ON THE EFFICACY OF CONCRETE PRODUCED USING NIGERIAN CEMENT IN SHIELDING GAMMA AND X-RAY FACILITIES

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Abstract: The radiation shielding quality of concrete samples fabricated from three selected Nigerian cement brands were studied in this work. Three sets of concrete blocks of different thicknesses were produced using concrete mixes ratio of 1:2:4. The density of each block was determined and the average for each of the three sets were evaluated and found to be 2204 ± 0.024, 2269.109 ± 0.027, and 2235.705 ± 0.022 kg/m^3, respectively. These results were found to have high precision with the world standard density for ordinary concrete (2350 kg/m^3). The concrete block samples were exposed to a ^{60}Co gamma radiation source and monitored using Sodium Iodide thallium activated detector. The average linear attenuation coefficient for the three sets samples were found to be 12.270 ± 0.021, 12.604 ± 0.070 and 12.189 ± 0.028 m^{-1}, respectively. From the results, the quality of ordinary concrete produced from Nigerian cement demonstrated good fidelity with the world standard.

Keywords: Attenuation, cement, concrete, density, gamma radiation, radiation, shielding

Introduction

Cement has been identified as an essential commodity that has very high demand in Nigeria (Mojekwu *et al*., 2013). The craving demand may be attributed to fact that many researchers have reported the indispensable role of cement in both concrete and sandcrete structures (Mohammed and Anwar, 2014; Chanthima *et al.,* 2012; Sam *et al.,* 2013; Umoh and Femi, 2013). A study conducted by Kazeem *et al.* (2015) showed that quality of cement determines the workability, compressive strength, porosity and concrete fracture. Hence, it is important to conduct regular study that will result to a continuous assessment of cement quality vis-a-vis concrete efficacy. Maslehuddin *et al.* (2013) reported that concrete is extensively used as a shield in nuclear plants, radio therapy and diagnosis rooms, transporting and storing radioactive wastes and radioactive sources. Osman *et al.* (2010) also reported that concrete is a very important shielding material that have gained versatile application in facilities having radiation generating equipment and radioactive sources. On a similar note, Maslehuddin *et al.* (2013) substantiated that because of its flexibility and versatility, concrete is the most common material used in the construction of commercial buildings, bunkers for housing radioactive sources, reactor core housing and X-ray rooms. Currently ordinary concrete (density about 2350 kg/m^3) is widely used as shielding material for superficial and orthovoltage radiotherapy and radiography rooms (IAEA, 2006). A survey conducted by Kazeem *et al.* (2015), revealed that building experts have identified the use of low quality building materials (such as cement, sand among others), as the major reason for the incessant collapse of buildings in Nigeria.

Cement is known to consist of a mixture of clinker and gypsum and the variation of its quality arises from the variations in the proportion clinker-gympsum in the mixture, and the quality of the clinker (Sam *et al.,* 2013). The study conducted by Muibat (2009) revealed that most Nigerian local cements conform well to the American Society for Testing and Materials (ASTM) and British Standard (BSI) guidelines. Ndefo (2013), identified cement as the chemically active component of concrete and its characteristics to a large extend determines the quality of concrete produced from it. In May 13th, 2014, Standard Organization of Nigeria (SON) approved the new standard of Nigerian cements based on the recommendations of the technical Committee set by the governing board (Vanguard; Nigerian Daily Newspaper, March 13th, 2014). Stakeholders gave mandatory order for compliance by the local manufacturers of cement and importers as well.

The new approved standard of cement (NIS 444-11:2014) allowed the addition of limestone to about 6-35% and reduction of clinker content to 65-95%. This changed the quality of Nigerian local cement from ordinary Portland cement (OPC) to that of Portland-limestone cement (Kazeem *et al.*, 2015). The report published by Cement manufacturers association of Nigeria (CMAN, 2016) showed that there are currently five major cement manufacturing companies in Nigeria namely: Dangote, Boa, Ashaka, Sokoto and Burham cement; and that each of this cement companies produces cements in grades (32.5, 42.5 and 52.5) depending on the level of limestone content. Though Kazeem *et al.* (2015) reported that only grades 32.5 and 42.5 are found in Nigerian open market. As demonstrated by Kazeem *et al.* (2015), addition of excess limestone to OPC reduces the compressive strength of cement and the extent of reduction depends directly on the percentage of limestone added to the cement. Consequently, the quality of concrete produced from this cement may not be the same as that produced using ordinary Portland cement. It is therefore imperative to design a work as this to assess the quality of concrete produced from this cement and their radiation shielding properties with the aim of having optimum local radiation protection guidelines established.

Materials and methods

Concrete fabrication

Three cement brands grade 42.5 (Dangote, Boa and Ashaka cement) were collected from the local cement vendors and used in fabricating three sets of concrete blocks. The selection of cement brands was based on their availability within the area of study and were designated A, B and C for easy identification during the experiment. 4 – 5 mm river sands were used together with 20 mm crushed granite aggregate collected from a quarry site located at Ban-Zazzau, Zaria Kaduna state. This type of aggregate is commonly used for concrete production in Nigeria (Kazeem *et al.*, 2015). Fifteen concrete blocks were produced using the three cement brands (A, B and C) and grouped into three sets with each set consisting of 5 concrete blocks of different thicknesses. The thicknesses of the concrete slabs were so chosen in such a way that will enable ease in handling and fitting the geometry of the radiation sources. These samples of concrete were produced according to the standard of American Society for Testing and Materials (ASTM) no C637 (ASTM C37, 1998). The mixture of cement-sand-gravel was based on the concrete mixes 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 was adopted (Azeez *et al.,* 2013). 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 laboratory temperature of 28°C to prevent the thermal stresses that could result in cracking (James *et al.*, 2011). After the curing days, the concrete samples were removed, sun dried, weighed and conveyed for exposure to ^{60}Co gamma radiation source at the Centre for Energy Research and Training, Ahmadu Bello University Zaria, Nigeria.

Estimation of concrete attenuation properties

The measurement was performed using gamma ray 2”×2” NaI (Tl) Inspector 1000 detector with a Multi-Channel Analyser (MCA). The detector was operated at dose rate mode and in such a way that it gives direct instantaneous dose rate measurements. Four measurements of dose rate were taken at four different positions of each concrete sample and the average was computed. The distances from the source to the sample and from the source to the detector were chosen in such a way that the build-up factor becomes negligible and was kept constant throughout the experiment at 30 and 60 cm, respectively. The source strength as at the time of the experiment (March 27th, 2016) was 5 mCi. The source produces a well collimated beams of mono-energetic gamma rays of energies 1.173 and 1.332, respectively. Before the insertion of each concrete sample of thickness x, initial ambient dose rate was taken as $\dot{D}_o$(mSv/h) while other dose rate measurements $\dot{D}_x$(mSv/h) were taken after the insertion of the concrete sample between the source and the detector. The linear attenuation coefficient (m^{-1}) was determined from Eq. 1 (Knoll, 2010) using Microsoft Excel 2013.

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

Where: $\dot{D}_x$ is the dose rete measured when a sample of thickness x is inserted between the source and the detector; $\dot{D}_o$ is the initial dose rate; μ is the linear attenuation coefficient and x is the thickness of concrete slab.

Estimation of density of the fabricated concrete

The density of each concrete sample in each set was evaluated using Eq. 2 after the measurement of mass and volume of the samples using a weighing balance and a meter rule, respectively. The standard error (SE) was computed using Eq. 3 (Nicholas, 1995).

$$\rho = \frac{m}{V} \quad (2)$$

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

$$SE = \frac{\sigma}{\sqrt{N}} \quad (3)$$

Where σ the standard deviation from the average value and ‘N’ is the number of samples in each set

Results and Discussion

From the results presented in Table 1, the average density of concrete produced from cement A, B and C were found to be 2204 ± 0.024, 2269.109 ± 0.027, and 2235.705 ± 0.022 kg/m^3, respectively. These results were compared with the world standard density for ordinary concrete (2350 kg/m^3) using Microsoft Excel 2013 to obtain the percentage difference between the standard value and each of the above density values. It was found that the density of concrete produced from A, B and C were less than the standard value by 6, 3 and 5%, respectively. This implies that the quality of Nigerian Portland cement despite the addition of limestone and reduction of clinker content remained significantly unaffected with respect to concrete quality. Also, the difference in the average values of concrete density of samples produced from (A and B), (A and C) and (B and C) were found to be 2.8, 1.3, and 1.5%, respectively. This showed that the cements have almost the same quality irrespective of the brand.

Table 1: Densities of concrete samples fabricated for the cement brands

S/N	Cement Brand	M (kg)	SE (kg)	V(m^3) X10^{-2}	SE(m^3) X10^{-6}	ρ(kg/m^3)	SE (kg/m^3)
1	A	3.45	0.029	0.157	3.33	2202.128	0.029
2		5.517	0.017	0.235	5.77	2347.518	0.017
3		7.317	0.017	0.315	3.33	2325.212	0.017
4		9.05	0.029	0.392	5.77	2308.673	0.029
5		11.05	0.029	0.472	3.33	2339.45	0.029
					Average	2204.596	0.024
1	B	3.55	0.029	0.157	3.33	2265.957	0.029
2		5.25	0.029	0.235	5.77	2234.043	0.029
3		7.15	0.029	0.315	3.33	2272.246	0.029
4		9.033	0.033	0.392	5.77	2304.422	0.033
5		10.717	0.017	0.472	3.33	2268.878	0.017
					Average	2269.109	0.027
1	C	3.417	0.017	0.157	3.33	2180.851	0.017
2		5.317	0.017	0.235	5.77	2262.411	0.017
3		7.15	0.029	0.315	3.33	2272.246	0.029
4		8.85	0.029	0.392	5.77	2257.653	0.029
5		10.417	0.017	0.472	3.33	2205.363	0.017
					Average	2235.705	0.022

Table 2: Measured attenuated dose rates

S/N	Cement Brand	Initial dose rate (μSvh^{-1})	X(m)	Mean dose rate (μSvh^{-1})	SE (μSvh^{-1})	μ (m^{-1})
1	A	3.050 ±0.006	0.05	1.533	0.033	13.76
2			0.08	1.3	0.058	10.663
3			0.11	0.75	0.029	12.755
4			0.14	0.567	0.009	12.021
5			0.17	0.413	0.009	11.759
1	B	3.050 ±0.006	0.05	1.55	0.029	13.54
2			0.08	0.983	0.044	14.15
3			0.11	0.73	0.015	13
4			0.14	0.61	0.006	11.492
5			0.17	0.483	0.009	10.835
1	C	3.050 ±0.006	0.05	1.45	0.029	14.88

The measured dose rate before and after the insertion of concrete samples between the sources and the detector are presented in Table 2. The average values of linear attenuation coefficients of the three sets of concrete blocks produced from A, B and C were computed again using Microsoft excel 2013 and the results were found to be 12.270 ± 0.021, 12.604 ± 0.070 and 12.189 ± 0.028 m^{-1}, respectively. From the results, it is clear that the average linear attenuation coefficients of the concrete block samples produced from the three cement brands under consideration that the average linear attenuation coefficients have high fidelity. The linear attenuation coefficients were also analyzed using Microsoft excel 2013 T-test (pair two samples for means) at P< 0.05 one – tail in order to determine the extent to which the values differ from each other and the result indicated that the difference between the shielding properties of concrete produced from Nigerian local cement brands was not significant. Consequently, the results from this work showed that the Nigerian local cement has good quality as there was a very close precision in the average density of the concrete samples produced with the standard density for ordinary concrete as recommended by the international atomic energy agency.

Conclusion

Three brands of Nigerian local cement (designated A, B and C) were used to produce three sets of concrete blocks of different thicknesses. Each set of concrete blocks consisted of 5 blocks giving a total of 15 blocks all together. The density of each block was determined and the averages were evaluated and found to be 2204 ± 0.024, 2269.109 ± 0.027, and 2235.705 ± 0.022 kg/m^3, respectively. These results were found to have good precision with the world standard density for ordinary concrete (2350 kg/m^3) by 6, 3 and 5%, respectively. Upon exposure of the concrete blocksamples to a ^{60}Co gamma radiation source and monitored, the linear attenuation coefficient for each sample was evaluated and the averages were found to be 12.270 ± 0.021, 12.604 ± 0.070 and 12.189 ± 0.028 m^{-1}, respectively. The attenuation coefficients were analyzed using t-test statistics to ascertain the level of their difference, and the results showed that there is no significant difference in the shielding properties of concrete produced from the three cement brands studied. Consequently, the Nigerian local cements were found to have good quality and could be used in building structures to shield gamma and X-ray facilities independent of the brand.

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Conflict of Interest

The authors declare that there is no conflict of interest related to this study.

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