Available online at www.sciencedirect.com
SCIENCE DIRECT

Cement & Concrete Composites 28 (2006) 153–157

Cement & Concrete Composites

www.elsevier.com/locate/cemconcomp

Radiation shielding of concretes containing different aggregates

I. Akkurt [a,*], C. Basyigit [b], S. Kilincarslan [b], B. Mavi [a], A. Akkurt [c]

[a] *Suleyman Demirel University, Fen-Edebiyat Fakultesi Fizik Bol., Isparta 32260, Turkey*
[b] *Suleyman Demirel University Teknik Egt. Fak. Yapi Egt. Bol. Isparta 32260, Turkey*
[c] *Afyon Kocatepe University Fen-Edebiyat Fakultesi Fizik Bol. Afyon, Turkey*

Received 24 November 2004; accepted 26 September 2005
Available online 22 November 2005

Abstract

The shielding of γ-rays by concrete has been investigated for concretes containing different amounts of barite and normal weight aggregates. The linear attenuation coefficients (μ, cm^{-1}) have been calculated at photon energies of 1 keV to 100 GeV using XCOM and the obtained results compared with the measurements at the photon energies of 0.66 MeV and 1.33 MeV. It is shown that the type of the aggregate is more important than the amount of aggregate used in concrete for γ-ray shielding.

Keywords: Concrete; γ-rays shielding; Photon attenuation

1. Introduction

Concrete which contains water, cement and aggregate, is widely used in building construction such as nuclear power stations, particle accelerators and medical hospitals. The type and quantity of aggregate in the concrete are important components for radiation protection properties of concretes. Using barite ($BaSO_4$) in building construction surely would be a good choice to protect against radiation, but this is not feasible as there is not enough barite reserve in the world. Using barite-loaded heavy concrete is one of the alternative ways in building construction to provide radiation protection. The interaction of γ-rays depends on the incoming photon energy [1], and it is difficult to shield γ-rays as it has no mass and charge. The linear attenuation coefficient (μ), which is defined as the probability of a radiation interacting with a material per unit path length, is the most important quantity characterizing the penetration and diffusion of γ-rays in a medium. Its magnitude depends on the incident photon energy, the atomic number and the density (ρ) of the shielding materials [2]. Several works have been performed to obtain linear attenuation coefficients (μ) theoretically and experimentally for different elements, compounds and mixtures [3], for different building materials [4], for concretes [5,6] and for some aqueous solutions [7]. In this paper, the linear attenuation coefficients (μ) were extracted from the mass attenuation coefficients (μ/ρ) calculated using the computer code XCOM, to investigate the contribution of different types (barite or normal aggregate) and different content of aggregates in concretes for photon attenuation. The results were compared with the experimental data obtained with 0.66 MeV and 1.33 MeV photons.

2. Materials and methods

Five different series of concrete, each having three different classifications (in total 15 different), were prepared to test the contribution of barite and normal aggregate content in concrete to protect against γ-rays. Each concrete was prepared using a different ratio of water (w), cement (c), normal aggregate and barite. These are according to mixing value; if the whole volume of aggregate is normal aggregate the concrete is called A; if it is barite it is called

* Corresponding author. Tel.: +90 246 211 4033; fax: +90 246 237 1106.
E-mail address: iskender@fef.sdu.edu.tr (I. Akkurt).

0958-9465/$ - see front matter
doi:10.1016/j.cemconcomp.2005.09.006

Table 1
Composition of all types of concrete (kg/m^3)

	A2	A3	A4	B2	B3	B4	K2	K3	K4	AB2	AB3	AB4	BA2	BA3	BA4
Cement	310	362	425	310	362	425	310	362	425	310	362	425	310	362	425
Water	201	183	183	201	183	183	201	183	183	201	183	183	201	183	183
w/c	0.65	0.51	0.43	0.65	0.51	0.43	0.65	0.51	0.43	0.65	0.51	0.43	0.65	0.51	0.43
Fine normal aggregate	697	697	679	–	–	–	349	349	338	697	697	679	–	–	–
Coarse normal aggregate	1092	1092	1061	–	–	–	545	547	531	–	–	–	1092	1092	1061
Fine Barite aggregate	–	–	–	1113	1114	1083	557	558	542	–	–	–	1113	1114	1083
Coarse Barite aggregate	–	–	–	1700	1701	1653	850	850	826	1700	1701	1653	–	–	–

B; if the fine aggregate is normal and coarse aggregate barite it is called AB while coarse aggregate that is barite and the fine aggregate normal it is called BA; if half of aggregate is normal and the other half barite it is called K. The indices of 2, 3, 4 represent the w/c ratio of 0.65, 0.51 and 0.43, respectively. The percentage values of composition of all the types of concrete are given in Table 1. The preparation of the concretes in more details can be found in elsewhere [8].

The linear attenuation coefficients (μ) were extracted from the mass attenuation coefficients (μ/ρ) calculated using the XCOM code and data base at photon energies of 1 keV to 100 GeV [9]. The XCOM data base runs on a PC and was prepared by combining previously existing data bases for coherent and incoherent scattering, photoelectric absorption, and pair production cross-sections. It uses the chemical structure of materials as input for concretes. The linear attenuation coefficients (μ) were determined by measuring the transmission of γ-rays through targets of three different thicknesses (2 cm, 4 cm, and 6 cm in this study) and the γ-rays were obtained from ^{137}Cs and ^{60}Co sources which emit photons of 0.66 MeV and 1.33 MeV, respectively. The linear attenuation coefficient (μ) was obtained by Lambert's law

$$N = N_0 e^{-\mu x} \quad (1)$$

where x is the sample thickness and N and N_0 are the number of counts recorded in the detector with and without the shielding targets, respectively. Plotting each $\ln(N_0/N)$ versus x would give a straight line and the linear attenuation coefficient can be obtained using the value of the slope.

3. Results

The linear attenuation coefficients (μ) for the 15 different concretes have been calculated at photon energies of 1 keV to 100 GeV and measured at photon energy of 0.66 MeV and 1.33 MeV. The measured results are tabulated in Table 2 for the energy of 0.66 MeV and 1.33 MeV. In Fig. 1 the calculation and measured linear attenuation coefficients (μ) are displayed for the ordinary concretes (upper) and for concretes loaded with barite (lower). It can be seen that the linear attenuation coefficients (μ) are the same in magnitude for the same aggregate even though the w/c ratios are different (A2, A3, A4 upper and B2, B3, B4 lower). It can be noted that the calculated and measured values are in good agreement. To investigate the contribution of normal aggregate and barite to the radiation shielding the linear attenuation coefficients are displayed in Fig. 2 for different w/c ratios. As can be seen from those figures, the linear attenuation coefficients (μ) are higher for barite-loaded concrete than for ordinary concrete, and this leads to the conclusion that barite is an important material to be used in radiation shielding. The linear attenuation coefficient (μ) has been calculated for all concretes as a function of photon energy. It is interesting to investigate the contribution of different contents of aggregate used in concrete to the linear attenuation coefficients (μ). This is shown in Fig. 3 for different w/c ratios and compared with the measured data obtained at photon energies of 0.66 MeV and 1.33 MeV. It can be seen from this figure that the agreement between calculation and measurement is good and the linear attenuation coefficient does not vary with the content of normal and barite aggregate used in concrete (AB, BA, K). As the interaction of radiation with matter depends on the material's density, it is interesting to display linear attenuation coefficients (μ) as a function of concrete's density. This is shown in Fig. 4 (for photon energy of 0.66 MeV and 1.33 MeV) where it can be seen that the linear attenuation coefficient (μ) increases with an increase in concrete density.

Table 2
The measured results of μ obtained for 0.66 MeV and 1.33 MeV photons

Concrete	0.66 MeV	1.33 MeV
A2	0.212 ± 0.038	0.1072 ± 0.016
B2	0.253 ± 0.037	0.1567 ± 0.023
K2	0.249 ± 0.037	0.1300 ± 0.019
AB2	0.265 ± 0.039	0.1280 ± 0.019
BA2	0.248 ± 0.037	0.1221 ± 0.018
A3	0.242 ± 0.036	0.1020 ± 0.0153
B3	0.248 ± 0.037	0.1386 ± 0.020
K3	0.241 ± 0.036	0.1304 ± 0.019
AB3	0.260 ± 0.039	0.1457 ± 0.021
BA3	0.266 ± 0.039	0.1368 ± 0.020
A4	0.248 ± 0.037	0.1046 ± 0.015
B4	0.255 ± 0.037	0.1490 ± 0.022
K4	0.256 ± 0.038	0.1495 ± 0.022
AB4	0.266 ± 0.039	0.1317 ± 0.019
BA4	0.265 ± 0.039	0.1184 ± 0.017