

THE EFFECTIVE OF STEEL SLAG AND STONE DUST ON THE GAMMA-RAY SHIELDING IN CONCRETE BLOCK

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Abstract

This research has studied in the effectiveness of steel slag and stone dust for the radiation shielding of concrete blocks. Compton scattering techniques were used to derive experimental value at energy of 662 keV. Phy-x/PSD software was used to derive theoretical values in an energy range of 15-1.5×10⁴ keV. Compression testing was used to analyze the physical properties of concrete blocks for 28 days' age. The results showed that SCB2, SCB3, and SCB4 had better radiation shielding ability than SCB1 in energy range of 10-100 keV. At an energy of more than 100 keV, the radiation shielding efficiency of SCBs was very similar. The results indicated that steel slag can improve the radiation shielding efficiency of the concrete blocks in an energy range of 10-100 keV. In addition, the results of strength and tensile strength for SCBs decreased with increasing steel slag volume. Whereas surface of samples had smoother due to stone dust can bond better with concrete than steel slag. However, SCBs samples had a quality in engineering standards that samples can be used in the construction.

Keywords: Steel slag, stone dust, concrete block, radiation shielding

Introduction

Stones dust are remnants of rock blasting and the most difficult to remove. They are added value, used as the main ingredient of concrete blocks. Concrete blocks are the primary materials used for radiation shielding materials in radiation laboratories (Chitrakha, 2005; Agosteo *et al.*, 2008; El-Khayatt, 2010; Pomaro *et al.*, 2011; Gencel, 2012) and several researchers have been studied radiation shielding

properties of concrete blocks (Hassan *et al.*, 2020; Hernandez-Murillo *et al.*, 2020; Aygün, *et al.*, 2021). The rapid decline in stone dust has been prompted by researchers which aim to find the alternative materials to mix concrete blocks instead of stone dust (Verma *et al.*, 2020). The aim of the study on the use of hard to destroy waste materials was to develop renewable materials.

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Slag is an industrial waste that researchers are trying to make it more environmentally friendly. The researchers attempted to mix slag with concrete and conduct the experimental analysis on the modulus of elasticity for slag-based concrete (Kalla *et al.*, 2021). Steel slag is the main material used in road engineering and improves its adhesion to cement. Iron slag mixture has good economic and environmental benefits compared to limestone mixture (Gencel *et al.*, 2021). Tanvi Gupta & S.N. Sachdeva (Gupta and Sachdeva, 2020) showed the properties of modulus and compressive strength of concrete slag used to build a hard pavement, the results of construction efficiency experiments were found to be within criteria for construction. In 2016, Y.K. Sabapathy (Sabapathy *et al.*, 2016) demonstrated a good ratio of cement, rock dust, and aggregate slag mixtures, resulting in the improved compressive strength and tensile strength. An examples of research using lead and steel to to increase the efficiency of radiation shielding are many which refer: (Sharma *et al.*, 2009; Akkurt *et al.*, 2010; Ochbelagh *et al.*, 2011). Several studies have shown that slag mixing in concrete can increase the mass attenuation coefficient, resulting in better radiation shielding (Alam *et al.*, 2001; Singh *et al.*, 2004; Salinas *et al.*, 2006; Turkmen *et al.*, 2008).

Creating an alternative material that uses industrial waste (steel slag) to replace stone dust from rock blasting is an interesting material that reduces industrial waste and increases its friendliness to nature. In this study, 4 samples of slag mixed concrete block (SCBs) were produced with different mixing ratio between steel slag and stone dust. All four samples were made in two sets of different sizes for easy analysis, are sizes 5×5×2 cm and 10×10×10 cm. The main parameters to be analyzed are chemical composition, mass attenuation coefficient (μ_m), half-value layer (HVL), mean free path (MFP), strength, and tensile strength. The shielding radiation parameters were analyzed as an experimental value (Ex) using the Compton scattering technique and compared with the theoretical values (Th) which analyzed by Phy-x/PSD software at energy of 662 keV.

Materials and Methods

The SCBs of concrete blocks used in this research are cubic shapes which shown in Figure 1 produced by the Rim Theerakun Factory and the volume mixing ratio were shown in Table 1.

The compressive strength and tensile strength determination testing were performed using a cubic shape with dimension 10×10×10 cm. The test style is compressive testing of concrete blocks at 28 days'

age. The reference standards adopted are IS: 516-1959 and ASTM (C496-96), which was used to perform the compressive strength and tensile strength (MPa) respectively.

The density of SCBs (ρ_{SCBs}) was determined by the relationship between weight in the air (W_{air}) and weight in water (W_{water}) and density of water (ρ_{water}), as shown in Equation

$$\rho_{SCBs} = \frac{W_{air}}{W_{air} - W_{water}} \times \rho_{water} \quad (1)$$

Figure 2 shows the Compton scattering technique used to analyze the gamma-ray shielding properties of the SCBs samples. The SCBs sample used for analysis had a cubic size of 5×5×2 cm and the results obtained from the experiment was compared with the theoretical values analyzed by Phy-x/PSD software at energy of 662 keV.

The result obtained from the Compton scattering technique is the radiation intensity through (I) SCBs. The radiation intensity through four sample materials can be calculated for the mass attenuation coefficient by relation:

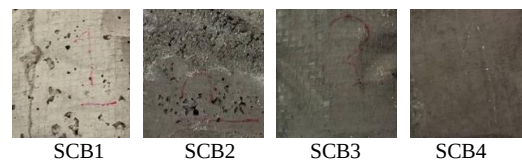


Figure 1. The SCBs samples for investigations

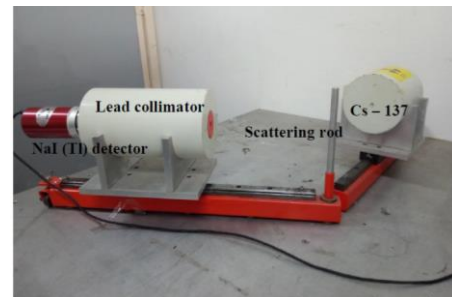


Figure 2. Shows Compton scattering technique at 662 keV

Table 1. Mixture proportions of SCBs

Sample	Steel slag mixed concrete block			
	Cement (kg/m ³)	Water (L)	Stone dust (kg/m ³)	Steel slag (kg/m ³)
SCB1	24	15	251	0
SCB2	24	15	198	63
SCB3	24	15	132	129
SCB4	24	15	66	195

$$I = I_0 e^{-\mu_m(x)} \quad (2)$$

where I_0 is the intensity of radiation before the incident and x is the thickness of SCBs. In this work, SCBs samples were used to find the mass attenuation coefficients from the different thickness of four samples such as 1.91, 2.41, 1.16, and 1.65 cm.

For Z_{eff} and N_{el} can be simulated by Equations (3) and (4) (Levet *et al.*, 2020; Abdel-Latif *et al.*, 2020; Prabhu *et al.*, 2020; Mahmoud *et al.*, 2020):

$$Z_{\text{eff}} = \frac{\sum_i f_i A_i (\mu_m)_i}{\sum_i f_i \frac{A_i}{Z_i} (\mu_m)_i} \quad (3)$$

where f_i , Z_i and A_i mean mole fraction, atomic number and atomic weight, respectively, of i th constituent elements.

$$N_{\text{el}} = N_A \frac{Z_{\text{eff}}}{A} \quad (4)$$

where $N_A = 6.02 \times 10^{23}/\text{mol}$ and A mean total atomic weight of glass sample.

Result and Discussion

The SCBs had been analyzed μ_m values at energy of 662 keV by using the Compton scattering technique. The theoretical values obtained from Phy-x/PSD software and compared with the experimental values at this energy while chemical composition and density of SCBs samples were shown in Table 2. From Tables 3, 4, and 5 the results showed that in this energy, the μ_m had %RD between 0.316-0.806%. However, the μ_m value of SCBs sample is very close, especially in SCB3 and SCB4. The MFP and HVL were related to μ_m . At this energy, the SCB1 showed the best radiation shielding due to the highest density and chemical composition of calcium around 0.77279 wt%.

The SCBs were analyzed for Z_{eff} and N_{el} value at energy of 662 keV by using the Compton scattering technique. The theoretical values obtained from the Phy-x/PSD software are compared with the experimental values at this energy. From Tables 6 and 7, the results showed that at this energy, Z_{eff} and N_{el} value had %RD between 0.00–0.002% and 0.036–0.068%, respectively. The Z_{eff} and N_{el} value decreased with the steel slag mixing ratio increased. This result was consistent with Tables 3, 4, and 5.

Figure 3 shown μ_m of SCBs in an energy range from 15 to 1.5×10^4 keV which determined based on the analysis of chemical composition obtained from XRF and density. The results from experimental and Phy-x/PSD software represented that in an energy range from 15 to 100 keV, SCB1 had a lower μ_m

Table 2. Chemical composition in %wt and density of SCBs

Chemical composition (%wt)	Steel slag mixed concrete block			
	SCB1	SCB2	SCB3	SCB4
Mg	0.02793	0.02074	0.00924	0.00648
Al	0.02478	0.03019	0.04363	0.04538
Si	0.14042	0.16641	0.30052	0.32500
S	0.00521	0.00457	0.00616	0.00562
K	0.00234	0.00407	0.00765	0.00883
Ca	0.77279	0.57497	0.34210	0.28253
Ti	0.00125	0.00316	0.00446	0.00454
Cr	-	0.00093	0.00129	0.00143
Mn	0.00034	0.01458	0.02448	0.02911
Fe	0.02131	0.17593	0.25438	0.28464
Ni	-	0.00019	0.00011	0.00014
Sr	0.00051	0.00045	0.00048	0.00056
Zr	-	0.00029	0.00046	0.00061
Ag	0.00312	0.00240	0.00339	0.00298
Ba	-	0.00112	0.00165	0.00215
Density (g/cm ³)	2.63	2.57	2.52	2.41

Table 3. The μ_m value of SCBs samples at energy of 662 keV

SCBs	μ_m (cm ² /g)		
	Th	Ex	%RD
SCB1	0.078	0.079	0.806
SCB2	0.077	0.077	0.345
SCB3	0.076	0.076	0.316
SCB4	0.076	0.076	0.661

Table 4. The MFP value of SCBs samples at energy of 662 keV

SCBs	MFP (cm)		
	Th	Ex	%RD
SCB1	4.902	4.902	0.000
SCB2	5.070	5.070	0.000
SCB3	5.206	5.206	0.000
SCB4	5.457	5.457	0.000

Table 5. The HVL value of SCBs samples at energy of 662 keV

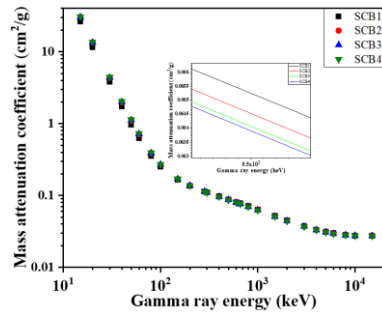
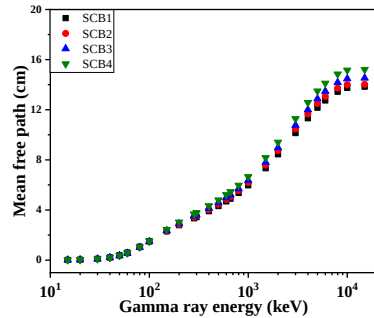
SCBs	HVL (cm)		
	Th	Ex	%RD
SCB1	3.397	3.398	0.020
SCB2	3.513	3.514	0.020
SCB3	3.608	3.609	0.020
SCB4	3.782	3.783	0.020

Table 6. The Z_{eff} value of SCBs samples at energy of 662 keV

SCBs	Z_{eff} (electron/atom)		
	Th	Ex	%RD
SCB1	18.445	18.444	0.002
SCB2	18.898	18.898	0.000
SCB3	18.239	18.240	0.002
SCB4	18.205	18.206	0.002

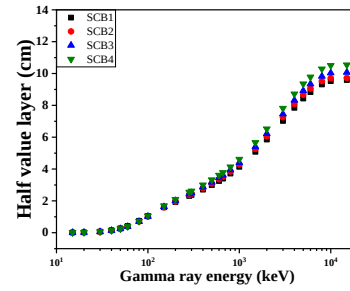
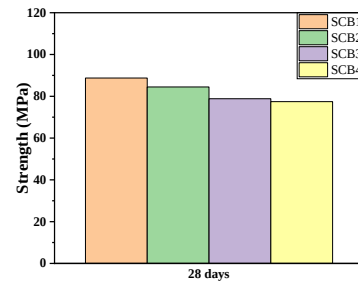
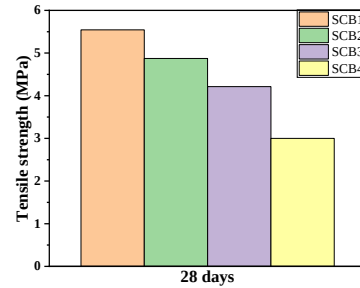
Table 7. The N_{el} value of SCBs samples at energy of 662 keV

SCBs	N_{el} ($\times 10^{23}$ electron/gram)		
	Th	Ex	%RD
SCB1	2.996	2.997	0.036
SCB2	2.961	2.963	0.054
SCB3	2.941	2.943	0.064
SCB4	2.934	2.936	0.068

**Figure 3.** μ_m of sample in an energy range of 15-1.5 $\times 10^4$ keV**Figure 4.** Mean free path of SCBs in an energy range of 15-1.5 $\times 10^4$ keV

value than the other samples. At energy more than 100 keV, all SCBs samples had very close μ_m value and tendency of μ_m decreased with increasing energy.

Figure 4 shows the MFP of SCBs in an energy range of 15-1.5 $\times 10^4$ keV. The MFP was obtained from an inverse relationship with linear attenuation coefficient (μ) according to this Equation

**Figure 5.** HVL of SCBs in an energy range of 15-1.5 $\times 10^4$ keV**Figures 6.** The strength (MPa) of SCBs at 28 days**Figures 7.** The tensile strength (MPa) of SCBs at 28 days

$$\text{MFP} = \frac{1}{\mu} \quad (3)$$

In low energy range, all SCBs had MFP value very similar. For more than 2,000 keV, SCB3 and SCB4 shown a higher MFP trend. This result reflects a reduced probability of radiation interaction in SCB3 and SCB4, corresponding to μ_m .

Figure 5 shows the HVL value of SCBs in an energy range of 15-1.5 $\times 10^4$ keV. The HVL value was obtained from 0.693 times of the inverse relationships with linear attenuation coefficient (μ) according to this Equation

$$\text{HVL} = \frac{0.693}{\mu} \quad (4)$$

In low energy range, all SCBs had HVL values very similar. For energy more than 2,000 keV, SCB3 and SCB4 shown a higher HVL trend. This result reflected the decreased probability of interaction in SCB3 and SCB4 as corresponding to μ_m and MFP.

Figures 6 and 7 show the test style is compressive testing of concrete blocks at 28 days' age. The reference standards adopted are IS: 516-1959 and ASTM (C496-96), which was used to perform the compressive strength and tensile strength (MPa), respectively. The results showed that the strength of the 4 SCBs samples had values in a range from 88.758 to 77.458 MPa. The results shown here imply that when steel slag increased, the strength and density of the concrete block were decreased. The tensile strength of all samples tended to decrease with increased steel slag and had values in a range from 5.543 to 3.000 MPa. However, these results, both strength, and tensile strength are similar to those of Ali G. Hassan's research (Hassan *et al.*, 2020).

Conclusions

This work aimed to study the effectiveness of steel slag and stone dust for the radiation shielding of concrete blocks. Compton scattering techniques, Phy-x/PSD software, XRF, and compression testing were used for analysis. The results showed that SCB2, SCB3, and SCB4 had better radiation shielding ability than SCB1 in an energy range of 10-100 keV. For an energy of more than 100 keV, the radiation shielding efficiency of SCBs was very similar. The results indicated that steel slag could improve the radiation shielding efficiency of concrete blocks. In addition, the results of strength and tensile strength for SCBs decreased with increasing steel slag volume. Whereas surface of samples had smoother due to stone dust can bond better with concrete than steel slag. However, all SCBs samples had a quality in engineering standards that can be used in the construction.

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