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Photon attenuation properties of concrete produced with pumice aggregate and colemanite addition in different rates and the effect of curing age to these properties

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ABSTRACT

Radiation shielding properties of lightweight concrete produced with pumice aggregate and colemanite addition in different rates and effect of cure ages to the radiation shielding were investigated by using ^{60}Co (1250 keV) radioactive source. Gamma rays were counted by 0.6 cc, Farmer type PTW™ Ion chamber. Experimental results were compared with the theoretical values calculated by WinXCom program. Consequently, colemanite addition make enhancement in the radiation shielding of the lightweight concrete, however there is no directly proportional relation between colemanite rate (0.4 −2%) and attenuation properties of the lightweight concrete and cure age especially long timed, raises the linear attenuation coefficient and decreases the mean free path values. The theoretical values were obtained as nearby the experimental results, especially in the later cure ages (360 day).

1. Introduction

Concrete is the most widely used man-made construction material. Concrete with a general expression, is a construction material which happens at the result of mixing materials such as sand and gravel with water and cement that is adhered them at the different ratios. Workability, density, strength, thermal characteristics, modulus of elasticity and environment conditions can be showed as concrete parameters (Ekinci, 2006). In turkey, to produce lightweight concrete, pumice is the most widely used lightweight aggregate and there are a considerable value of about 3 billion m^3 pumice reserve according to predictions (Gündüz and Uğur, 2005; Bideci et al., 2014). Low density, allowing construction on ground with only moderate bearing capacity, needing less reinforcement, to construct higher buildings, low cost in lifting and higher thermal insulation are the advantages of the lightweight concrete (Gündüz and Uğur, 2005). For radiation shielding purposes, heavy elements such as lead or tungsten are ideal material, but because of durability and economic problems, they cannot be used directly in building construction (Akkurt et al., 2010a). Boron addition to ordinary concrete was more effective, comparing with addition to heavy concrete for radiation shielding (Kaplan, 1989). Colemanite, Tincal and Ulexite are the boron ores of Turkey and approximately 60% of the boron reserves of the world is in Turkey. Boron is used as a control absorber in nuclear reactors and a neutron shielding material, due to property of high absorption of neutron (Demir and Keles, 2006).

The linear attenuation coefficient (μ), is defined as “the probability of a photon interacting in a particular way with a given material per unit path length”, and very important in matters regarding of radiation shielding. Linear attenuation coefficients depend on the density (ρ) of the shielding material and the density of the material depends on the physical state of the material, like Concrete and its moisture content. To avoid the effects of variations in the density of the material, the linear attenuation coefficient is, for reference purposes, expressed as a mass attenuation coefficient (μ/ρ) which is “the linear attenuation coefficient per unit mass of the material” (Kaplan, 1989). A study about the radiation transmission of lightweight concrete including pumice has been carried out by Akkurt and Akyildirim (2012) and according to Akkurt and Akyildirim (2012), pumice is not an ideal material in terms of radiation shielding properties, as aggregate in concrete. On contrary,

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Tapan et al. (2014) reported that, photon energy absorption parameters are directly proportional to Fe_2O_3, CaO, MgO, TiO_2 content of pumice samples. In some other studies (Oto et al., 2013; Demir and Keles, 2006; Demir et al., 2010; Demir, 2010; Boncukçuoğlu et al., 2005; Binici et al., 2014; Korkut et al., 2010) shielding properties of the concrete with boron and boron waste additions were investigated. Furthermore, miscellaneous studies related to radiation shielding of ordinary concrete, heavyweight concrete, cement and with a variety of additives and mixtures also exist, (Kurudirek et al., 2009; Kharita et al., 2009, 2008; Sharifi et al., 2013; Facure and Silva, 2007; Makarious et al., 1996; Şahin et al., 2011; El-Sayed Abdo, 2002; Mostofinejad et al., 2012; El-Khayatt, 2010; Turkmen et al., 2008; Gencel et al., 2011; Bashter, 1997; Yılmaz et al., 2011; Binici et al., 2014; El-Faramawy and El-Hosiny, 1998; El-Hosiny and El-Faramawy, 2000; Akkurt et al., 2010a,b,c; Akkurt et al., 2005, 2006).

In this work, the values of mean free path (mfp), linear attenuation coefficient (μ) and mass attenuation coefficient (μ_ρ) for lightweight concretes which contains pumice aggregate and colemanite addition is determined experimentally and calculated theoretically for gamma rays of 1250 keV energy in order to demonstrate the effect of colemanite on photon attenuation properties of lightweight concrete produced with pumice aggregate that is widely used in Turkey. Improving photon attenuation properties of lightweight concrete would be economical in terms of radiation shielding and would make more durable constructions possible. On the other hand, according to Kaplan (1989), boron addition to ordinary concrete was more effective, comparing with addition to heavy concrete for radiation shielding. From this perspective, use of boron as a supplementary cementitious material in lightweight concrete may be more effective for radiation shielding when compared with ordinary concrete. In our knowledge, there isn't any research focused on effect of boron addition on radiation shielding properties of lightweight concrete. Therefore, this research is a supplementary study for the research focused on boron addition to ordinary concrete related to radiation shielding.

In order to demonstrate the real effect of the colemanite on radiation shielding properties of lightweight concrete, pumice aggregate was used to produce lightweight concrete samples with a density of 1.08–1.27 g/cm^3. Additionally, the effect of curing time on radiation shielding of ordinary lightweight concrete and colemanite added lightweight concretes was also studied by curing the samples under water during 28, 56 and 360 days. Also, theoretical values of attenuation coefficients of the concrete mixture were calculated by WinXcom (Gerward et al., 2004) program and compared with the experimental results.

2. Materials and methods

2.1. Materials

Crushed powder colemanite is supplied from “Eti Mine Works, Emet Boron Management directorate in Turkey”. Before adding mixture for replacing cement, the colemanite is sieved in 63 micron sieve. The pumice, as aggregate, was obtained from Kocapınar-Erciş, a town in the east of Turkey, and the cement as binder was obtained from Cement Factory in Van, Turkey. The chemical compositions of materials in concrete mixture are given in Table 1.

2.2. Concrete mixture

In this study, six different groups of concretes (C [C is control group], C1, C2, C3, C4, and C5) were produced with pumice aggregate that contained colemanite addition by replacing cement in the rate of 0%, 0.4%, 0.6%, 0.8%, 1% and 2% respectively. The mixture proportions are given in Table 2. The fresh concrete was moulded into cubics (10 cm^3). Hardened concrete blocks were unmolded 24 h later and cured in the water at 20 °C, during 28, 56 and 360 days. In the trial mixtures, the colemanite rates 2 and 6% in concrete delayed initial setting times. Likewise, the concrete with the colemanite rates 10 and 20% dispersed while unmolding and lost binder characteristics. For this reason, in this study the colemanite rates have been chosen as between 0.4 and 2%. After curing periods, all samples were dried on 105 ± 5 °C for 24 h and from each group 5 samples, totally 90, were taken for radiation experiment.

Table 1
Chemical composition of pumice colemanite and cement.

Compounds	Pumice[a]	Colemanite	Cement
SiO_2	71.35	4.00	18.92
CaO	1.84	27.00	60.15
MgO	0.01	3.00	2.82
Al_2O_3	13.2	0.40	4.5
Fe_2O_3	1.54	0.08	3.28
SO_3	0.04	–	2.6
Na_2O	3.4	0.35	0.21
K_2O	5	–	0.53
Cl	–	–	0.0079
SO_4	–	0.60	–
SO_3	–	–	2.6
B_2O_3	–	40.0	–
H_2O	–	1.0	–
TiO_2	0.25	–	–
Heat loss	3.05	24.60	6.44

[a] Uysal et al., 2004.

Table 2
Concrete mixture proportions.

Concrete name	Water (kg)	Cement (kg)	Aggregate (pumice)		Replacing by cement	
			Coarse (kg)	Fine (kg)	Colemanite (%)	Colemanite (kg)
C0	130.9	400	330.05	441.06	0	0
C1	130.9	398.40	330.05	441.06	0.4	1.60
C2	130.9	397.60	330.05	441.06	0.6	2.40
C3	130.9	396.80	330.05	441.06	0.8	3.20
C4	130.9	396.00	330.05	441.06	1	4.00
C5	130.9	392.00	330.05	441.06	2	8.00

2.3. Radiation experiment

Concrete samples (5 from each group totally 90) were irradiated by 1250 keV photons, emitted from ^{60}Co radiation source that built in Thratron 1000E™ device using for radiotherapy purposes. To obtain a narrow beam, firstly a 5 × 5 cm^2 collimator and secondly a lead have 1 cm^2 hole were used as seen in Fig. 1. In order to minimize the back scattering, the water equivalent phantoms (1 g/cm^3 density) were used. I/I_0 photon transmission values have been

Table 3
Theoretical results of linear attenuation coefficients and mean free path at 1250 keV for the cure ages by WinxCom.

Concrete	28 Day		56 Day		360 day	
	μ (cm^{-1})	λ (cm)	μ (cm^{-1})	λ (cm)	μ (cm^{-1})	λ (cm)
C	0.0646	15.482	0.0662	15.105	0.0688	14.532
C1	0.0702	14.253	0.0696	14.358	0.0748	13.367
C2	0.0692	14.442	0.0683	14.651	0.0746	13,398
C3	0.0706	14.167	0.0699	14.313	0.0740	13.516
C4	0.0682	14.671	0.0689	14.510	0.0736	13.594
C5	0.0689	14.503	0.0689	14.361	0.0737	13.570