Absorption characteristics of composite ordinary portland cement (OPC)/Fe_2O_3/BaO X-ray shield applications

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Abstrak Composite materials for X-ray shield aplications have been synthesized used the ordinary portland cement (OPC) as matrix material and Fe_2O_3 and BaO as fillers material. There are four compositions of the (Fe_2O_3 + BaO); namely OFB 1 for 0%, OFB 2 for 5% , OFB 3 for 10%, and OFB 4 for 15%. The chemical composition of the composites were determined by X-ray fluorescence (XRF) spectroscopy and for structural properties determined by X-ray diffraction (XRD). For the absorption characteristics were determined by using mobile X-Ray and analysis the linear coefficient attenuation (μ), the half value layer (HVL), the tenth value layer (TVL), and the absorbed dose (S) for various of the tube voltage; 60 kV, 70 kV and 80 kV. The absorption dose was increase with increasing the amount of (Fe_2O_3 + BaO) as fillers at the same tube voltage, but decreasing the absorption dose for the tube voltage of radiation source increased. The best absorption dose is for composite OFB 4 on the source tube voltage of 60 kV with the value of μ, HVL, TVL and S are 0.32 mm^{-1}, 2.13 mm, 7.09 mm, and 99.85%, respectively.

1. Introduction

X-rays are ionizing radiation that has been used in various fields, one of which is in the field of medical imagingr [1,2]. X-rays can be used in the field of diagnostics and therapeutic processes to cure various diseases, but uncontrolled X-rays are very dangerous because they can damage of the tissue and even pose a risk of cancer [3,4]

Therefore, we needed a shield material for protection from the X-ray radiation. So far, lead is widely used as a radiation shield because it has a high density and atomic number. So lead is able to withstand of the radiation. However, lead is an expensive material and has toxic effects on human, animal and environmental health [5,6].

The research about the materials shield radiation has been developed by researchers as an lead replacement alternatives that have been used as commonly radiation shield aplications [7]. Researchers have been doing several studies to utilize cement as a construction material for radiation shied aplications by adding filler material such as iron. Because, iron is a material that are cheap, efficient and abundant in the nature. Iron material is widely studied to produce X-ray radiation shield material because it is based on research conducted by Abo-El-Enein et al. used the iron in a certain amount as a filler in cement can increase mechanical strength, thermal resistance and resistance to radiation [8]. The addition of iron to OPC can also reduce porosity and produce a more uniform microstructure [9].

In addition, research on the addition of barium is also widely studied by researchers as a radiation shield material. Barium is one of the important materials in the industrial field. Barium is a heavy metal carbonate that has thermodynamically stable crystals. Barium material can be used as a composite material because it has a good catalytic activity properties [10]. Research conducted by Ripin et al. utilizing barium material as a radiation-shield composite material shows that the addition of barium is effective as a shield of X-ray radiation. X-ray attenuation obtained in samples not using barium is only 46.2%. However, after the addition of 50 wt% barium materials, X-ray attenuation increase to 99.11% at 70 kV tube voltage [11].

Therefore, we conducted research using materials Fe_2O_3 and BaO as filler materials in Ordinary Portland Cement of x-ray radiation shield for the building construction applications. This research is to produce construction materials that are resistant to radiation, so that the composite material can be used as construction materials for special buildings such as in hospital for radiology room.

2. Research methods

2.1. Material synthesis

This research is a laboratory experiment to produce building construction composite materials which can be applied as X-ray radiation shields. The process of sample synthesis have been doing by the blending method using OPC as a matrix and powder of Fe_2O_3 and BaO as fillers material.

Samples of OFB composites synthesized by four different compositions with the sizes of each samples is 6 cm x 6 cm x 2 cm. each composition materials of samples is presented in Table 1. The first step on sample synthesis each of samples is prepared the tools and materials needed. Then the second weigh OPC powder, Fe_2O_3 powder and BaO powder according to the predetermined composition. Third, Mixing Fe_2O_3, BaO and OPC materials using macine blender until homogeneous. Fourth, form OFB composite paste by adding water to the mixture of materials. Fifth, the OFB composite paste is inserted into the mold and stored at room temperature for 24 hours. Sixth, the sample is removed from the mold and left at room temperature for 28 days. Seventh, do the XRF and XRD characterization was performed on each sample that was synthesized, density measurement and testing mobile X-Ray.

Table 1. Composition of matrix materials and fillers used to synthesize each of OFB composite.

Material Powder (Weight %)			
Samples	OPC	Fe_2O_3	BaO
OFB 1	100	0	0
OFB 2	95	2.5	2.5
OFB 3	90	5	5
OFB 4	85	7.5	7.5

2.2. X-Ray Fluorescence Characterization (XRF)

XRF characterization had been doing to analyze the chemical components contained in the matrix and filler material used on composite and each sample that was synthesized.

2.3. X-Ray diffraction Characterization (XRD)

The characterization of XRD aims to analyze the phases criystal of the matrix material and filler material and each sample that has been synthesized with the angular range $30^o \leq 2\Theta \leq 70^o$. XRD characterization performed used XRD Shimadzu 7000 with cu kα of radiation ($\lambda = 1.5405$ Å).

2.4. Measurement of Density

This measurement is performed to determine the density of each sample. This test is done by

determining the mass and volume of each sample, then analyzed using the equation (1) [12]:

$$\rho = \frac{m}{V} \quad (1)$$

Where:

ρ = Density (gr/cm^2)
m = mass (gr)
v = volume (cm^3)

2.5. The Mobile X-Ray Testing

Mobile X-Ray testing was carried out to analyze the absorption of each sample against radiation given at the source tube voltage of 60 kV, 70 kV and 80 kV. The measured value in this study are the intensity of the radiation exposure dose and the intensity of the dose transmitted after the application of each sample. This value are used to determine μ (mm^{-1}), HVL (mm) dan TVL (mm) and the absorbed dose of the x-ray radiation given for each sample.

Mobile X-ray testing was conducted in the Mobile X-Ray laboratory at the Makassar Health Facilities Management Agency. The process of testing each sample are done by placed the test sample on a radiation detector that is perpendicular to the source of radiation at a distance of 1 m. The process can be seen in Figure 1.

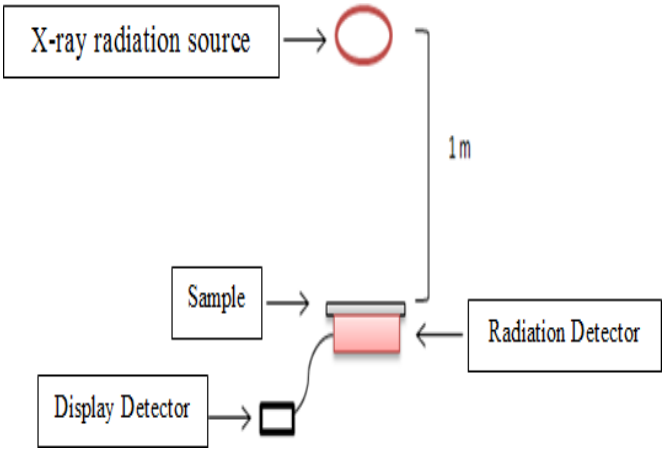

Figure 1. Schematic diagram of the characterization system in this study for determining the absorption characteristics by using the mobile X-ray testing

According to Florez et al. value of the μ (mm^{-1}), HVL (mm) dan TVL (mm) can be determined using equations Lambert-Beer's 2, 3 and 4 [13]:
1. The linear Coefficient attenuation ( ) can be determined by using equation (2):

$$\mu(E) = -\frac{1}{n} ln\left(\frac{I_x(E)}{I_0(E)}\right) \quad (2)$$

Where, I_x is the intensity of the dose of radiation exposure and I_o is the intensity of the dose transmitted. The intensity of exposure to the radiation dose is determined before the application of the radiation shield sample.

2. The half value layer (HVL) dan the ten value layer (TVL), are the thickness of the material needed to reduce the intensity of radiation exposure given by 50% and 90%, respectively. HVL and TVL

values can be determined according to the following equation (3) and (4):

$$HVL = \frac{0.693}{\mu} \quad (3)$$

$$TVL = \frac{2.303}{\mu} \quad (4)$$

The absorbed dose of X-ray radiation (S) given to each sample was analyzed using the equations (5) [7]:

$$S = \frac{I_x - I_0}{I_x} \times 100\% \quad (5)$$

3. Results and Discussion

3.1. The XRF Characterization Results

The data obtained from the XRF characterization results show that the chemical components of the material fillers used are Fe_2O_3 and BaO which have purities of 97.13 and 99.03 respectively. OFB 1 samples synthesized with 100 wt% OPC contained chemical component CaO, SiO_2, SO_3, Fe_2O_3, TiO_2 and LOI which can be seen in Table 2. The results obtained correspond to wt% of the matrix material and fillers used to synthesize the sample. The chemical component derived from OPC was seen to decrease with the decrease in the composition of wt% material OPC in the sample and the chemical component derived from material fillers increased with the increase in the amount of wt% fillers material in the sample presented in table 1 earlier.

Tabel 2. The chemical composition by using XRF composite in this study (OFB1, OFB2, OFB3, and OFB4). We have included the composition of BaO and Fe_2O_3 for comparison.

Chemical	**Fe_2O_3**	**BaO**	**OFB 1**	**OFB 2**	**OFB 3**	**OFB 4**
Fe_2O_3	97.13	99.03	4.4	9.04	14.95	18.99
MnO	2.12	-	-	-	-	-
BaO	-	-	-	3.08	6.63	11.67
CaO	-	-	68.25	62.46	55.35	49.95
SiO_2	-	-	20.09	18.39	16.84	14.2
SO_3	-	-	5.78	5.61	5.02	4.1
TiO_2	-	-	1.32	1.28	1.06	0.97
LOI	0.75	0.97	0.16	0.14	0.15	0.12

3.2. The XRD Characterization Results

Figure 2 is the graph of the XRD data analysis results of each OFB samples that have been synthesized and the fillers. Graph (a) OFB 1 is a sample synthesized using 100 wt% OPC, the graph shows that the crystalline phase of Fe_2O_3 has been seen at the angle of 2 theta around 34°-35°. This is consistent with the characterization XRF results presented in Table 2, the OPC material used as matris already contain chemical components Fe_2O_3. the crystalline phase formed between samples (b) OFB 2, (c) OFB 3 still looks the same as the crystal phase OFB 1, the forerunner to the formation of the BaO crystalline phase has begun to form but has not been clearly seen at the addition of BaO of 2.5 wt% and 5 wt% respectively. The crystalline phases of Fe_2O_3 and BaO were clearly formed in sample (d) OFB 4 with the use of Fe_2O_3 and BaO filler materials a number of 7.5 wt% respectively in composite samples. The BaO crystal phase is seen at the angle of 2 theta around 49° - 50° and 66°-67°.

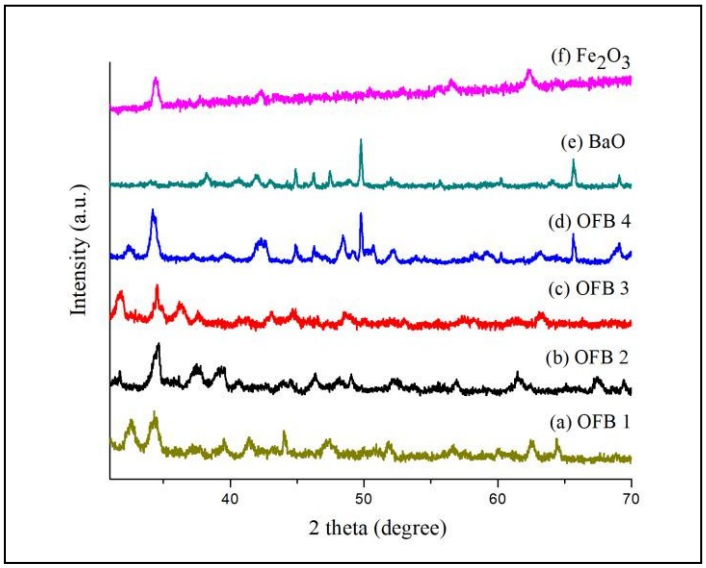

Figure 2. The XRD spectra of composite in this study for OFB1, OFB2, OFB3, and OFB4. We have included the XRD spectra of BaO and Fe_2O_3 for comparison.

3.3. Density Measurement Results

The results of density measurement (gr/cm^3) of each OFB composites sample are presented in Figure 2. The data shows that the addition of Fe_2O_3 and BaO material can increase the density value of the sample, the density value increases with the increase in wt% of Fe_2O_3 and BaO material on the mortar ordinary portland cement. The maximum density value is obtained in OFB 4 sample, the composition of sampel OPC: Fe_2O_3: BaO are 85 wt% : 7.5 wt% : 7.5 wt% respectively. This is in accordance with the Ling et al. which states that increasing the atomic weight of the filler material used in the material can increase the density of the sample as we expected [14].

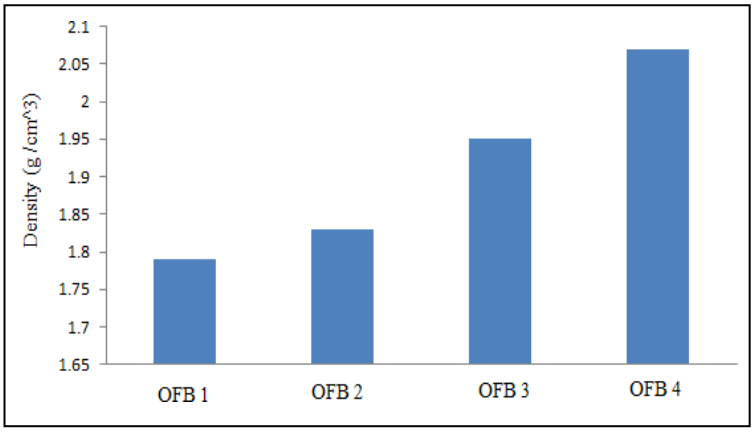

Figure 3. Density of each samples in this study determined by the equation (1).

3.4. The Testing Mobile X-Ray Reault

The value of μ is the coefficient used to determine HFL and TVL. Based on the results of the study, the value of μ obtained increased when wt% filler material Fe_2O_3 and BaO were given an increase in source tube voltage of the X-ray radiation that was given the same for each sample. However, the μ value of each sample decreases when the given tube voltage increases. The maximum μ value obtained in OFB 4 samples at each source tube voltage used, it is the use the composition of OPC : Fe_2O_3 :

$BaCO_3$ are 85 wt %: 7.5 wt% : 7.5 wt% respectively at the tube voltage 60 kV. The μ value is inversely proportional to the HVL and TVL values. The greater of the μ value will produce the HVL value and the smaller TVL, it shows that the quality of the material is getting better [13]. This is consistent with the data obtained in this study. The HVL and TVL values obtained in Figure 3 (b) and (c), appear to decrease with the increase in wt% filler material Fe_2O_3 and BaO are given. The maximum HVL and TVL values in OFB 1 sample are samples synthesized using 100 wt% OPC material without the addition of filler material Fe_2O_3 and BaO and the minimum HVL and TVL values in the OFB 4 sample. This shows that an increase in wt% filler material in the OPC matrix contributes well to absorption the X-ray radiation.

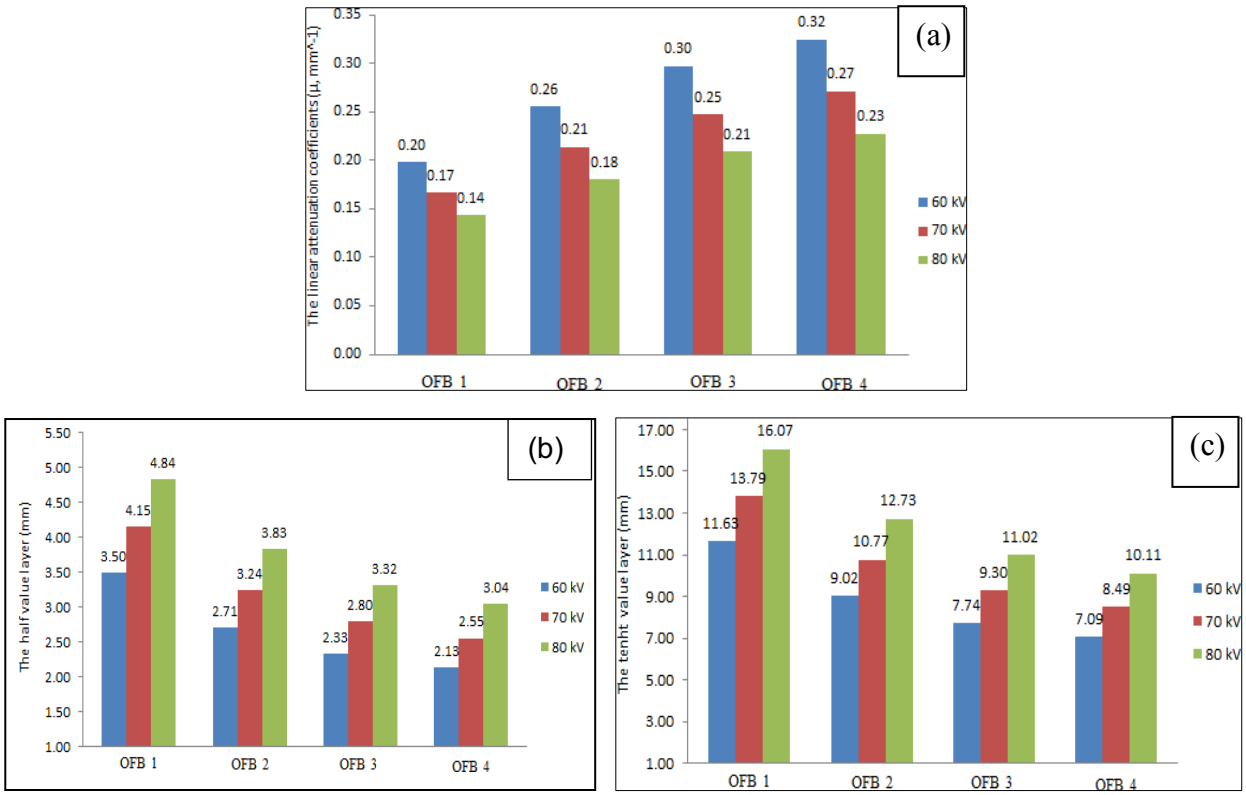

Figure 4. (a) The linear coefficient attenuation (μ), (b) the half value layer (HVL) dan (c) the tenht value layer (TVL) for various tube voltage (60 kV, 70 kV, and 80 kV).

The absorbed dose of X-Ray radiation using a mobile X-Ray presented in Figure 4 show that, ordinary portland cement material with a thickness of 20 mm was able to absorbed radiation of 98.10% at a tube voltage of 60 kV. However, if the tube voltage increase, the ability to absorbed of the X-ray radiation is decrease. The addition of Fe_2O_3 and BaO as a fillers material to ordinary portland cement matrix shows positive results. The ability to absorbed of X-ray radiation increases with an increase in wt% of the Fe_2O_3 and BaO fillers material in each sample with the same tube voltage. In addition, the effect of an increase in tube voltage from 60 kV, 70 kV to 80 kV was seen to be getting smaller in each sample with an increase in wt% Fe_2O_3 and BaO filler material on the samples. The maximum absorbed dose of X-Ray radiation value obtained in OFB4 samples at each tube range 60 kV, 70 kV and 80 kV that are equal to 99.85%, 99.56% and 98.95 respectively. This value is in accordance with the assessment made by Ripin et al. which synthesizes kaolin and barite based composites by 50% each at a thickness of 5 mm that is 99.11% at 70 kV tube voltage [11].

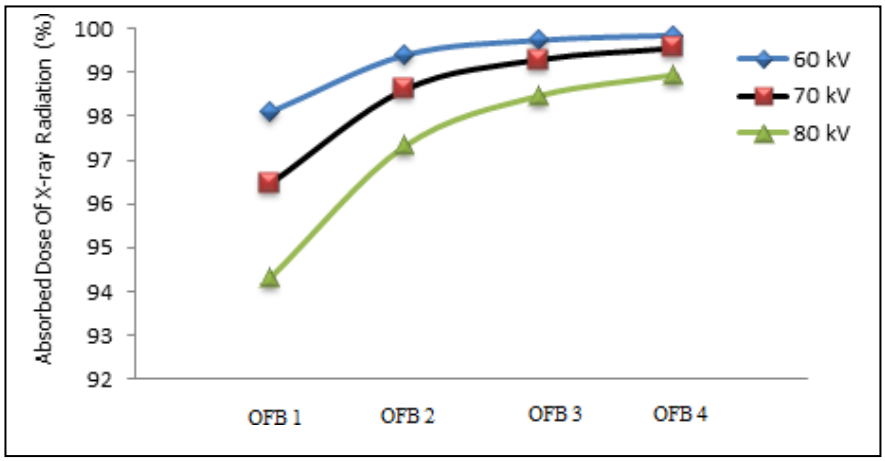

Figure 5. The Absorbed Dose Of X-ray Radiation (%)

4. Conclusion

The XRF characterization results showed that the material fillers used were Fe_2O_3 and BaO which had purities of 97.13 and 99.03, respectively. The matrix material OPC contains chemical components of kimia CaO, SiO_2, SO_3, Fe_2O_3 and TiO_2. The results of XRD characterization showed that the best OFB sample was OFB 4, the sample had clearly seen the formation of Fe_2O_3 and BaO crystalline phases used as filler material in the OPC matrix material. The addition of material fillers in OFB composite samples can increase the density of the sample. In addition, the value of μ obtained increases when the use of filler material increases in the sample at the same tube voltage. However, the μ value of each sample shows a decrease when the tube voltage of the X-ray radiation source given increases. This is in accordance with the HVL and TVL values obtained, the HVL and TVL values obtained are getting smaller with increasing use of wt% matrial fillers in composite OFB samples, but it appears to increase when the tube voltage of the X-ray source radiation given increases. the mobile X ray test results show that the greater the amount of wt% material fillers in the sample, the ability to absorb radiation given to each tube voltage increases. The maximum absorbed dose of X-ray radiation value obtained in OFB 4 sample at tube voltage of 60 kV is 99.85%.

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