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Mechanical and radioactivity shielding performances of mortars made with colemanite, barite, ground basaltic pumice and ground blast furnace slag

Hanifi Binici[a,*], Orhan Aksogan[b], Ahmet Hayrullah Sevinc[a], Adnan Kucukonder[c]

[a] Department of Civil Engineering, Kahramanmaras Sutcu Imam University, Kahramanmaras 46100, Turkey
[b] Department of Civil Engineering, Toros University, Mersin 33140, Turkey
[c] Department of Physics, Kahramanmaras Sutcu Imam University, Kahramanmaras 46100, Turkey

HIGHLIGHTS

- All building materials contain more or less natural radioactivity.
- The concrete strength at later ages has increased significantly by using blast furnace slag.
- Linear absorption coefficient decreased with increasing colemanite ratio.
- Barite, colemanite and blast furnace slag wastes are effective to prevent radiation transmission.
- They seem to be promising materials for gamma ray shielding in mortars.

GRAPHICAL ABSTRACT

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ABSTRACT

All building materials contain more or less natural radioactivity. The present paper reports the results of an experimental study on the mechanical and radiological aspect of the use of colemanite, barite, ground basaltic pumice and ground blast furnace slag as additives in the production of special mortars. The results show that the compressive and flexural strengths of the mortars at later ages has increased significantly by using blast furnace slag as an additive. However, the compressive strength was lower than those of the reference samples for all the samples with different additive percentages of pumice and barite for all ages. Linear absorption coefficient decreased in samples with colemanite additive with increasing colemanite ratio. From the linear absorption experiments, increases in the coefficient were observed in the samples with blast furnace slag at the beginning, but opposite effect starts for values higher than 2.5%. Mortars with colemanite and blast furnace slag had low radioactive permeability. These samples should be preferred for places which are exposed to radioactive effect.

The linear absorption coefficients of samples with 5% pumice additive were very near to those of the samples with barite additive. Hence pumice may be used in regions where radiation is effective. It can easily be used in walls and coverings of medical buildings and nuclear reactors.

1. Introduction

The recycling of waste by-products, nowadays, gaining more and more importance, research on that kind of materials is being carried out and such materials are utilized as additives in the

* Corresponding author. Tel.: +90 (344) 219 1278; fax: +90 (344) 219 1250.
E-mail addresses: hbinici@ksu.edu.tr (H. Binici), aksogan@cu.edu.tr (O. Aksogan), ahsevinc@yahoo.com (A.H. Sevinc), akucukonder@ksu.edu.tr (A. Kucukonder).

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production of special mortars in many countries. For example, in Turkey bricks are being made with fly ash, waste ash and basaltic pumice [1–6]. In Brazil phosphogypsum is obtained during the production of phosphoric fertilizer which is used as a building material [7] and in Hungary, coal slag is being used in floors of structures as an insulating filling material [8]. Recently, several studies have been carried out [9,10] on the possible use of recycle aggregates as additives in the production of building materials.

As radiation of terrestrial origin in buildings does not only originate from the soil, but also from the used building materials, a greater absorbed dose rate can be measured within buildings [11]. The EU details Radiation Protection principles in issue 112 of radiation protection. Controls should be based on dose criterion, which was established considering the overall national circumstances within the EU. It is recommended that controls should be based on a dose in the range of 0.3–1 mSv a^{-1}. Doses exceeding these values should be taken into account from a radiation protection point of view. This is the excess gamma dose to that received outdoors. The activity concentration index should not exceed the values presented in Table 1.

When industrial by-products are incorporated in building materials and there is reason to suspect that these contain enhanced levels of natural radionuclides, the activity concentrations of these nuclides in the final product should be measured or assessed reliably depending on the activities of all the component materials. Typical and maximum concentrations in common building materials and industrial by-products used in building materials in the EU are presented in issue 112 of the Radiation Protection. Some data are presented in Table 2 and several gamma emitting radionuclides and their features are given in Table 3. Beta, because of its mass and univalence like alpha particles, can be stopped and do not have the chance of penetrating the materials (Fig. 1).

Heavyweight mortar is defined as mortar with unit weight ranging from 2900 to 6000 kg/m^3 while unit weight of conventional mortar varies between 2200 and 2450 kg/m^3 [12–17]. Barite ore includes $BaSO_4$ which is a good photon radiation absorbent and is a heavyweight aggregate used in the mortar industry. Colemanite which is one of the most important underground sources of Turkey, on the other hand, is a boron ore that is employed as a constituent material of neutron shielding because of its high absorption of thermal neutrons.

Table 1
The activity concentration index ("*I*").

Dose criterion	0.3 mSv y^{-1}	1 mSv y^{-1}
Materials used in bulk amounts, e.g. mortar	I<0.5	$I \leqslant 1$
Superficial and other materials with restricted use: tiles, boards, etc.	$I < 2$	$I \leqslant 6$

Boron is one of the most important underground reachnesses of Turkey, having about 60% of the world boron reserves. Boron used in various areas of industry is also employed as a control absorber in nuclear reactors and as a constituent material of neutron shields because of its high absorption of neutrons. Commercial boron ores of Turkey are colemanite, tincal and ulexite. After colemanite is mined, it is concentrated in concentration plants, and then, reacted with sulphuric acid to produce boric acid. The waste of concentration plants is called colemanite concentrator waste and that of boric acid plant, borogypsum. These wastes contain about 4.2% and 6.3% B_2O_3, respectively [18].

Heavyweight mortar has been widely used for protection against radioactive rays in nuclear power plants, medical units, and in structures where radioactive impermeability is required. Heavyweight mortar absorbs the energy of neutrons via its contents, and for this reason, heavyweight mortar can be used as a perfect protective material. Neutrons have a significant role in atomic reactors in that they are particles having no electric charge, high energy, and the property of great penetration. Neutron reaction upon the material does not always vary with the atomic number of each material, which is a different situation compared to g-rays. At the same time, absorption occurs by the realization of secondary g-rays and the abundance and energy of these rays varies from one material to another. For this reason, a reactor shield should be selected after considering the dominating properties of that reactor. In general, the strength of the shield against radiation penetration has a direct relationship to the thickness of the shield. The most difficult problem to consider when designing a shield is fast neutrons [19]. In accordance with Turkish Code 3440, conventional mortar should be durable against harmful water, fluids, and gases [20]. However, there is no such necessity in heavyweight mortar, but only in those used as protectors against radiation.

Almost 155,000 km^2 of Turkey (country) is covered by Tertiary and Quaternary-age volcanic rocks, among which tuffs occupy important volumes. There is huge basaltic pumice reserves estimated to be approximately 1.000 million tons which are located in the Cukurova region (Southern Turkey) [21]. Also, there is a huge amount of disposed ground blast furnace slag waste in Iskenderun in Southern Turkey. This material causes serious environmental problems, despite the fact that they can easily be utilized as additives in the production of mortars. Additives are used to improve the mechanical durability, workability and economy of mortars. Two of the additives used in this study, namely ground basaltic pumice and ground blast furnace slag, have been investigated for their properties previously [22–27].

Naturally occurring radioactive materials are present everywhere in the environment as well as the grounds on which humans settled in the past [28,29]. All the effects of radiation on human beings is called "radiation injury" as a collective term. It includes

Table 2
Typical and maximum activity concentrations of clay and gypsum.

Material	Typical activity concentration (Bq kg^{-1})			Maximum activity concentration (Bq kg−1)		
	^{226}Ra	^{232}Th	^{40}K	^{226}Ra	^{232}Th	^{40}K
Clay	50	50	670	200	200	2000
Gypsum	390	20	60	1100	160	300

Table 3
Several gamma-emitting radionuclides and their properties.

Radionuclide	Cobalt $^{60}Co_{27}$	Caesium $_{137}Cs^{55}$	Iridium $_{192}Ir^{77}$	Radium $_{225}Ra^{88}$	Americium $_{241}Am^{95}$
Material half-life	5.3 years	30 years	74 days	1600 years	432 years
Gamma energy	1.33 MeV	0.66 MeV	0.9 MeV	2.5 MeV	60 keV