found in hospitals to private clinics. The extent of the use of X-ray instruments starting from conventional X-ray instruments, CT scan which is used for examination of the limbs, and X-rays which is used for dental examinations. That is why, it certainly requires good protection to keep the exposure dose of X-ray radiation to public remains low.

Various kinds of materials are used to minimize X-rays exposure, and lead is the best radiation shielding material, because lead which has density of 11.34 g / cm$^3$ can absorb all X-rays energy with a power of 100 keV only with a thickness of 2 mm [1]. Other materials that can also absorb X-rays radiation with the same ability as lead with a thickness of 2 mm are concrete with a thickness of 15 cm and a brick with a thickness of 25 cm [2], combined of sodium pentaborate and barium sulfate [3]. Another X-rays radiation shield used as an apron is made from a cotton cloth coated with silicone rubber consisting of a mixture of tungsten, bismuth or barium sulfate powder with the same heavy fraction [4]. Even in 2016 a study was conducted by Seon Chil Kim who combined barium sulfate with silicone fluids to form an apron, and the result showed that the apron had the ability to absorb the same energy with lead, but the weight of the apron was only one-fifth of lead apron [5]. Actually, X-rays radiation shields on the market today, usually made from a mixture of lead that is quite heavy, or glass fiber which is quite expensive, so it is necessary to obtain a cheap and easily obtained shielding material.

Material that is easily obtained, because this material is a waste that can pollute the environment is fly ash. Fly ash is residual combustion of coal, which contains silica or silica + alumina compounds. In a very fine form, fly ash can react with calcium hydroxide (at sufficient humidity and room temperature) to form a material that has binding or solid. The binding properties of the fly ash are then used as additives in concrete mixtures and cement making mixtures. Fly ash generally has the form of solid, round, or round hollow particles, or round particles that contain other smaller round particles. solid, round, or round hollow particles, or round particles that contain other smaller round particles.
material has a size that varies from less than 1 μm to more than 100 μm (some literature mentions a size of 0.5 μm - 300 μm), but mostly we find less than 20 μm [6]. Research about utilization of fly ash as a radiation shield material have been done by researchers from all over the world, for example a research was carried out by Harjinder Singh Mann et al in 2018, who made clay fly ash bricks as gamma-ray shielding materials [7], and Kanwaldeep et al tries to compare the use of a mixture of cement in concrete with a mixture of fly ash in concrete as a shielding materials for gamma-ray radiation [8].

Other material which is easily obtained in nature is iron. Iron does not exist in the form of atoms, but in the form of molecules consisting of oxygen and iron atoms which are bonded together, known as iron ore. Iron ore itself is usually obtained in the form of magnetite (Fe₃O₄), hematite (Fe₂O₃), goethite, limonite or siderite. Iron can be used as a mixture to form a radiation shield, while iron itself is not good to be used as a shield of X-rays radiation, because radiation shielding materials must have a large atomic number, such as lead.

The utilization of fly ash as a radiation shield without mixture is not good, because the form of fly ash which is round will form a cavity in its solid form. Therefore, a mixture is needed, so that the shielding material can be dense and not easily broken. In this study, a mixture of fly ash with (Fe₂O₃) was used, with the aim to obtain X-rays radiation shielding material that is cheap, easily found, not easily destroyed, and preserves the environment through the use of coal burning waste.

2. Material and Method

Fly Ash (FA) used in this study is fly ash with type C or has CaO concentration more than 20%. It is taken from the Jeneponto Steam Power Plant - Jeneponto Regency and Iron ore or Fe₂O₃ which has a grain size of 5-9 μm with a purity of 99.5%.

20 grams of fly ash is mixed with 0.20 grams of Fe₂O₃. The mixture is binded with an alkaline solution which is a mixture of Na₂O, SiO₂, NaOH, and H₂O. After the mixture has thickened and can be formed, the mixture is poured in containers of size (6 cm x 6 cm x 2 cm), (6 cm x 6 cm x 4 cm), and (6 cm x 6 cm x 6 cm), and heated at 70ºC for 1 hour and let it rest for 24 hours at 28ºC.

Radiation exposure to samples is carried out using Siemens X-rays instrument with the type of multimobile digital as a source of ionizing radiation. The detector used is Pen Dosimeter. The X-rays plane tube is set at a fixed voltage of 90 Kv, current of 32 and 40 mA, and the distance between focus and material is 100 cm, the Pen Dosimeter is placed under the object, the radiation area has size area of 25 cm x 25 cm. The exposure for each material which has a different thickness is then carried out by putting the center of the beam right at the center.

When light or radiation passes through the medium, we can observe a decrease in the intensity of light or transmitted radiation. This is because some of the intensity of light or radiation is absorbed by the medium. Radiation absorption by the medium follows the Lambert-Beer law, which can be written as:

\[ I = I_0 e^{-\mu x} \]  

with \( I_0 \) is the initial intensity, \( I \) is the intensity transmitted, \( x \) is the thickness of the medium, and \( \mu \) is the coefficient of absorption or attenuation.

The ability of reducing X-rays energy by radiation shielding material is presented by half value layer (HVL) parameter. The HVL parameter can be determined using the equation which can be written as:

\[ HVL = \frac{0.693}{\mu} \]
## 2.1 Result and Discussion

The sample is a mixture of fly ash with Fe$_2$O$_3$, with the same area of 36 cm$^2$, but different thicknesses are 2, 4 and 6 cm (Figure 1). Furthermore, the measurement of density was carried out, and we obtained 2.21 g / cm$^3$.

![Figure 1. Samples thickness of (1) 6 cm, (2) 4 cm, and (3) 2 cm.](image)

After sample is dry, the sample is then irradiated with X-rays. X-rays instrument is arranged to operate at a maximum electrical voltage of 90 kV and two electric current values of 32 mA and 40 mA. The rate of radiation dose coming out of the X-rays instrument was measured with the Pen Dosimeter detector was 930 µGy/s for a 32 mA electric current, and 931 µGy/s for a 40 mA electric current.

### Table 1. Sample characteristics at irradiation with currents of 32 mA.

| Samples | Thickness (cm) | Voltage (kV) | Current (mA) | Rate of radiation dose (µGy/s) | Rate of radiation dose transmitted (µGy/s) | Linear attenuation (cm$^{-1}$) | HVL (cm) |
|---------|----------------|--------------|--------------|-------------------------------|-------------------------------------------|-------------------------------|----------|
| 1       | 2              | 90           | 32           | 330                           | 135                                       | 0.518046                     | 1.34     |
| 2       | 4              | 90           | 32           | 930                           | 135                                       | 0.482477                     | 1.44     |
| 3       | 6              | 90           | 32           | 85                            | 135                                       | 0.398756                     | 1.74     |

Result did not show a significant difference in the rate of radiation dose in the setting of a low electric current with a higher one. The size of linear attenuation is calculated using the equation in the theory and linear attenuation values showed that there was an influence of medium thickness on attenuation values, where increasing thickness of the material decreases attenuation values or reduces the ability of the medium to absorb X-rays radiation.

### Table 2. Sample characteristics at irradiation with currents of 40 mA.

| Samples | Thickness (cm) | Voltage (kV) | Current (mA) | Rate of radiation dose (µGy/s) | Rate of radiation dose transmitted (µGy/s) | Linear attenuation (cm$^{-1}$) | HVL (cm) |
|---------|----------------|--------------|--------------|-------------------------------|-------------------------------------------|-------------------------------|----------|
| 1       | 2              | 90           | 40           | 412                           | 170                                       | 0.407618                     | 1.70     |
| 2       | 4              | 90           | 40           | 931                           | 170                                       | 0.425115                     | 1.63     |
| 3       | 6              | 90           | 40           | 105                           | 170                                       | 0.363716                     | 1.91     |

We also observed that the increase in X-rays energy which was in this research presented by the increase in electric current could reduce the ability of the medium to absorb X-rays radiation or material attenuation (Table 1 and 2) (Figure 2). This is due to the composition of the material can affect the interaction between the material and the photon, thus affecting the attenuation of the material. This was
also observed by Danial Salehi who found that the ability of soft tissue attenuation depends on the energy of the photons [9].

![Figure 2](image-url)

**Figure 2.** Material attenuation as a function of material thickness.

The ability of the material to absorb radiation energy is shown by the half value layer (HVL) parameter. The highest HVL is seen in high material thickness and for high X-rays radiation energy, whereas the lowest HVL value is found in materials with low material thickness and for low X-rays radiation energy. As a result the radiation shielding material that can absorb X-rays radiation energy is a material with a thickness of 2 cm for low radiation energy.

### 3. Conclusions

The best radiation shielding materials for X-rays radiation are materials with large atomic numbers, such as lead, but lead has a large density, so radiation shields which are made of lead will be heavy, and furthermore the price of lead is also expensive. To overcome this, research on the use of materials that are easily obtained in the environment is carried out and can also preserve the environment. The material is fly ash which is a waste and Fe₂O₃ which is easily obtained. The results showed that radiation shielding material which is a mixture of fly ash and Fe₂O₃ that can absorb X-rays radiation energy is a material with 2 cm thick for low radiation energy.

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