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Full Length Research Paper

Determination of mass attenuation coefficients for concretes containing tincal concentrator waste

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This study is concerned with the use of the concrete samples produced by tincal concentrator waste as a gamma radiation shield. The values of mass attenuation coefficients for concrete samples measured at 59.54 (Am-241) and 80.99 (Ba-133) keV photon energies. Gamma rays were counted by a NaI(Tl) detector coupled to multi channel analyzer (MCA) using narrow beam transmission arrangement. Theoretical values of mass attenuation coefficients were obtained by using WinXCom computer program and compared with the experimental results. The study reveals that the concrete samples under investigation are more effective than ordinary concrete in small rates for the attenuation of gamma rays.

Key words: Tincal concentrator waste, NaI(Tl), WinXCom.

INTRODUCTION

Boron is one of the most important underground ores of Turkey and it is predicted that about 70% of the known boron reserves of the World are in Turkey. Well-known boron minerals are colemanite ($Ca_2B_6O_{11}.5H_2O$), tincal ($Na_2B_4O_7.10H_2O$) and ulexite ($NaCaB_5O_9.8H_2O$). After boron ores are concentrated in concentration plant, concentration wastes are accumulated in ponds. Boron content of these wastes dissolves by rain and snow waters and passes to soil, surface water and underground water and this pollution causes some serious health and environmental problems. For this reason, the possible application areas of boron wastes must be investigated. In some studies, the possibility of using boron waste as a shielding material has been investigated (Demir and Keleş, 2006; Boncukcuoğlu et al., 2005; Içelli et al., 2003).

The probability of photon interacting in a particular way with a given material per unit path length is usually called 'the linear attenuation coefficient', $\mu(cm^{-1})$. μ is dependent on the density (ρ) of the shielding medium and (μ/ρ) ratio is called 'mass attenuation coefficient, μ_ρ (cm^2g^{-1})'. μ_ρ is a measure of the average number of interactions between incident photons and matter that occur in a given mass-per-unit area and it is very important parameter in fundamental physics and many applied fields for determining the penetration of gamma rays travelling in absorber.

There are studies for the evaluation of boron minerals and wastes as an additive in cement (Erdoğan et al., 1992, 1998; Kula et al., 2002) and different researches have been conducted on the linear and mass attenuation coefficient for different types of materials such as boron compounds (Singh et al., 2004; Içelli et al., 2004), boron ores (Demir, 2010; Demir et al., 2010), pumice (Akkurt et al., 2009) and natural minerals (Han et al., 2011).

In this study, concrete samples produced by using this boron waste have been measured for gamma radiation transmission at 59.54 and 80.99 keV energies. The measured results have been compared with the calculations obtianed from WinXCom. By this work, the usability of TCW as a radiation shielding material was aimed.

MATERIALS AND METHODS

In this study, six concrete samples including tincal concentrator waste (TCW) in the ratios of 0, 2.5, 5.0, 7.5, 10 and 20% (in weight) to the cement were produced. In order to prepare shielding concrete samples, cement, modular sand and TCW were mixed homogenously by using mixer and then adding water mortar was prepared. For this, 450 g of the cement samples, 1350 g of modular

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Table 1. Chemical composition of TCW and cement.

Compounds	TCW (%)	Cement (%)
SiO_2	28.45	20.8
CaO	18.85	61.4
MgO	14.20	2.78
Al_2O_3	1.37	5.53
Fe_2O_3	0.44	3.41
SO_3	0.34	5.02
Na_2O	2.06	0.10
K_2O	1.05	0.80
MnO		0.11
Cl		0.01
Ignition loss	22.72	
B_2O_3	10.52	

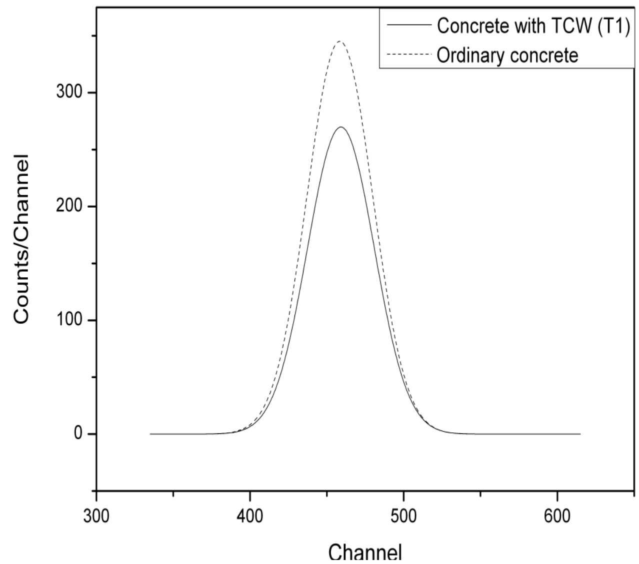

Figure 1. Spectrums of 59.54 keV gamma rays obtained from concrete with and without TCW.

sand and 225 g water were used. The mortars were poured to 15×15×4 cm molds. The molds were left to room having 25°C temperature and then the concrete samples taken from the molds were left to basin filled water with 28 days.

Cement and TCW used in the experiments were provided from Van Gölü Cement Factory in Van, Turkey and Eti Mine Works, Turkey, respectively. The TCW was dried under ambient conditions sieved by a 100 mesh Standard sieve to obtain -100 mesh samples. B_2O_3 content of this waste was determined by titrimetrical method and the results of elemental analysis of other contents determined by X-ray fluorescent method are given in Table 1. The intensities of gamma-rays were measured using a NaI(Tl) detector which has a resolution of 122 keV full width at half maximum at 662 keV connected to a multichannel analyzer and analysis was performed using Genie2000 software. 59.54 and 80.99 keV gamma photons from the filtered radioactive point sources Am-241 and Ba-133 of intensity 100 and 10 mCi were used to irradiate the concrete, respectively. The source-concrete and concrete-detector distance was set to 10 cm and 5 mm, respectively. The measurements were repeated 3 times under the same experimental conditions. A spectrum of 59.54 keV gamma ray transmission through concrete is shown in Figure 1.

The linear attenuation cofficients (μ,cm^{-1}) and mass attenuation cofficients (μ_ρ,cm^2/g) were obtanied by Lambert law's;

$$I = I_0 e^{-\mu_\rho \rho x} \quad (1)$$

where ρ is the density of the material and x is sample thickness (mass-per-unit area), I and I_0 are photon intensity recorded in detector with and without material between detector. The theoretical mass attenuation coefficients which were obtained using WinXCom computer code were compared with the measured mass attenuation. This program depends 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., 2004).

RESULTS AND DISCUSSION

The values of mass attenuation coefficient for concrete samples have been measured by a scintillation detector and calculated using WinXCom program at photon energies of 59.54 and 80.99 keV. The results are listed in Table 2. It is seen from this table that there are differences between experimental and theoretical values and estimated error in the experimental measurement was approximate ≤10%. The experimental values of mass attenuation coefficients for concretes containing TCW are plotted in Figure 2. It is obvious from this figure that the experimental values of mass attenuation coefficients for concretes containing TCW are higher than the ordinary concrete (K) expect for T5 concrete (20%). It is seen from this figure that the mass attenuation coefficients decrease with increasing concentration of TCW.

When gamma ray passes through an absorber, it is attenuated. The degree of attenuation depends on scattering and different absorption processes. Photoelectric effect is more dominant at 59.54 keV energy thus photons more absorbed by concerete and mass attenuation coefficients are higher at this energy. As the energy value increases Compton scattering becomes more dominant and mass attenuation coefficients decrease with increasing gamma ray energy.

The concrete samples containing TCW in small rates more absorbed photon than the ordinary concrete. The mass attenuation coefficients for T5 (20%) concrete is smaller than the ordinary concrete (K).

Mass attenuation coefficients of some shielding materials prepared from colemanite concentrator waste (2.5%) and borogypsum (2.5%) at 59.54 keV energy have been reported to be 0.0876 and 0.0830 cm^2 g^{-1}, respectively and at 80.99 keV energy have been reported to be 0.0599 and 0.05213 cm^2 g^{-1}, respectively (Demir and Keleş, 2006). Boncukcuoğlu et al. (2005) reported that TSW-containing cement will have lower radioactive permeability in according to normal Portland cement and

Table 2. The values of mass attenuation coefficients at 59.54 and 80.99 keV.

Concrete	59.54 keV		80.99 keV	
	Mass attenuation coefficients (μ_ρ)			
	Experimental	WinXCom	Experimental	WinXCom
K	0.329±0.0011	0.347	0.216±0.0025	0.230
T1	0.357±0.0000	0.345	0.234±0.0008	0.229
T2	0.351±0.0003	0.345	0.228±0.0000	0.229
T3	0.344±0.0003	0.345	0.225±0.0014	0.229
T4	0.330±0.0003	0.345	0.220±0.0006	0.229
T5	0.309±0.0003	0.345	0.207±0.0003	0.229

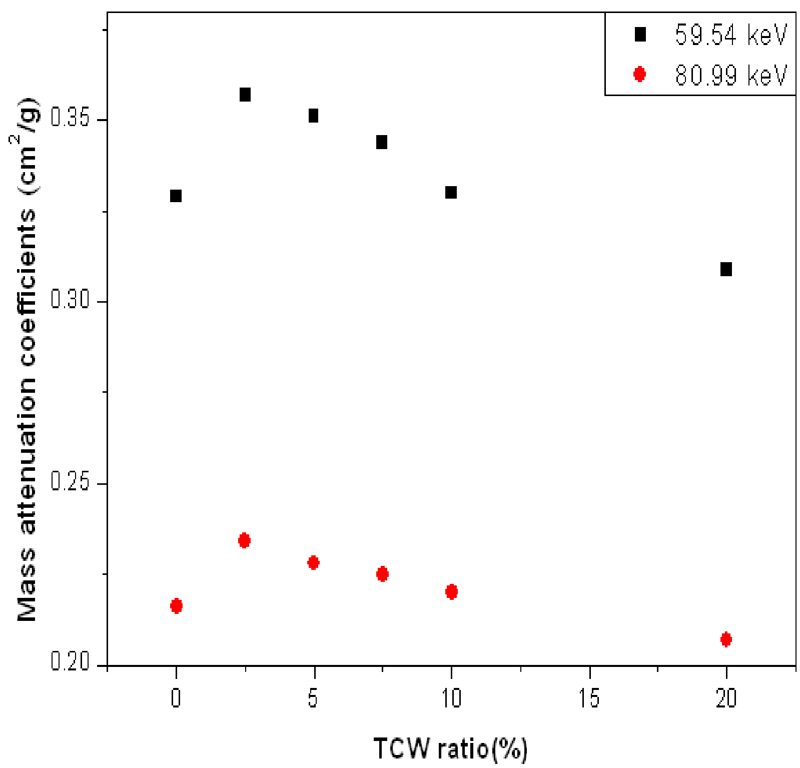

Figure 2. Variation of experimental mass attenuation coefficients with the TCW rate for concretes.

boron compounds decrease radioactive permeability of the concrete.

In conclusion, T5 (2.5%) concrete is the best photon attenuator at photon energies of 59.54 and 80.99 keV and gamma radiation shielding capabilities of concrete can be enhanced by using TCW in small ratios (10%≤).

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