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EVALUATION OF RADIATION SHIELDING INTEGRITY OF FABRICATED CONCRETE WITH SOME SELECTED AGGREGATE SIZES

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ABSTRACT

Shielding is regarded as one of the three ways of minimizing radiation exposure to the workers and members of the public. Concrete is the most available and cheap material used in shielding, though its integrity in shielding radiation depends on the materials used in its production and the choice of the materials also depends on the type of radiation to be shielded. Due to the rapid increase in the number of unregulated usages of radiation facilities in Nigeria and the lack of locally established concrete shielding data for construction of such facilities, it is imperative to carryout research to generate such data. In this work, the radiation shielding properties of fabricated concretes with aggregates sourced from indigenous granite gravels of sizes 10 mm, 15mm and 20 mm is presented. Gamma rays of energies 0.662MeV from ^{137}Cs, 1.173Mev and 1.332MeV from ^{60}Co were used to expose the concrete samples, and the radiation attenuation coefficients were determined using NaI (Tl) gamma ray detector with a Multi-Channel Analyser. The average linear attenuation coefficients of the concrete samples with aggregate sizes of 10mm, 15 mm and 20 mm were found to be 11.10 ± 0.02cm^{-1}, 15.02 ± 0.03cm^{-1}, 12.19 ± 0.03cm^{-1} for ^{137}Cs source and 7.24 ± 0.07cm^{-1}, 9.66 ± 0.07cm^{-1}, 8.73 ± 0.07cm^{-1} for ^{60}Co source respectively. The results showed that the concrete mix obtained using 15mm aggregate size attenuated the radiation much higher than that of 10mm and 20mm, and is a promising candidate for cheap gamma rays shielding.

Keywords: Radiation Shielding, Concrete, Aggregate size, attenuation coefficients

INTRODUCTION

Due to the rapid increase in the number of unregulated usages of radiation facilities in Nigeria (Oluwafisoye *et al*, 2010), workers and members of the public need to be protected against undue exposure to the radiation during any practice involving radiation sources. Time, distance and shielding are regarded as the basic radiation protection measures against any external radiation sources (Azeez et al, 2013; IAEA, 2005). It has been demonstrated that Lead and Iron shields were found to be effective in radiation shielding, but mechanical and economic factors such as difficulty in fabrication and high cost limit their usage to highly specialised areas such as nuclear reactor cores, nuclear spent fuel pools, radiation detectors, and linear accelerators (Akkurt et al, 2010). In search for an effective substitute to the lead and iron, Osman *et al*, (2010) reported concrete to be a good substitute candidate material due to its versatile application in radiation shielding as it can easily be cast into various shapes and sizes with different types of mixture constituents depending on the type of radiation under consideration. Ordinary concrete has a density of 2350 kg/m^3 and is composed of Portland cement, sand, aggregate (stones, gravel, etc.), and water (IAEA, 2005 and Sun et al, 2012). Recently, concrete is commonly used in the construction of commercial buildings, orthovoltage radiotherapy rooms, bunkers for housing radioactive sources, reactor core housing and X-ray rooms due to its relative flexibility (Maslehuddin et al, 2013; Sun et al, 2012). The efficiency of concrete in radiation shielding depends on the size of the aggregates used in the concrete production (Azeez *et al.* 2013, Jimoh and Awe, 2007 and Maslehuddin *et al*, 2013). This work investigated the shielding properties of concrete produced with indigenous granite rocks of different sizes conventionally used as aggregates in the production of concrete for construction of different types of structures in Nigeria, with the aim of coming up with an optimum aggregate size for radiation shielding purpose.

MATERIALS AND METHODS

10 mm, 15 mm and 20 mm aggregates from granite gravels were sourced from local quarries in Kaduna state, Nigeria and were used in fabricating three sets of concrete samples. The selection of these aggregate sizes was based on the fact that they are the most widely and commonly used aggregates for building walls and barriers in most Nigerian concrete buildings (Kazeem et al, 2014). In the production of the concrete, American Society for Testing and Materials method was adopted as described in ASTM C637 (ASTM, 1998).

The mixture of cement-sand-gravel was based on the concrete mix ratio 1:2:4 consisting of cement 5 kg, sand 10 kg, gravel 20 kg and the water to cement (w/c) ratio 2:5 as described by Azeez et al, (2013). The concrete samples comprised of three sets of concretes with each consisting of 5 slabs of different thicknesses produced with one aggregate size, giving a total of 15 concrete slabs all together. The dimensions of the concrete slabs were chosen in such a way that will fit the geometry of the radiation sources. The concrete samples produced were cured for 28 days to ensure maximum compressive strength (Raheem and Bamigboye, 2013). Curing of the samples was done by ponding method; the water in the curing pond was kept at an average ambient laboratory temperature of 28^{o}C to prevent the thermal stress that could result in concrete cracking (James et al, 2011). The concrete samples were removed, sun dried, weighed and conveyed to the Radiation Monitoring Laboratory at Centre for Energy Research and Training, Ahmadu Bello University Zaria, Nigeria. The samples were then exposed to ^{137}Cs and ^{60}Co radiation sources of strength 22 mCi and 5 mCi respectively. The measurements were performed using gamma ray 2”×2” NaI (Tl) Inspector 1000 detector coupled to a Multi-Channel Analyser (MCA). The detector was operated at dose rate mode and the experiment was set-up as schematically shown in Azeez, et al., (2013). Four measurements were taken at four different positions of each concrete sample and the average was computed. The distance from the source to the sample and from the source to the detector was chosen in such a way that the build-up factor becomes negligible and was kept constant throughout the experiment at 30 cm and 60 cm respectively. The radiation sources used produced well collimated beams of gamma ray energies 0.662 MeV for ^{137}Cs, 1.173 and 1.332 MeV for ^{60}Co source. During the measurements, concrete samples were inserted in between the source and the detector, the ambient dose rates were taken before and after the insertion of each concrete sample. Considering the sample thickness as x, ambient dose rate before the concrete insertion as $\dot{D_o}$ (mSv/h) and the ambient dose rate after the concrete insertion as $\dot{D_x}$ (mSv/h), the linear attenuation coefficient μ (m^{-1}), Half (HVL) and Tenth value layers (TVL) were determined from Eq. 1, 2 and 3 respectively (Knoll, 2010).

$$\dot{D}_x = \dot{D}_o e^{-\mu x} \quad (1)$$

$$HVL = \frac{ln2}{\mu} \quad (2)$$

$$TVL = \frac{ln10}{\mu} \quad (3)$$

The standard error (SE) was computed using Eq. 4 (Nicholas, 1995).

$$SE = \frac{\sigma}{\sqrt{N}} \quad (4)$$

where σ the standard deviation from the average value and ‘N’ is the number of samples in each set. The density of each concrete sample in each set was evaluated using Eq. 5 after the measurement of mass and volume of the samples using a weighing balance and a meter rule respectively.

$$\rho = \frac{M}{V} \quad (5)$$

where ρ (kg/m^3) is the density, M (kg) is the mass and V is the volume (m^3).

RESULTS AND DISCUSSION

Table 1 presents the average thickness, linear attenuation coefficients, mass attenuation coefficients, half value layer (HVL) and tenth value layers for the fabricated concrete of aggregate sizes of 10, 15 and 20 mm. The values of linear attenuation coefficients for concrete sample produced using 15 mm aggregate size were found to be higher than that of 10 and 20 mm, this is attributed to the fact that during the sample preparation the highest aggregate compaction within the concrete matrix was achieved at 15 mm and also the fact that during mixing, effective aggregates packing per unit volume of concrete increases with decrease in aggregate size and aggregates atom density increases with size of aggregates, the 15 mm aggregate size compensates the size-atom density difference between 10 mm and 20 mm aggregates. Hence, concrete blocks produced with local granite rocks of 15 mm size will provide better and more effective shielding of gamma radiation over that of 10 mm and 20 mm respectively since effective shielding of gamma rays is an atomic event which depends both on aggregates compaction and aggregates’ atoms per unit volume of the concrete. Also, a closer look at the evaluated half and tenth value layers showed that the values obtained for 15mm were less than that of 10 and 20 mm. It could be inferred from the results that, concretes produced using 15 mm aggregate size will be more suitable for gamma radiation shielding than that of 10 and 20 mm when produced under the same conditions. The results were correlated using Microsoft excel 2013 analysis tool package. The T-test (pair two samples for means) analysis at significance level $P<0.05$ was performed and the results are presented in Table 2. From the results, the differences between the shielding properties of 15 mm and 10 mm, 20 mm concrete samples were found to be significant. Hence the results of this study are significantly important in shielding estimations of gamma ray facilities in Nigeria. However, the obtained results were in disagreement with that reported by Azeez *et al* (2013) and is attributed to the inherent difference in the local aggregates used for the concrete production since geological formation of rocks varies with geographical locations.

Table 1: Shielding parameters obtained for the concrete samples exposed to ^{60}Co and ^{137}Cs gamma ray sources.

Shielding Parameters	^{60}Co source	^{137}Cs source	Aggregate sizes
$\bar{\mu}$ (m^{-1})	9.10 ± 0.07	10.86 ± 0.02	
HVL (m)	0.07 ± 0.02	0.06 ± 0.01	10 mm
TVL (m)	0.23 ± 0.03	0.21 ±0.01	
$\bar{\mu}$ (m^{-1})	11.91 ± 0.07	14.40 ± 0.03	
HVL (m)	0.06 ± 0.02	0.05 ± 0.01	15 mm
TVL (m)	0.19 ± 0.03	0.16 ± 0.01	
$\bar{\mu}$ (m^{-1})	10.65 ± 0.07	12.27 ± 0.03	
HVL (m)	0.07 ± 0.02	0.57 ± 0.01	20 mm
TVL (m)	0.22 ± 0.03	0.19 ± 0.01	

Table 2: t-test: Paired Two Samples for mean of μ (m^{-1}). P <0.05 (one tail)

Aggregate Size (mm)		t- Stat	P -value	Level of Difference
15	10	-9.928	0.005	Significant
15	20	4.628	0.022	Significant

CONCLUSION

In this study, three sets of concrete samples were fabricated using three different aggregate sizes 10 mm, 15 mm and 20 mm of crushed granite rocks sourced from local quarries. The concrete samples of different thicknesses were exposed to ^{60}Co and ^{137}Cs gamma radiation sources at fixed distances, and an Inspector 1000 NaI(Tl) detector coupled to a multichannel analyser was used to monitor the radiation attenuation of each concrete sample exposed. The values of average linear attenuation coefficients obtained from the exposure of the concrete samples were 11.10 ± 0.02 cm^{-1}, 15.02 ± 0.03cm^{-1}, 12.19 ± 0.03 cm^{-1} for ^{137}Cs source and 7.24 ± 0.07 cm^{-1}, 9.66 ± 0.07 cm^{-1}, 8.73 ± 0.07 cm^{-1} for ^{60}Co source respectively. The results showed that the concrete mix obtained using 15 mm aggregate size attenuated the radiation much higher than the mix from 10 mm and 20 mm aggregates. Since effective aggregate packing increases with decrease in size and aggregate atom density increases with increasing size, this result is attributed to the achievement of equilibrium between aggregate compaction and aggregates' atom density at 15 mm which yielded low porosity that accounted for the better radiation attenuation performance.

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