Composites Based Ordinary Portland Cement and Fe$_2$O$_3$ for X-Ray Shield Applications

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**Abstract.** The shielding material of X-Ray has been synthesized from Ordinary Portland Cement (OPC) as a matrix and Fe$_2$O$_3$ (FE) as a filler by four different composition are A1, A2, A3 and A4 for 0 wt%, 5 wt%, 10 wt% and 15 wt% of Fe$_2$O$_3$, respectively. The matrix and filler materials are characterized using X-Ray Fluorescence (XRF). For OPC-FE composites were characterized using X-Ray Diffraction (XRD) and Mobile X-ray with tube voltages are 63 kV & 73 kV and 85 kV for each samples to analyze the absorption characteristics. The results obtained showed that the dose reduction of X-Ray radiation increases with increasing wt% of FE, but decreased with increasing tube voltage. The best results were obtained on A4 samples when the tube voltage is 63 kV, the value of $\mu$ is 0.22 mm$^{-1}$, HVL is 3.12 mm, and the absorption from the X-Ray radiation source is 98.82%.

1. **Introduction**

X-Rays were used extensively in various fields, one of them in the field of medical imaging [1]. The use of X-Rays in medical imaging are used in the radiology department for diagnose the internal parts of the human body [2]. The results of the study in Azadi-Duhok Hospital, Emergency-Duhok and dobam-sumial shows that the radiology field in examining the inside of the abdomen, pelvic chest, cervix and skull is 60 kV - 83 kV of used X-Ray tube voltage [3]. In radiology department is needed a special room for protection of emission of X-Ray radiation which can cause damage of human organs, X-Rays also can change DNA, and trigger cancer risk [4],[5].

Therefore, we need materials for infrastructure building in radiology department which can be able as X-Ray shielding. In general, the material used for radiation protection is lead (Pb), but Pb is classified as expensive material and has a toxic effect in the environment and the human health [6]. Iron material has been studied as reported in Ref, [7] for alternative radiation protector due to availability and relatively cheaper. In addition of Fe$_2$O$_3$ can increase compressive strength, thermal resistance and radiation resistance on material [8]. Based on several previous studies, we used Fe$_2$O$_3$ as a filler on the Ordinary Portland Cement (OPC) matrix to synthesize materials for shielding X-Ray radiation. This research is expected to be able to produce materials that can be used as special for radiology department in development of new building infrastructure.

2. **Research Methods**

2.1 Material synthesis

In this study we used matrix OPC and commercial material Fe$_2$O$_3$ as filler, then used the water as solvent to synthesized OPC-FE composites for X-Ray Shield Applications. OPC-FE composite synthesized on four different variation types of compositions: A1, A2, A3 and A4. The sample composition used can be seen in the table 1. Each of samples are synthesized in several stages. The first, mixing the powder of OPC and Fe$_2$O$_3$ in a container and stirring for 30 minutes. Second, a mixture powder of OPC and Fe$_2$O$_3$ which has been mixed well is added with water then stirred for 15 minutes to form paste. Third, the paste that has been formed is inserted into the mold measuring 6 cm x 6 cm x 2 cm, then left at room temperature for 24 hours. Fourth, each of samples are removed from the mold and placed at room temperature for 28 days. Then the fifth, the samples were characterized using XRD and tested using mobile X-Ray.
Table 1. Composition material OPC and Fe$_2$O$_3$

| Sample | Material powder (weight %) |
|--------|---------------------------|
|        | OPC | Fe$_2$O$_3$ |
| A1     | 100 | 0           |
| A2     | 95  | 5           |
| A3     | 90  | 10          |
| A4     | 85  | 15          |

2.3 Characterization microstructure of OPC-FE composite
The XRF characterization had been doing to determine the chemicals components of OPC and Fe$_2$O$_3$ materials. While the XRD characterization had been doing by using Shimadzu 7000 X Ray diffraction with wavelength 1.5405 Å in the angle range 20° - 70° to determine the crystal phase of each samples.

2.4 Mobile X Ray Testing
Mobile X-Ray testing used to determine the linear attenuation (µ), the half value layer (HVL) and the dose reduce of X-Ray radiation for each samples. The testing process using the Mobile X-Ray from the hall security of health facility makassar. The sample tested is placed perpendicular to the radiation source as far as 1 m, at the tube voltage of 63, kV, 73 kV and 85 kV. The process can be seen in Figure 1.

The measurement results obtained from mobile X-Ray are the intensity of the radiation exposure dose from the radiation source and the intensity of the radiation transmitted after the application of A1, A2, A3 and A4 samples. The linear attenuation (µ) and the half value layer (HVL) are determined using lambert-Beer equation (1) and (2) [9]:

\[ \mu(E) = -\frac{1}{x} \ln \left( \frac{I_x(E)}{I_o(E)} \right) \]  

(1)

and

\[ \text{HVL} = \frac{0.693}{\mu} \]  

(2)

The percentage dose reduction of X-Ray radiation are determined using the following equation (3) [9]:

\[ S = \frac{I_0 - I_x}{I_0} \times 100 \% \]  

(3)
Where $I_x$ is the intensity of the radiation exposure dose and $I_0$, is the intensity of the dose transmitted.

3. Results and Discussion

3.1 XRF Characterization Results

The XRF characterization is used to analyze the chemical components contained in the matrix and filler. The results of material characterization are presented in table 2. Which shows that OPC is dominated by CaO and SiO$_2$. Besides that it also contains Fe$_2$O$_3$ of 4.65 wt%. While the filler material used is a material of Fe$_2$O$_3$ with a purity of 97.28%.

Table 2. The Result of Characterization of XRF Ordinary Portland Cement and Commercial Materials of Fe$_2$O$_3$

| Chemical  | OPC (Wt %) | Fe$_2$O$_3$ (Wt %) |
|-----------|------------|---------------------|
| CaO       | 71.92      | -                   |
| SiO$_2$   | 22.97      | -                   |
| Fe$_2$O$_3$ | 4.65      | 97.28               |
| MnO       | -          | 2.15                |
| LOI       | 0.46       | 0.57                |
| Total     | 100        | 100                 |

3.2 XRD Characterization Results

The results of XRD characterization of filler material, A1, A2, A3 and A4 samples can be seen in Figure 2. The figure shows that the crystal phase of Fe$_2$O$_3$ is seen at the angle of 2 theta around $43^0 - 44^0$ and $64^0 - 65^0$, while the crystalline phase of 100wt% OPC cement (A1) is seen at the angle of 2 theta around $28^0 - 34^0$. The crystalline phase in A2 and A3 samples is still the same as the A1 sample, besides that the crystal phase for Fe$_2$O$_3$ material has not been formed. A4 sample shows that the OPC and Fe$_2$O$_3$ material has reacted well, it can be seen that the cement phase at the angle of 2 theta around $280 - 340$ is reduced and the crystalline phase is formed at an angle of 2 theta around $43^0 - 44^0$ and $64^0 - 65^0$.

![Figure 2. The results of XRD characterization](image)

3.3 Mobile X-Ray Test Results

The linear coefficient attenuation ($\mu$) in each sample appears to increase with the addition of Fe$_2$O$_3$ at the same tube voltage. However, the value of $\mu$ decreases as the voltage of the mobile X-Ray tube increases. This can be shown in figure 3. The value $\mu$ is used to determine The Half Value Layer (HVL). The greater the value of $\mu$, give the smaller the value of HVL to be obtained. HVL is the
thickness needed to reduce 50% of the radiation given [8]. So the smaller of the HVL value obtained, the better the quality of the material for a shield radiation. The Half Value Layer (HVL) obtained for A1, A2, A3 and A4 samples is shown in Figure 4. The HVL value decreases with increasing weight percentage of Fe₂O₃ on the same mobile X-Ray tube voltage. However, it increases as the tube voltage increases.

Figure 4 is the result of X-Ray reduction. The figure shows the X-Ray radiation reduction dose for the use of A1, A2, A3 and A4 materials on 3 tube voltages of mobile X-Ray used. The X-Ray radiation reduction dose obtained increases with increasing addition weight percentage of Fe₂O₃ at the same tube voltage. However, it decreases when the given tube voltage of mobile X-Ray increases. This shows that the material is efficiently used at low tube voltages. Dose reduction of X-Ray radiation the maximum obtained on the A4 sample is the tube voltage 63 kV = 98.82%, 97.63% = 73 kV and 85 kV = 95.76%. The test results have approached the maximum value obtained in testing kaolin derived mullite-barites ceramic samples. The maximum dose reduction of X-Ray radiation obtained in the composition of 50wt% barite and 50wt% kaolin samples with a sample thickness of 5 mm which reached 99.11% [10].

4. Conclusion

OPC-FE composites for shielding of X-Ray have been studied with 4 types of samples; A1, A2, A3 and A4. However, the XRD characterization results show that the reaction between OPC and Fe₂O₃ is only seen well in the A4 sample, with the addition of 15 wt% Fe₂O₃. The results of the mobile X-Ray test also shows that dose reduction of the X-Ray radiation increased with increasing addition weight percentage of Fe₂O₃. Then, the dose reduction of X-Ray radiation of each sample decreases when the given tube voltage increases. The dose reduction value maximum of X-Ray radiation is obtained in the A4 sample with a tube voltage of 63 kV, which is equal to 98.82%.
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