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Gamma-ray shielding of concretes including magnetite in different rate

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The effect of magnetite ore rate on the gamma radiation shielding properties of concrete samples have been measured by using the transmission method for 59.54 and 80.99 keV gamma rays with a NaI(Tl) detector. Linear attenuation coefficients of concrete samples including magnetite in different rates were obtained by Lambert law in which measured gamma ray intensities were used. They were compared with theoretical values calculated from WinXCom computer software. It was determined that linear attenuation coefficients increased with increasing magnetite rate in concrete samples.

Key words: Linear attenuation coefficients, magnetite, concrete, WinXCom.

INTRODUCTION

There are some methods that control the intensity of radiation received from a radioactive source. One of the most significant of these methods is the radiation shielding, which is the science of protecting people and the environment from the harmful effects of radiation. The principle of the radiation shielding is to decrease the intensity of external radiation to the desired level. A good photon shielding material should have high value of photon attenuation coefficients and irradiation effects on its mechanical properties should be small. Concrete is an excellent sheilding material most widely used for radiation shielding of nuclear plants, in the walls of radiology and oncology departments in hospitals (Kaplan, 1989). In medical accelerator room's construction, high-density concrete (3.0 to 5.0 g/cm^3) is employed to provide shielding against radiation (Facure and Silva, 2007). Concrete density depends on aggregate weight. Heavy or high-density aggregates are used to increase the density of concrete. Magnetite (Fe_3O_4) having a high density (4.9-5.2 g/cm^3) is an effective shielding material for γ-rays (Bashter, 1997; El-Sayed and Megahid, 2001). In recent years, several studies relevant to the measurement of linear and mass attenuation coefficients for different types of materials have been published (Akkurt et al., 2009, 2010, 2012; Demir and Keleş, 2006; Han et al., 2011; Oto et al., 2013; Seven et al., 2004; Shirmardi et al., 2013; Medhat, 2009; Mostofinejad et al., 2012).

In the present work, linear attenuation coefficients of concrete samples with magnetite (Fe_3O_4) at the energies of 59.54 and 80.99 gamma rays were obtained experimentally, and calculated using WinXCOM computer code. The experimental results have been compared with the calculations.

MATERIALS AND METHODS

Preparation of concrete samples

In this study, four concrete samples including magnetite with

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Table 1. The result of the chemical analysis of magnetite.

Compound	Magnetite (%)
CaO	1.15
MgO	0.50
Al_2O_3	1.26
Na_2O	0.195
SiO_2	8.41
MnO	0.44
CuO	0.013
FeO	85.74
BaO	2.24

Table 2. Amounts of concrete composition.

Concrete	w/c ratio	Magnetite rate (%)	Aggregate (kg/m^3)
K*	0.5	0	1350
M1	0.5	2.5	1350
M2	0.5	5	1350
M3	0.5	10	1350
M4	0.5	20	1350

*Oto et al. (2013).

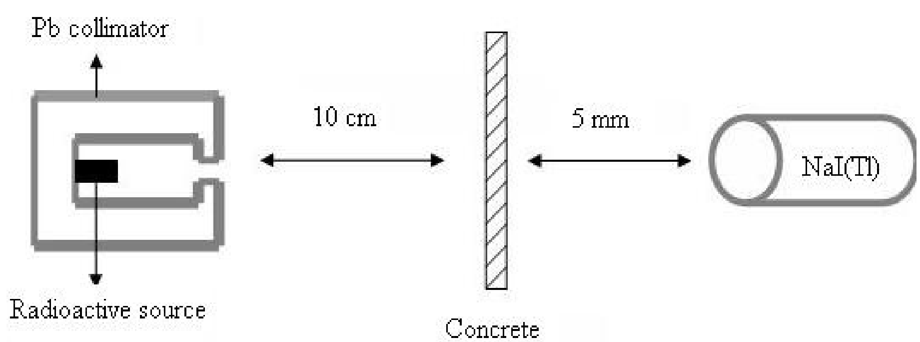

Figure 1. Schematic diagram of the experimental arrangement.

different rates have been produced. Cement and modular sand used in the concrete samples were provided from the Van Gölü Cement Factory in Van, Turkey and magnetite supplied from the Cataş Mine Works in Elbistan, Turkey. The result of elemental analysis of magnetite determined by X-ray fluorescent method and result is given in Table 1. The magnetite was used in fractions of 2.5, 5, 10 and 20% in weight of cement. Amounts of concrete composition are listed in Table 2. Aggregates used in this work were 0 to 4 mm and 8 to 16 mm grain sizes. In order to prepare concrete samples, magnetite sieved by a 100 mesh standard sieve. For the measurements 15×15×4 cm concrete samples were prepared.

Experimental details

The linear attenuation coefficients of concrete samples have been measured using NaI(Tl) detector which connected to a multichannel analyzer. The gamma photons were obtained from ^{241}Am (59.54 keV) and ^{133}Ba (80.99 keV) radioactive sources. These sources were shielded by the pin hole lead collimators to obtain a narrow beam. For each energy, all concrete samples were irradiated three times by gamma rays.

The schematic arrangement of the experimental setup used in the present work is given in Figure 1. The source-sample and sample-detector distance was adjusted as 10 cm and 5 mm, respectively. The data were collected into 4096 channels of a Desktop Inspector Digital Spectrum Analyzer, connected with the PC by Genie 2000(3.0) software. The linear attenuation cofficients (µ,cm^{-1}) was obtained by Lambert law's:

$$I = I_0 \exp(-\mu x) \tag{1}$$

where x is material thickness (mass-per-unit area), I_0 is the incident

Table 3. Experimental (E) and theoretical (T) linear attenuation coefficients at 59.54 keV and 80.99 keV.

			59.54 keV		80.99 keV	
Concrete	**Magnetite rate (%)**	**Density**	**µ (E)**	**µ (T)**	**µ (E)**	**µ (T)**
K*	0	1.94	0.640 ± 0.00110	0.673	0.420 ± 0.00100	0.446
M1	2.5	2.11	0.708 ± 0.00066	0.736	0.463 ± 0.00185	0.485
M2	5	2.12	0.738 ± 0.00233	0.742	0.469 ± 0.00120	0.489
M3	10	2.16	0.763 ± 0.00266	0.768	0.489 ± 0.00260	0.503
M4	20	2.22	0.819 ± 0.00202	0.812	0.514 ± 0.02107	0.528

*Oto et al. (2013).

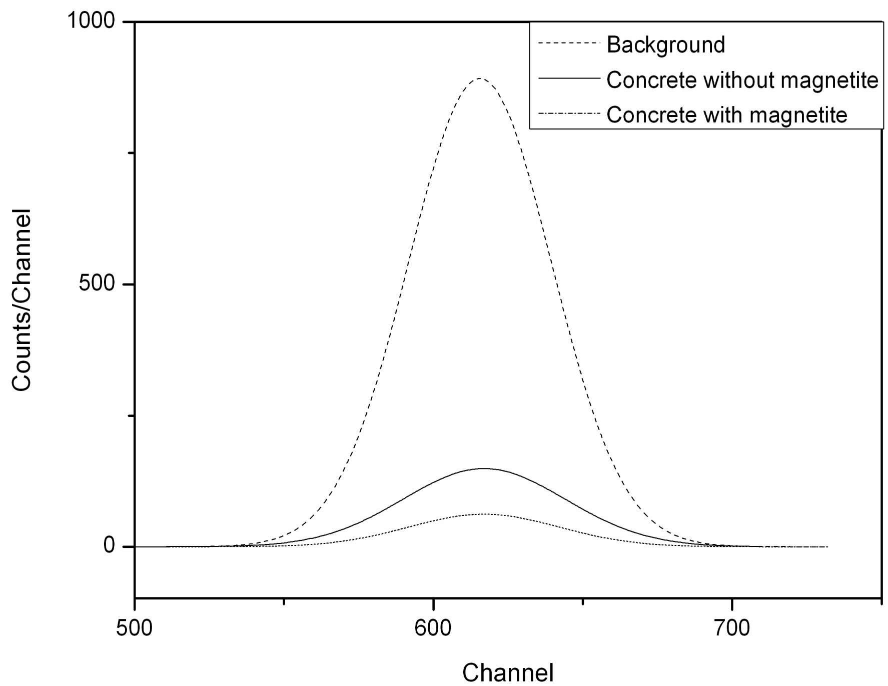

Figure 2. Spectrums of gamma radiation obtained background, concrete samples with and without magnetite.

gamma ray and I is the photon intensity recorded in detector. The theoretical linear attenuation coefficients which were calculated using WinXCom computer code were compared with the measured linear attenuation coefficients. WinXCom based on applying the mixture rule to calculate the partial and total mass attenuation coefficients for elements, mixtures and compounds for photon energies ranging from 1 keV to 1 GeV (Gerward et al., 2001).

RESULTS AND DISCUSSION

In this study, the measured intensities of transmitted gamma ray (I) through the concrete samples with or without magnetite and the incident gamma ray (I_0) were using in Lambert law, linear attenuation coefficients were obtained experimentally and theoretical mass attenuation coefficients were calculated from WinXCom software at the energies 59.54 and 80.99 keV. The value of linear attenuation coefficient of ordinary concrete sample without magnetite, (K, 0%), was taken from our previous study (Oto et al., 2013). The measured and calculated results are listed in Table 3. It can be seen from this table that there is a good agreement between experimental and theoretical results. A typical spectrum of 80.99 keV gamma ray transmissions through the concrete sample with and without magnetite is shown in Figure 2. It is seen from this figure, gamma rays intensity obtained from concrete samples with magnetite is lower than that of ordinary concrete samples. For all types of concrete samples, linear attenuation coefficients decrease with increasing gamma ray energy.

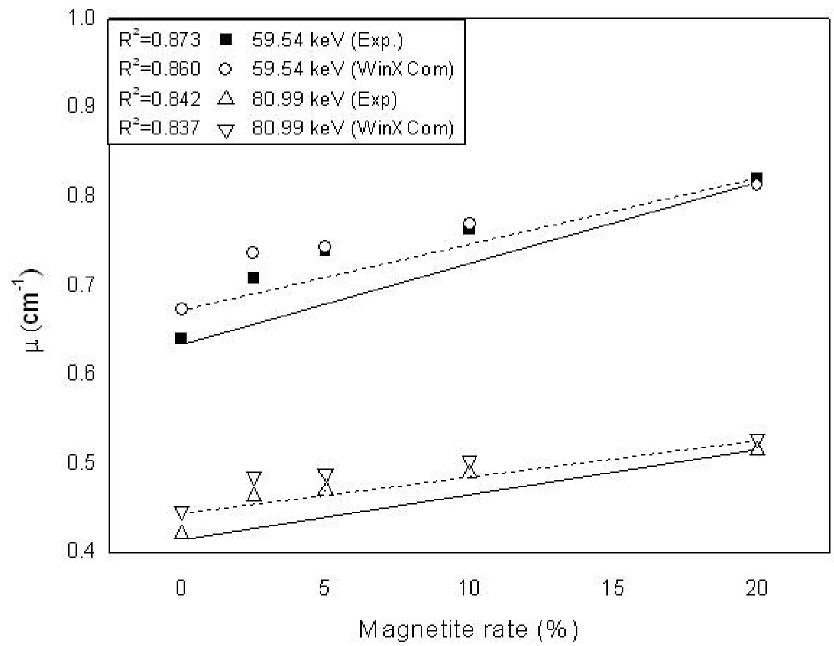

Figure 3. Linear attenuation coefficients of the concrete samples versus magnetite weight concentration for two photon energies.

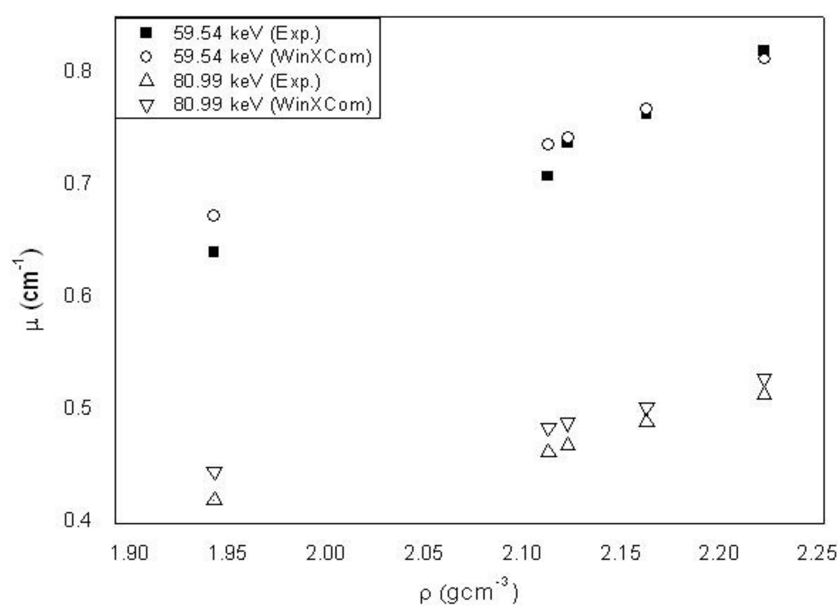

Figure 4. Linear attenuation coefficients of the concrete samples versus density for 59.54 and 80.99 keV energies.

The experimental and theoretical linear attenuation coefficients of concrete samples versus the sample types were plotted in Figure 3 using the least-squares methods. The correlation theory is used to confirm the linearity of the experimental and theoretical values. For 59.54 and 80.99 keV photon energies, the correlation coefficients of the experimental and theoretical values are R^2 = 0.873, R^2 = 0.860 and R^2 = 0.842, R^2 = 0.837, respectively. It can be seen from Figure 3 that the linear attenuation coefficients of concrete samples with magnetite are higher than the ordinary concrete (K) and the linear attenuation coefficients increase with increasing magnetite rate. This means that concrete samples with magnetite attenuated gamma rays more than the ordinary concrete.

Figure 4 shows the variation of linear attenuation coefficients with density of concrete samples for both experimental and theoretical values. It is clear from this figure that, with regard to gamma-ray shielding, the concentration rates of magnetite in concrete samples increase the density of the sample, because the concrete samples with magnetite have iron content. Also (μ) values of concerete samples containing magnetite are greater than the ordinary concrete. For 1.5 MeV gamma energy, linear attenuation coefficients of the two concretes prepared from steel-magnetite (ρ = 5.11 gcm^{-3}) and basalt-magnetite (ρ = 3.05 gcm^{-3}) have been reported to be 0.220 and 0.139 cm^{-1}, respectively (Bashter et al., 1997). Akkurt et al. (2009) studied the radiation shielding of concretes containing barite in different ratios (Akkurt et al., 2010). They have found that, linear attenuation coefficients of BC0 (%0 barite), BC50 (%50 barite), BC100 (%100 barite) samples were 0.257 ± 0.012, 0.287 ± 0.014, 0.297 ± 0.014 at 662 keV gamma energy, respectively and their results showed that linear attenuation coefficient was a function of concrete density. It is clearly seen that the linear attenuation coefficients depend on the photon energy and density of the shielding material, and the concrete samples containing magnetite are remarkably effective for shielding gamma rays. It can be concluded that concrete samples with magnetite have better properties than the ordinary concrete.

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