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Investigation of gamma radiation shielding and compressive strength properties of concrete containing scale and granulated lead-zinc slag wastes

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ABSTRACT

This paper summarizes the results of investigations of hybrid concrete containing scale and granulated lead–zinc slag wastes as substitutes for sand. Specifically, scale and granulated lead–zinc slag wastes are completely substituted for natural sand in concrete. The aim of this study was to investigate the effects of these waste materials on gamma radiation shielding and on the compressive strength properties of concrete. The linear attenuation coefficient (μ, cm^{-1}) and compressive strength of the samples were measured experimentally and calculated, and the experimental values were subsequently compared with those of conventional concrete. The results clearly showed that hybrid scale waste/granulated lead–zinc slag waste concrete (Sc/Glzs-C) has better radiation shielding and compressive strength properties than conventional concrete. An additional objective of this study was to calculate the thickness of the hybrid concrete shield to be used instead of conventional concrete. The results showed that the produced concrete demonstrates better radiation attenuation properties with thinner thickness compared to conventional concrete. As a result, the new concrete containing scale waste and granulated lead–zinc slag waste is suitable for gamma radiation attenuation.

1. Introduction

Waste generation is one of the most obvious impacts of exponential population growth, industrial and technological development, and rising consumerism, leading to potential waste disposal crisis and environmental degradation (Mannan and Ganapathy, 2004). A key to solving this problem is to develop a waste management program based on the waste-generation hierarchy for preventing waste production through waste minimization and through the use of waste as a substitute for primary materials as the primary waste management technology, followed by various methods available for waste disposal.

At present, gamma radiation shielding is the main part of radiation attenuation for essential applications of radiation in fields such as health care facilities conducting radiation therapy, medicine, industry, and nuclear research and their applications (Yadollahi et al., 2016). One of the most important challenges in shielding engineering is to reduce exposure to radiation to the standard acceptable level in order to protect human beings, equipment, and structures from the harmful effects of radiation (El-Sayed and Bourham, 2015; Yadollahi et al., 2016).

On the one hand, lead has long been considered as a highly effective material for gamma radiation attenuation owing to its high density. On the other hand, because lead is expensive and toxic, several researchers have recently been investigating alternative materials for gamma radiation attenuation (La et al., 2016). One such material investigated by researchers is concrete, due its good mechanical properties and high durability, can be easily prepared in different compositions, and can be easily formed and used in construction work (Teixeira et al., 2016; Uddin and Shaikh, 2016). Moreover, it is inexpensive and shows good radiation shielding properties depending on the material components (Al-Humaiqani et al., 2013).

Although concrete is highly versatile, its production entails significant environmental damage. At least three-quarters of the total volume of concrete consists of aggregates that strongly influence its properties (Kosmatka et al., 2002). The most versatile aggregates used in concrete production are derived from natural resources. Thus, the depletion of natural resources is nearly

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inevitable. Identifying alternative materials to decrease the consumption of natural resources has become an imperative task at this point to safeguard the interests of future generations (Nikbin et al., 2016; Mardani-Aghabaglou et al., 2014).

Recent decades have witnessed an unprecedented growth in industrial waste production. The majority of such waste is not put to effective use. Reusing such waste in concrete as a natural sand replacement is an essential solution for protecting the environment and preventing the depletion of natural resources.

Various waste materials have been investigated as substitutes for natural aggregates in concrete (Taha and Nounu, 2008; Ghannam et al., 2016; Senani et al., 2016; Singh and Siddique, 2016; Shettima et al., 2016; Ul Islam et al., 2016; Elçi, 2016; Tripathi and Chaudhary, 2016; Martínez et al., 2016; Singh and Siddique, 2014; Maslehuddin et al., 2013; Çullu and Ertaş, 2016; Dong et al., 2016; Erdem et al., 2010; Alwaeli, 2013). These substitutes not only limit the consumption of raw materials in the building industry but also enhance some properties of concrete (Hasanzadeh et al., 2012).

Scale and granulated lead–zinc slag wastes are by-products that may be utilized as substitutes for natural materials in concrete construction. The application of scale and granulated lead–zinc wastes that are otherwise sent to landfills in concrete can protect natural resources and reduce environmental problems related to aggregate consumption and waste disposal. Moreover, such materials can also increase the attenuation of gamma radiations because of their high density.

Because scale and granulated lead–zinc slag wastes have not been extensively tested thus far, the long-term objective of the present study was to investigate the effect of such waste materials on the compressive strength and gamma radiation shielding properties of concrete. Another objective was to calculate the thickness of the concrete shield to be used instead of conventional concrete.

2. Literature review

The absorption of gamma radiation in shielding materials is worth studying area in radiation physics. Sophisticated and considerable knowledge of the attenuation of X-rays in shielding materials is required to design protective shielding in facilities containing radioactive sources and radiation-generating equipment. In various applications, varied materials (e.g., tungsten, bismuth, lead, high density concrete and steel) are applied for the radiation shielding. There are several reports of experimental and theoretical works on radiation shielding with the usage of various materials.

Kharita et al. (2009) investigated the effect of carbon powder addition on the properties of hematite radiation-shielding concrete. They found that the addition of carbon powder by 6% (by wt.) of the concrete could increase the strength of the concrete by approximately 15%. The shielding effectiveness decreased for both gamma rays and neutrons with an increase in the carbon powder percentage. Experimental investigations of the mechanical and radiation-shielding properties of hybrid lead–steel fiber-reinforced concrete by Sharma et al. (2009) revealed that as compared to ordinary concrete, steel fibers increase all the mechanical properties of the concrete but do not enhance the radiation-shielding properties, whereas lead and alloy fibers do not enhance the mechanical properties of the concrete to which they are added, but very significantly increase its radiation-shielding properties. Concrete added with both lead/alloy and steel fibers displays a remarkable increase in both mechanical and radiation-shielding properties.

Costa et al. (2015) examined the shielding properties of four concrete compositions with hematite (Types H1 and H2), steel grit, and ordinary concrete. They found that the concrete with steel grit is more efficient as a shielding material than the other three types of concrete.

A novel shielding material produced by Erdem et al. (2010) with metallurgical solid waste containing lead was assessed as a shielding material for gamma radiation. They observed that the novel shielding material would be preferred as a shielding material for buildings against gamma radiation in regions with high photon energy.

Maslehuddin et al. (2013) in their work measured the radiation-shielding properties of concrete with electric arc furnace slag aggregates and steel shots. They concluded that concrete mixed with 50% electric arc furnace slag aggregates and 50% steel shots meets the weight and radiation requirements.

Recently, there is a tendency toward using various materials to enhance the shielding properties of concrete mixtures. Zorla et al. (2017) studied the radiation-shielding properties of high-performance concrete reinforced with basalt fibers infused with natural and enriched boron. The results showed that for gamma-ray shielding, the attenuation coefficients of the studied samples do not display any significant variation because of the addition of the basalt–boron fibers at any mixing proportion.

Çullu and Ertaş (2016) determined the effect of lead mine waste aggregate on the radiation absorption capacity and the compressive strength of concretes produced from lead mine waste. The experiments demonstrated that the best absorption was in concrete samples with 100% barite content.

Waly and Bourham (2015) added select materials as the weight fraction to the aggregate to provide relatively high mass attenuation rates. The results revealed that concretes with added materials in the aggregate can provide more efficient gamma-ray shielding than ordinary concrete.

Yao et al. (2016) fabricated bismuth oxide (Bi_2O_3)-based concrete mixtures by adding Bi_2O_3 powder in the ordinary concrete mixture. Concrete mixtures with lead oxide (PbO) additives were used for comparison. They concluded that the concrete mixture containing 25% Bi_2O_3 powder provided the best shielding capacity and mechanical performance among the considered mixes.

Several researchers have studied the possible utilization of industrial waste and by-products as sand and coarse aggregates in concrete and the effects of doing so on the radiation and compressive strength properties of concrete. Rezaei-Ochbelagha et al. (2012) compared the shielding and strength properties of concretes with and without silica fumes. The results revealed that although the addition of silica fumes results in a slight reduction of the attenuation coefficient, which is negligible, it increases the compressive strength of the concrete significantly.

González-Ortega et al. (2014) studied the radiological protection and mechanical properties of concretes with electric arc furnace slag aggregates. They concluded that the compressive strength of the concrete mixes with electric arc furnace slag aggregates was similar to or higher than that of the conventional concrete. In contrast, the radiological protection properties of the concrete mixes containing the electric arc furnace slag aggregates were worse than those of the concrete with barite.

Hassan et al. (2015) studied the effect of nano-lead compounds additives on the concrete shielding properties for gamma rays. The obtained data revealed that the gamma ray shielding properties of concrete with nano-PbO improved.

Rafieizonooz et al. (2016) investigated concrete specimens with 0%, 20%, 50%, 75%, and 100% bottom ash as sand replacement and 20% coal fly ash by mass as a substitute for ordinary Portland cement. Results revealed that at the early age of 28 days, no significant effect was observed in the compressive strength. After curing at 91 and 180 days, the compressive strength of both the