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Gradation of the Radiation Shielding Integrity of the Cement Brands in Botswana

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Abstract: A study of the radiation shielding properties of cement brands was carried out. The study established HVLs of the different cement brands. Cements suitable for construction of concrete bunkers for photon shielding were recommended. Three CEM I 42.5 N all-purpose cement which were the most prevalent brands in the market were chosen i.e. PPC, Afrisam and La farge cement by trade names. The cement block samples were prepared by mixing cement and water at a constant water to cement ratio of 0.32. The HVLs were determined using a diagnostic x-ray beams at 50 kVp through 125 kVp at 10 mAs in a 10 cm x 10 cm field size, 100 cm SDD and the Unifors XI detector. The PPC cement gave optimum HVLs for beams at below 110 kVp while Afrisam cement gave optimum values HVLs for the energies above 110 kVp. The most suitable for concrete construction was PPC cement for photons at 50 kVp to 110 kVp and Afrisam is most suitable cement for applications utilizing over 110 kVp to 125 kVp.

Keywords: Shielding, HVL, Lafarge, PPC, Afrisam.

1 Introduction

The utilization of ionizing radiation are realized in many applications. The applications are associated with potential harmful effects to human health. The effects are potentially of stochastic and deterministic nature [5,8,15].

The effects can be minimized through application of radiation protection measures. The measures practiced include time limitation to sources, maintaining distance away from sources and shielding against the sources. The latter method is most feasible and effective method of reducing public and occupational exposures [2,11].

The shielding walls are essentially concrete structures. Concrete has a well-established linear attenuation coefficient for photons, it's mixing and casting is not highly sophisticated, adaptable to many wall designs, the strength and density ate acceptable and can be locally constructed. Concrete is usually used without any added high radiation attenuating material [1-5].

Concrete is a composite material and consists of a mixture of aggregates and paste. The aggregates are sand, natural gravel and or crushed stone whereas the paste is cement and water. The paste serves to bond the aggregates together and constitutes about 25% on average of the total volume of the Concrete [6-8].

Since cement constitutes such a significant volume on the total volume of concrete, its photon attenuation properties are of high interest. The cement's photon attenuation properties can be used to hypothesize the cement's contribution on the total photon attenuation of the concrete. It is therefore essential to examine the photon attenuation properties of cement.

2 Experimental Section

2.1 Cement Brands and Types

A comparison was made between three brands of Pretoria Portland Cement (PPC) (LOA Nr: AZ/9085/2008/0024), Afrisam cement (LOA Nr: AZ/9085/2012/0122) and La Farge cement (LOA Nr: AZ/9085/2007/0222). The CEM I 42.5N all-purpose cement was chosen across the brands as it was normally used in a wide variety of building and masonry applications due to its consistent strength and workability.

2.2 Cement Mold Design

The molds for casting the cement blocks were designed and constructed at the Faculty of Engineering and Technology Design Laboratory at the University of Botswana. The mold

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was constructed using Aluminium sheet. The sheets were measured and marked using a metal marker. The sheets were then cut using a metal cutting shears and bent using a metal bender to obtain the mold in the form of a cuboid shape [9].

Five molds were created of similar dimensions of length and width and different thicknesses (heights). The various molds' thicknesses were 1.0 cm, 1.5 cm, 2.0 cm, 2.5 cm and 3.0 cm. The dimensions represented in **Figure 1** are for the mold with 1.0 cm thickness.

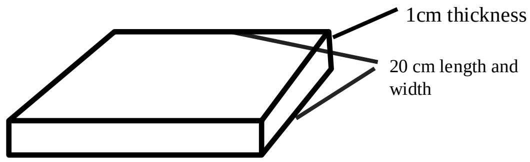

Fig. 1: The dimensions of one of the molds constructed

2.3 Cement Block Construction

The cement blocks were constructed at the faculty of engineering and technology construction laboratory. Cement blocks of identical size and shape were made for different brands of cement by mixing with water. The cement blocks were made of cement and water only. This was to ensure uniformity between the blocks. A constant water volume mixing ratio was maintained across all the cements. The ratio of water to cement used was 0.32. The cement and water were weighed using a weighing balance. A container which when filled with cement, contained 1.7 kg of cement was used to gauge the cement which was then mixed with water filled in a 500 ml cylinder [10].

The mold was first smeared with grease to prevent the cement paste from sticking to the surface of the mold. The cement was mixed with water using a trowel in a mixing pan. The cement paste was then filled in a mold using a trowel. A handheld compactor was then used to compact the cement paste inside the mold. The trowel was then also used to level the cement paste mold. The cement paste was then left in the mold overnight to set before being removed.

The cement blocks were then removed after being left overnight to set. The blocks were covered to prevent rapid moisture loss in order for them to gain strength. All the block were then heated in an oven at the same time at a temperature of 60 ^{0}C for 30 minutes to improve uniformity of moisture content among all the blocks. The cement blocks thickness was the measured with a micrometer screw gauge. The thicknesses were measured at four points around the block and the average was calculated and recorded. The lengths and widths of the block were measured using a ruler. The masses of the blocks were measured using a weighing balance. The blocks were weighed three times and the average calculated and recorded [11-13].

2.4 Determination of Half Value Layers (HVLs)

The measurements of HVLs were carried out at the X-RAY Diagnostic Centre, a privately owned clinic in Gaborone, Botswana. **Figure 2** shows some of the materials used i.e. x-ray beams; cement blocks; Unifors Xi detector; FH40 GL-10 proportional counter; measuring tape; thermometer; barometer; and plastic sheets.

The apparatus was setup at the centre of the x-ray room so

Fig. 2: Cement water mix, mold and experiment layout

that the radiation scattered from the walls would have had minimal effects on the detector dose. The procedure was as follows:

a. The apparatus was set up as shown in **Figure 2**.

b. The x-ray source to detector distance (SDD) was set and maintained at 100.00 cm.

c. The background radiation, humidity and temperature were read and recorded.

d. Collimators were set to field size of 10 cm x 10 cm

e. The x-rays were switched on for 50 kVp and 10 mAs and dose rate exposure in mGy/s was measured without the absorber.

f. The absorber (cement block) was then placed 50 cm from the x-ray source, about midway between the source and the detector.

g. The x-rays were switched on and transmitted dose rate in mGy/s measured.

h. Data was recorded as shown in **Table 1.**

i. The steps (c) to (h) were repeated for tube voltages from 60 kVp in steps of ten up to 125 kVp and for absorbers of different thicknesses.

3 Results and Discussion

The HVLs of the cement brands were extracted from the plots of dose rates and block thicknesses. The comparisons between HVLs between the cements and the various s tube voltages is as shown in **Figure 3**. The Aluminium has the lowest HVLs across all kVps while the PPC and Afrisam had intermediate values. La farge cement gave the highest HVL values.

The photon attenuation properties of cement brands were determined. Other aggregates of concrete i.e. sand, gravel and crushed stone were excluded from the study. This was based on the assumption that all cement are mixed in the similar proportions.

Table 1: HVLs of X-ray beams in terms of cement and Al.

		HVLs		
kVp	mm PPC	mm Afrisam	mm La Farge	mm Al
50	3.81	5.25	5.95	1.81
60	4.39	5.41	6.14	2.23
70	4.48	5.43	6.21	2.65
80	5.21	6.21	7.81	2.93
90	7.81	7.99	9.65	3.33
100	7.99	8.21	10.03	3.61
125	11.41	10.99	13.79	4.18

The photons energies are as shown in **Table 1** and the percentage difference between the displayed kVp and the set kVp was less than 5 %. Therefore percentage error due to tube voltage accuracy was minimal.

The dose rates were measured and HVLs in mmAl calculated by the Unifors and used as a reference standard. Conditions of good geometry were observed i.e.10 cmx 10 cm field size; block placed at 50% of SDD to minimize scatter to the detector; and all blocks were at least 100 cm^2 to allow complete beam irradiation. There was no other scattering material in the vicinity of the detector.

The Al had the lowest HVLs across all the kVps. Al thus attenuated the beam more than cement. The cement brands PPC and Afrisam had intermediate HVLs across all kVps c.f to La farge cement which had highest values of HVLs. Consequently, PPC and Afrisam cement are attenuating than La farge cement.

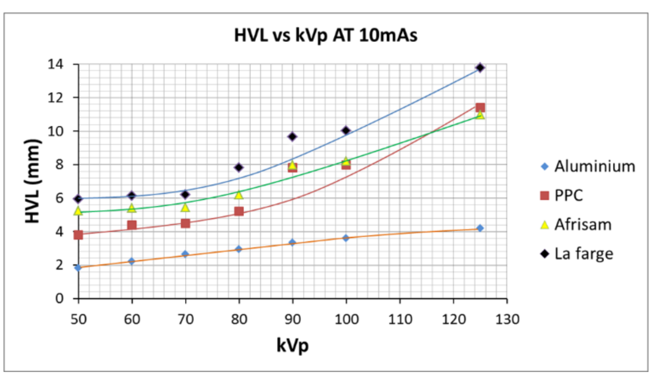

Fig. 3: Plot of HVL against kVp

The differences in shielding properties of cement may be due to the differences in metal type and or proportion in the raw materials. The trace elements like Cr, Ni, Cd, Cu, Co, Zn are some of the raw materials added during the manufacturing processes [14]. The observed high attenuation property of PPC cement compared to other brands of cement could be due to higher concentration of these metals.

4 Conclusions

The HVLs were determined for various settings of peak tube voltage of an x-ray beam. From 50.00 ± 0.05 kVp to 110.00 ± 0.05 kVp at 10mAs, PPC cement recorded the optimum values of half value layers beam when compared with Afrisam and La farge cements. Between 110.00 kVp and 125.00 kVp settings of an x-ray beam, Afrisam cement recorded the optimum values of half value layers when compared with PPC and La farge cements.

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