ISSN Online: 2756-3898, ISSN Print: 2714-500X https://doi.org/10.47514/phyaccess.2022.2.2.013

Determination of shielding Effectiveness of Concretes with different Aggregate and cement composition

Anas M Salisu[1], Joseph I Abaleni[2] and Abdullahi S Aisha[1]

[1] Department of Physics, Ahmadu Bello University, Zaria, Kaduna State, Nigeria
[2] Department of Physics, Kaduna State College of Education Gidan Waya, Kaduna State, Nigeria

Corresponding E-mail: abuumair399@gmail.com

Received 15-11-2022
Accepted for publication 20-12-2022
Published 21-12-2022

Abstract

The shielding effectiveness of concretes with different aggregate and cement composition was determine by shielding Co-60 gamma radiation source at center for energy research and training (CERT), Ahmadu Bello University Zaria with block concretes that contain aggregate 5.00 mm, 10.00 mm and 15.00 mm respectively. A concrete with thickness of 0.0762 m with dimension of 0.30 m x 0.30 m was formed from each of the aggregates with equal volume of sharp sand and cement. The result revealed the calculated mean free path (MFP) with values within a range of (0.033 to 0.070) m for samples DG (Dangote) and BU (BUA), mass attenuation coefficient (MAC) and half value layer (HVL) values within a range of (1.9 to 2.75) x 10^{-3} m^2/kg and (0.023 to 0.049) m respectively. This shows that samples DG1, DG2 and DG3 have better shielding ability due to its lower MAC, MFP and HVL compared to samples BU1, BU2 and BU3.

Keywords: Attenuation coefficient; radioactive; aggregate sizes; concrete; gamma ray shielding

I. INTRODUCTION

Concrete is a composite material whose major constituents include cement, fine aggregates, coarse aggregates and water. Admixtures can be added to cement, aggregates and water to achieve a particular purpose. The constituent components of plain concrete have significant roles which they are expected to play in their service conditions with the intention of achieving desired characteristics and quality. While the cement is serving as a binder, the fine aggregates help in reducing the occurrence of voids, the coarse aggregates impact adequate strength to the concrete and the water activates the binding capability of the cement. The qualities of concrete include inter alia workability, durability and strength. These qualities can best be achieved when the various components of concrete are in the right proportion and this leads to the concrete mix design ratio. The relative quantities of cement, aggregates and water in concrete control the properties of concrete in the wet state as well as in the hardened state [1] and [2].

Concrete serves many purposes and its intended purpose determines the proportions of the cement, aggregates, water and possibly some admixtures.

Radiation shielding concrete can be used to easily attenuate neutrons, x-rays and gamma ray photons. Although the shielding properties of concrete may vary depending on the material components of the concrete, aggregates are the largest constituent (about 70 – 80%) of the total weight of normal concrete [3]. Various types of artificial and natural aggregates are utilized to promote the features of the concrete. For this purpose, concrete is considered as an excellent and versatile shielding material widely used for shielding radiation sources. It is a relatively inexpensive material, which may be easily handled and cast into complex shapes.

The utilization of aggregates of the highest possible density in the concrete mix is an effective measure in shielding enhancement [4]. The quality of concrete in terms of compressive strength and density largely depend on a number of factors such as: type of aggregates, size of aggregate, cement – water ratio, overall mixing ratio, quality (grade) and quantity of cement used, type of admixture, number of curing days and number of air voids [3]. When other factors are held constant with varying cement quality (grade) and aggregate size, an appreciable variation in concrete density can be observed [5]. The aim of this work is to determine the radiation shielding parameters of concrete made from Nigerian Portland-limestone cement and consequently, obtain a more appropriate thickness of concrete required to shield high energy radiation sources and facilities.

II. THEORETICAL CONSIDERATION

The background intensity of the laboratory was subtracted from the initial intensity I_0 and the Intensity I of the transmitted beam. The linear attenuation coefficient (μ) was determined by measuring the transmission of gamma-rays through the sample as a target of known thickness as presented (1) [6] and [2].

$$I = I_o e^{-\mu x} \quad (1)$$

Here I is the intensity of the photon I_0 is the intensity of the incident photon x is the thickness absorber and μ is the linear attenuation coefficients.

The average amount of material needed to absorb 50% of all radiation HVL (half value level) which is related to mean free path (MFP) and the mass attenuation coefficient (MAC) of the samples was determined using (2) and (3) respectively [7] and [8].

$$HVL = \frac{0693}{\mu} \quad (2)$$

$$MAC = \frac{\mu}{\rho} \quad (3)$$

Here ρ is the density of the concrete which depend on the volume and μ is the linear attenuation coefficient.

However, the mean free path (MFP) of a pencil beam of mono-energetic photons is the average distance that the photon travels between collisions with atoms of the absorbed material. It depends on the material and the energy of the photons, (MFP) was calculated using (4) [5].

$$MFP = \frac{1}{\mu} \quad (4)$$

The radiation protection efficiency (RPE) also known as radiological protection which described harmful effect of exposure from ionizing radiations due to internal and external radiation contamination was calculated using the (5) [7] and [2].

$$RPE = (1 - \frac{I}{I_0}) \times 100 \quad (5)$$

With I and I_0 as defined from (1).

III. METHODOLOGY

Six concrete sample sets coded BU1, BU2, BU3, DG1, DG2 and DG3 were fabricated utilizing different aggregate granule sizes of 5 mm, 10 mm and 15 mm, with the weight percentages of all concrete constituents kept constant. Sample BU1 and DG1 have granule size of 5 mm, BU2 and DG2 have granule size of 10 mm while BU3 and DG3 have granule size of 15 mm.

A. *Concrete production*

The mold was constructed using metal sheet with a dimension of $0.30\,m \times 0.30\,m$ and thickness of $0.0762\,m$. Coarse aggregate, fine aggregate and cement were thoroughly mixed together with the concrete mixer, after which the required water-cement ratio (w/c) was added. The entire constituents were mixed until an even paste was obtained as shown in Plate 1.

Plate 1 Paste of the sample production

B. *Experimental determination of linear attenuation coefficient*

The linear attenuation coefficient μ (m^{-1}) for the investigated samples were experimentally determined using a narrow-collimated mono-energetic beam of gamma rays from a 60-Co radiation source with the distance between the detector and radiation source set to $0.0762\,m$.

The initial intensity I_0 of the photon energy was measured first without the samples. The investigated samples were then placed between the source and the detector, and the intensity of the transmitted photons I was measured (Fig. 1). The intensities of incident I_0 and transmitted intensities, I of the photon were measured for a time duration of 20 minutes.

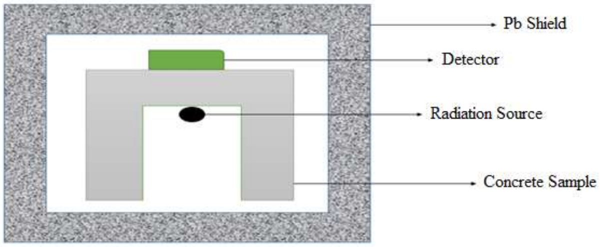

Fig. 1 Experimental set up for concrete shielding effectiveness

IV. RESULTS AND DISCUSSION

A. *Results*

The results of linear attenuation coefficient μ, half value layer (HVL), Mass attenuation coefficients (MAC) and mean free path (MFP) are presented in Table I to II, while a comparison of the obtained mean mass attenuation coefficient (MAC) with the literature is presented in Table III.

Table I: Results of the shielding properties of concrete samples with different aggregates.

Source	Parameters	Samples DG			Samples BU		
		DG1	DG2	DG3	BU1	BU2	BU3
Co-60	$\mu(m^{-1})$	30.676	30.218	29.399	14.440	16.078	14.191
	HVL(m)	0.023	0.023	0.024	0.049	0.043	0.048
	MFP (m)	0.034	0.033	0.033	0.070	0.062	0.069
	RPF (%)	90.34	90.00	83.36	88.50	91.37	88.93
	$MAC\ (m^2/Kg)\ (\times 10^{-3})$	2.02	1.95	1.90	2.73	2.75	2.72

Table II: The mass attenuation coefficient (MAC) of the samples

Samples Names		$MAC\ (m^2/Kg)\ (\times 10^{-3})$	Aggregate size (mm)
Samples DG	DG1	2.024	5
	DG2	1.951	10
	DG3	1.898	15
Samples BU	BU1	2.735	5
	BU2	2.751	10
	BU3	2.718	15

Table III A Comparison of the obtained mean mass attenuation coefficient (MAC) with the literature.

Studied samples (Top)	Average Mass attenuation coefficient (m^2/Kg) at photon energy of 1332.7 Kev	References
Brick	0.0510×10^{-1}	[3]
Soil	0.0540×10^{-1}	[1]
Concrete	0.0550×10^{-1}	[8]
Concrete (DG)	0.0196×10^{-1}	This Work
Concrete (BU)	0.0270×10^{-1}	This Work

B. *Discussion*

The mass attenuation coefficients of the samples at 1332.50 keV as measured experimentally using the set up shown in Fig. 1 were presented in Table II. From the table it can be seen that mass attenuation coefficients of all the investigated samples decreases with increasing aggregate size.

The mass attenuation coefficient is a function of photon energy range which may be divided into three regions based on the type of interaction between the photon and matter. In the low energy region, which extends from 15 keV to several hundred keV [6] and [9], attenuation decreases sharply with increasing energy. For low energy photons, photoelectric absorption is the dominant interaction mechanism. This interaction mechanism strongly depends on the atomic number of the absorbing medium

Table III shows the values of the linear attenuation coefficients μ of the samples and their variations with the aggregate size. Generally, the linear attenuation coefficient decreases with increase in aggregate size. It is reported that the linear attenuation values are influenced by chemical contents, photon energy and density [2]. Moreover, studies have shown that the linear attenuation of concrete varies with the addition of aggregate of different sizes and types [7] and [8].

Two important parameters that determine the capability of energetic photon to penetrate through a given sample are HVL and MFP [6]. The HVL and MFP were determined from the mass attenuation coefficient values obtained using (2) and (4) respectively and the results were presented in Table III. It was observed that HVL and MFP values for the photon energy (1332.5 keV) of all the samples are approximately equal.

In order to ascertain the radiation shielding effectiveness of the investigated samples, the result obtained for mass attenuation coefficient, linear attenuation coefficient, HVL and MFP were compared with that of ordinary, concrete [8], soil [1] and bricks [3] at photon energy of 1332.5 keV as shown in Table III.

However, it was observed from the result that the shielding efficiency of samples produced using cement brand 'DG' was found to be better for all the aggregate sizes under consideration in this work than those produced using 'BU' which is due to difference in clinker content (the cement binding agent) in the two local cement brands [9], [5] and [8].

V. CONCLUSION

The shielding properties of the fabricated Concrete samples from Dangote (DG) and BUA (BU) cement, granite gravels at different sizes were observed after exposure to Co-60 radiation source at center for Energy Research and Training ABU Zaria. The result shows that the attenuation data obtained were consistent. This implied that the binding efficiency (quality) of the local cements was essentially the same even though samples (DG1, DG2 and DG 3) were found to have better shielding properties than samples (BU1, BU2 and BU3) for all the aggregate sizes. The values of linear and mass attenuation coefficients as well as the half value layers for samples (DG1 and BU1) fabricated concretes using aggregate size 5mm, irrespective of the cement brand was found to be better against 10 mm and 15 mm aggregate sizes. The Nigerian locally manufactured cement was found to be suitable and can be used to achieve strong shielding barrier structures. In this study only two products, Dangote and BUA cements were considered. Thus it is recommended that, more cement products form Nigerian and foreign cement companies that find their way into the Nigerian market be considered so as to ascertain what and how the shielding effectiveness of these cements and aggregates could be improved.

ACKNOWLEDGMENT

The authors acknowledge the effort of Jamilu Abdullahi Yusuf of Centre for Energy Research and Training, Ahmadu Bello University, Zaria Nigeria, and U. M. Kankara of Physics Department ABU Zaria towards the successful completion of this work.

References

[1] K. S. Mann, B. Kaur, G. S. Sidhu and A. Kumar, "Investigations of some building materials for γ-rays shielding effectiveness". Radiat. Phys. Chem., vol. 87, pp. 16–25, 2013.

[2] S. F.Olukotun, S. T. Gbenu, F. I. Ibitoye, O. F. Oladejo, H. O. Shittu, M. K. Fasasi and F. A. Balogun, "Investigation of gamma radiation shielding capability of two clay materials". Nucl. Eng. & Tech., vol. 7, pp. 1- 6, 2018.

[3] M. N. Alam, M. M. Miah, M. I. Chowdhury, M. Kamal, S. Ghose and R. Rahman, "Attenuation coefficients of soils and some building materials of Bangladesh in the energy range 276-1332 keV". Appl. Rad. Isot., vol. 54, no. 6, pp. 973-976, 2001.

[4] A. B. Azeez, S. M. Kahtan, M. A. A Mohd, H. Kamaradin, V. S. Andrie and A. R Rafiz, "The Effect of Various Waste Materials Contents on the Attenuation Level of Anti-Radiation Shielding Concrete". Mat., vol. 27, pp. 1-7, 2013.

[5] A. K. Abubakar, Y. I., Zakari, U. Sadiq and T. J. Van Rooyen, "Investigation of Neutron and photon shielding Prospect of some Nigerian Mineral Ores, using the Monte Carlo Radiation Transport Code". *Published by IAEA/ INIS, Vol. 451, 18th Sep. 2014 MCN PX.* Available from Nigerian Atomic Energy Commission, pp. 6.

[6] A. W. El-Sayed, A. F. Michael and A. B. Mohamed, "Gamma-ray mass attenuation coefficient and half value layer factor of some oxide glass shielding materials" *Annals of Nuclear Energy,* vol. 96, pp. 26–30, 2016.

[7] S. Azimkhani, A. Kalhor, A. Rahmani and A. Sohrabi, "Investigation of Gamma Ray Shielding and Strength Properties of Concrete Containing Bismuth and Barite". *Iranian J. of Sci. and Tech.*, vol. 2, pp. 32-41, 2018. https://doi.org/10.1007/s40995-018-0655-0

[8] M. H. Sahadath, R. Biswas, M. F. Huq and A.S. Mollah, "Calculation of gamma-ray attenuation parameters for locally developed ilmenite-magnetite concrete". J. Bangladesh Acad. Sci., vol. 40, no. 1, pp. 11-21, 2016.

[9] S. Yesmin, B. S. Barua, M. U. Khandaker, M. T. Chowdhury, M. Kamal, M. A. Rashid, M. M. H. Miah and D. A. Bradley, "Investigation of ionizing radiation shielding effectiveness of decorative building materials used in Bangladeshi dwellings". Rad. Phy. and Chem., vol. 8, pp. 18-23, 2016. http://dx.doi.org/10.1016/j.radphyschem.2016.11.017