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Gamma-Ray radiation attenuated by barium sulfate–cement barrier

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ABSTRACT

The new shielding using a mixed of Barium Sulfate ($BaSO_4$) and cement accordingly to the ratio that desired which is from (1:99) to (20:80) respectively. The samples were in thickness of 1 mm, 5 mm and 10 mm with the ratio of $BaSO_4$ are 0, 5, 10, 15, and 20%.The samples are examined with XRD. The mixture ratio of barium sulfate that has 20% in the sample shows that the absorption of the energy is high. A high mass density material of sample as barium, which has high atomic number is suitable to absorb the energy of radiation. Increasing the material density leads to increase the attenuation. The results have shown a significant protection for hazardous of gamma ray.

Introduction

The Radiography is one of the non destructive testing techniques. Basically γ-ray is same as visible light rays. Both are carried by particles called photons in a wavelike form of electromagnetic energy. The energy level of the individual photons makes the difference between γ-rays and visible light rays. The movements of electrons in atoms produce visible light photons and γ-ray photons. Electrons occupy different energy levels or orbital, around an atom's nucleus [1]. Electron needs to release some energy and releases the extra energy in the form of a photon when it drops to a lower level. The energy of the photon depends on different energy between two levels. When a photon collides with another atom, the atom may absorb the photon's energy by boosting an electron to a higher level [2]. Γ-ray photon works to separate the electron from the atom, and the rest sends the electron flying through space. A larger atom is more likely to absorb a γ-ray photon in this way, because larger atoms have greater energy differences. When γ-ray photons collide with matter, the oscillating electric field of the radiation causes the charged particles of the object to oscillate with the same frequency as the incident radiation. Each oscillating dipole returns to a less energetic state by emitting an electromagnetic photon that can, in general, travel in any outward direction. The process is known as coherent scattering [3]. Radiography is a technique that use of highly penetrating, invisible, short wavelength electromagnetic radiation to nondestructively obtain an image of hidden details of a sample [4]. A γ -ray tube in laboratory equipment generates the radiation and penetrates through the sample of interest and it is attenuated depending on structure, density and thickness of materials. A higher signal produces by areas where more radiation is transmitted (light elements, thin sections) or a darker area on the film. Radiography basically involves the projection and penetration of radiation energy through the sample being inspected [5]. The radiation energy is absorbed uniformly by the material or component being inspected except where variations in thickness or density occur. The unabsorbed energy is passed through to a sensing medium that captures an image of the radiation pattern. The uniform absorption and any deviations in uniformity are subsequently captured on the sensing material and indicate the potential presence of a discontinuity.

The penetration and the resulting contrast of a specific object or structure in the body generally depend on the photon energy spectrum. The penetration through the body section to being imaged is affected by the spectrum. It has a significant effect on the radiation dose. As the penetration through a body section is reduced, the amount of radiation required from the γ-ray tube is increased with a resulting increase in x-ray tube heating. Gamma-ray has been used to characterize the samples, in this work.

Sample Preparation

The main material, cement, barium sulfate ($BaSO_4$) and water mixture were used to create the sample. Cement is a complex mixture; Portland cement which is the type commonly used for buildings. All the materials were mix together with certain ratio between cement and barium sulfate with the amount of water are the same in every mixture. The ratio of cement and barium sulfate is in every mixture, there will be 1% to 20% of barium sulfate in cement which will be (1:99) and (20:80).

Results and Discussion

XRD Test data

The highlight is the maximum intensity where the spacing is 3.45 and 2.04. The angle is 25.136 and 44.37 respectively. The hkl is 110 for the 3.54 spacing and 211 for 2.04 spacing.

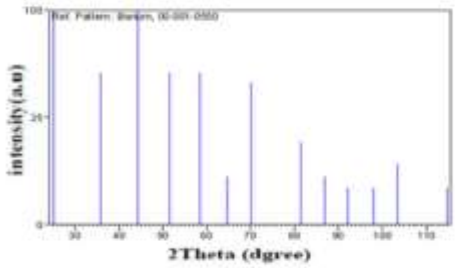

Figure 1: Stick Pattern for barium

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Fig. 1 shows that the maximum intensity is at 24.136 and 44.37. The lowest would be at 92.094, 98.085 and 114.674 where it is only 3% hence it is the lowest intensity. This data is the reference to measure the samples where every parameter is use to measure the samples. The measurement of 100% cement sample begins at 20.025 and end at 79.975 and we can see that the maximum peak is at 29.1679 where the spacing (d) is 3.06172 as shown in fig.2.

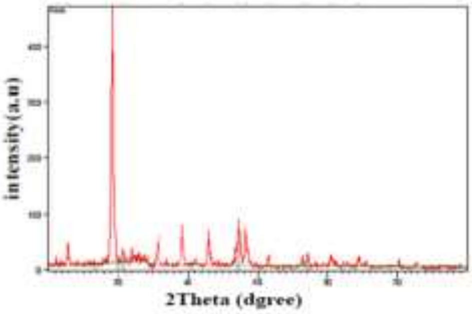

Figure 2: The maximum peak intensity for sample of 100% cement

To calculate the linear attenuation, the following equation can be used.

$$I = I_0 e^{-\mu t} \quad (1)$$

Where, I_o = net count rate without sample, I = net count rate with sample, μ = linear attenuation coefficient in cm^{-1}, t = thickness of the sample (cm). I_o = 851760

The value of linear attenuation is the basic quantity used in calculations of the penetration of samples. Table 1 show that gradual loss in intensity is extremely high in the 0.1 cm of 20% $BaSO_4$. This is due to the high ratio of $BaSO_4$ in the sample and the thickness of the sample also influences the absorption of the energy as shown in Figures 3 & 4.

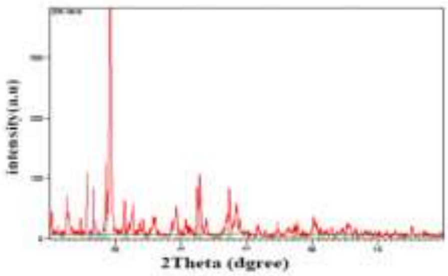

Fig 3: The maximum peak intensity for sample of 80% cement + 20% $BaSO_4$

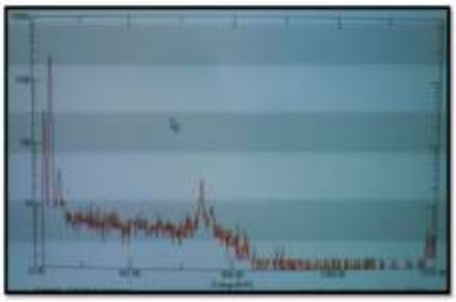

Fig 4: Energy against count rate for 10mm 80% Cement + 20% Barium Sulfate

Figure 5, extremely shows high attenuation value in 20% of $BaSO_4$ samples of 0.1 cm thickness. This value shows that very high intensity of barium absorbs the photons transmitted through the sample. There are slightly change in value between 5% and 10% at the thickness of 0.5 cm and didn't show much different between the values of attenuation in the pure sample. These values obtained the mass attenuation by dividing it with the value of density in each of the sample.

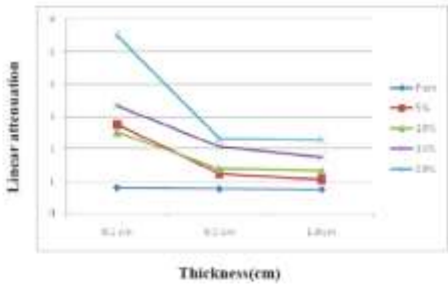

Fig 5: Linear attenuation versus thickness of samples

Calculating mass attenuation

After obtaining the value of linear attenuation coefficient, the mass attenuation coefficient can be calculated by dividing the value of linear attenuation coefficient with the density of the samples.

$$\frac{\mu}{\rho} = massattenuationcoefficient\left(cm^2/g\right) \quad (2)$$

The mass attenuation coefficient is used to describe the total reduction of the gamma radiation at the detector due to both energy absorption and scattering. The intensity of photons reaching a detector decreases as the mass attenuation coefficient increases for the same absorber thickness and photon energy. The mass attenuation coefficient tends to increase with increasing atomic number at the same photon energy. The result from Table 2 shows that the mass attenuation could be increased in term of increasing the thickness. The content mixture of $BaSO_4$ also greatly influences the amount of absorption of energy in the sample. It shows that barium with atomic number (56) is a good material in designing the γ-ray barrier.

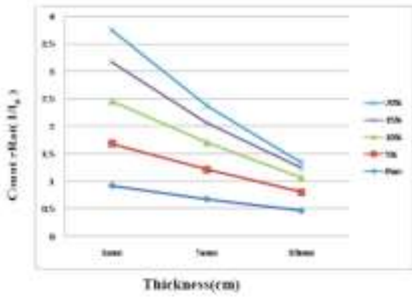

Fig 6: The exponential transmission curve I/I_0 versus thickness

Fig. 6 shows that the net count rate without sample divided by the net count rate without sample against the thickness of the sample. The amount of $BaSO_4$ does linearly influence the absorption of the energy in the sample. The value of net count rate of 1 mm sample thickness increases the absorbed energy dramatically from below 1 to nearly 4 when the amounts of $BaSO_4$ in the sample are increase.

Conclusion

The output of this research has showed that the thickness and the quantity of $BaSO_4$ affected on the absorption of the energy. The thickness of the sample does really influence the energy that penetrating the sample. Other than that is the ratio of the mixture of between cement and barium sulfate also influence the absorption of energy that are penetrating the sample. The mixture ratio of barium sulfate that has 20% in the sample really shows that the absorption of the energy is really high. It can be concluded that barium sulfate do influence the absorption and penetration of the energy of the gamma ray. These values can be easily achieved with increasing barium sulfate amount into the mixture of the sample.

Increasing the thickness of the sample also will cause more absorption and backscattered radiation. A high mass density material of sample is great for energy absorbing hence barium that has high atomic number is a good example. Increasing the material density will also increase the attenuation. This means that less transmission of photons as well as amount of backscattering. The result has shown a positive data to analyze for a better γ-ray shielding or barrier.

As for suggestion for future study and experimental, further work should be carried out to study the absorption and penetrating of energy to the sample. Another important experiment can be done to testing the backscattered radiation from the samples using other kind of material that has a high atomic number used in the mixture such as iodine and decreasing the thickness of the shield is crucial for better and good design in the future.

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Table 1: The value of linear attenuation for each sample

Sample	Thickness (cm)	μ (cm^{-1})
Pure (100% cement)	0.1	0.8105
Pure (100% cement)	0.5	0.7761
Pure (100% cement)	1.0	0.7587
95% Cement + 5% $BaSO_4$	0.1	2.7461
95% Cement + 5% $BaSO_4$	0.5	1.2489
95% Cement + 5% $BaSO_4$	1.0	1.0774
90% Cement + 10% $BaSO_4$	0.1	2.5139
90% Cement + 10% $BaSO_4$	0.5	1.3993
90% Cement + 10% $BaSO_4$	1.0	1.3425
85% Cement + 15% $BaSO_4$	0.1	3.3344
85% Cement + 15% $BaSO_4$	0.5	2.0719
85% Cement + 15% $BaSO_4$	1.0	1.7484
80% Cement + 20% $BaSO_4$	0.1	5.4921
80% Cement + 20% $BaSO_4$	0.5	2.3134
80% Cement + 20% $BaSO_4$	1.0	2.2769

Table 2: The value of mass attenuation coefficient for each sample

Sample	Thickness (cm)	μ_m (cm^2/g)
Pure (100% cement)	0.1	0.2471
Pure (100% cement)	0.5	0.4063
Pure (100% cement)	1.0	0.4286
95% Cement + 5% $BaSO_4$	0.1	0.8197
95% Cement + 5% $BaSO_4$	0.5	0.6471
95% Cement + 5% $BaSO_4$	1.0	0.6122
90% Cement + 10% $BaSO_4$	0.1	0.7687
90% Cement + 10% $BaSO_4$	0.5	0.7176
90% Cement + 10% $BaSO_4$	1.0	0.7500
85% Cement + 15% $BaSO_4$	0.1	0.9835
85% Cement + 15% $BaSO_4$	0.5	1.0680
85% Cement + 15% $BaSO_4$	1.0	0.9768
80% Cement + 20% $BaSO_4$	0.1	1.6346
80% Cement + 20% $BaSO_4$	0.5	1.1924
80% Cement + 20% $BaSO_4$	1.0	1.2792