HBRC Journal (2015) xxx, xxx–xxx

Housing and Building National Research Center

HBRC Journal

http://ees.elsevier.com/hbrcj

The effect of replacing sand by iron slag on physical, mechanical and radiological properties of cement mortar

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Received 14 December 2014; revised 1 April 2015; accepted 22 June 2015

KEYWORDS

Basic-oxygen furnace slag;
Cement mortars;
Fine aggregate;
Linear attenuation coefficient;
Half value layer;
Tenth value layer

Abstract In the present study, the effects of replacing sand by high percentages of basic-oxygen furnace slag on the compressive strength, bulk density and gamma ray radiation shielding properties of mortar have been investigated. Cement mortar of mix proportion 1:3 including various percentages of iron slag was designed. The percentages of replacement were 0%, 40%, 80% and 100% by weight of fine aggregate. Mortar mixes were prepared with water cement ratio of 0.44 and cured in potable water for 90 days. The attenuation measurements were performed using gamma spectrometer of NaI (Tl) detector. The utilized radiation sources comprised ^{137}Cs and ^{60}Co radioactive elements with photon energies of 0.662 MeV for ^{137}Cs and two energy levels of 1.17 and 1.33 MeV for the ^{60}Co. Likewise, half value layer (HVL), tenth value layer (TVL) and the mean free path (mfp) for the tested samples were measured. Results of this investigation indicated that the strength properties of mortars increased significantly upon replacing sand partially by iron slag. It was also observed that the inclusion of iron slag as partial replacement with fine aggregate enhances the bulk density of mortar. On the other hand, full sand replacement by iron slag has significant effects on shielding efficiency in thick shields, as it reduces the capture gamma rays better than normal mortar incorporating sand.

Introduction

Recycling or reuse of industrial by-products and wastes is economically and/or ecologically very important. The aggregates typically account for 70–80% of the concrete volume and play a substantial role in different concrete properties such as workability, strength, dimensional stability and durability. The use of different waste materials shows prospective application in construction industry as an alternative to conventional

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Peer review under responsibility of Housing and Building National Research Center.

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http://dx.doi.org/10.1016/j.hbrcj.2015.06.005
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materials. Such practice conserves natural resources and reduces the space required for the landfill disposal of these waste materials. The aggregates used for mortar and concrete can be conveniently divided into dense and lightweight aggregates. The former class includes all the aggregates normally used in mass and reinforced concrete such as sand, gravel, crushed rocks and iron slag. Steel slag is a material which could be used as a partial replacement for fine aggregate [1]. The consumption of waste materials can be increased manifold if they are used as aggregates in both cement mortar and concrete. These types of uses of waste materials can solve problems of lack of aggregates in various construction sites and reduce environmental problems related to aggregate mining and waste disposal. The use of waste aggregates can also reduce the cost of concrete production. Due to the fact that aggregates can significantly affect the properties of concrete, consequently, a thorough evaluation is necessary before using any waste material as aggregate in concrete. A range of slag textures could be formed by differing the cooling regimes and the resultant slag types exhibit different properties. Blast furnace slag is a non-metallic material consisting of silicates and aluminosilicates of calcium and magnesium together with other compounds of sulfur, iron, manganese and other trace elements. Air-cooled slag, which is allowed to solidify slowly in ladles or pits, is by far the most abundant and is a rock-like material which is almost wholly crystalline [2]. Blast-furnace slag aggregates generally have desirable properties such as soundness, strength, shape, abrasion resistance and gradation. Khalifa [3] mentioned that the reason for the use of iron waste in construction is because it is useful for both the economy and the environment; he concluded that there is an increase in industrial and technological by-products which are hazardous for both the environment and human health if not properly disposed of. Moreover, these by-products are the main cause of the evaporation of CO_2 and other harmful gases which cause global warming and the destruction of the ozone layer which protects the planet earth from harmful cosmic rays. Also, industrial wastes and by-products can be used as substitute materials in concrete and building units, which in itself is a better alternative to dumping such wastes as it will protect the environment and alleviate the consumption of natural resources.

Nadeem and Pofale [4] utilized granular slag as a replacement of natural fine aggregate in construction applications such as masonry and plastering. In this investigation, cement mortar mixes 1:3, 1:4, 1:5 and 1:6 by volume were selected for 0%, 25%, 50%, 75% and 100% replacements of natural sand with granular slag for w/c ratios of 0.60, 0.65, 0.70 and 0.72, respectively. The sand replacement from 50% to 75% improved mortar flow properties by 7%, whereas the compressive strength improved by 11–15% at the replacement level from 25% to 75%. At the same time brick mortar crushing and pull strengths improved by 10–13% at 50–75% replacement levels. The study concluded that, granular slag could be utilized as alternative construction material for natural sand in masonry and plastering applications either partially or fully. Ansu and Elson [5] studied the utilization of induction furnace slag as an alternative for conventional fine aggregate. In this study the compressive strength of mortar and concrete made with partial replacement of fine aggregate using induction furnace slag was determined. Pertaining to the experimental investigation, mixes were prepared with fine aggregates replacement using 20%, 30%, 40%, 50% and 60% induction furnace slag. Compressive strength tests on mortar and concrete were conducted and the obtained results indicated that fine aggregates replacement using 30% induction furnace showed a better performance compared to the control mix.

The main objective of this investigation is to study the effect of partial replacement of sand by the basic-oxygen furnace slag (BOFS) at percentages of 0%, 40%, 80% and 100% on the physico-mechanical properties of cement mortar and also study the attenuation of gamma-rays via heavy density mortar incorporating slag-fine aggregate using the radioisotopes of ^{137}Cs and ^{60}Co sources.

Experimental program

Materials

The material properties of mortar mix proportions and procedures for the preparation of mixes are discussed in this section. Type I Portland cement-CEM I (42.5 N), provided from Suez Cement Company in compliance with the requirements of ASTM C-150 [6] was used. Table 1 outlines the chemical composition using XRF Spectrometer PW 1400 and physical characteristics of the cement. The natural aggregate used for the preparation of cement mortar was sand (S). The basic-oxygen furnace slag (BOFS) with high density was used as a partial replacement material for natural aggregate, which is extensively produced as a by-product through iron and steel production at the Egyptian Iron and Steel Company, Helwan, Egypt.

Both sand and crushed slag were washed with water to remove the contaminated fine materials and oven dried at 100 °C for 24 h. The aggregates were passed through a sieve of 1 mm and retained on a sieve of 600 μm. The chemical composition and physical properties of fine aggregates are presented in Table 2. The main chemical constituents of the basic-oxygen furnace slag are CaO, Fe_2O_3 and SiO_2. During the conversion of molten iron into steel, a percentage of the iron (Fe) in the hot metal cannot be recovered into the steel produced. This oxidized iron is observed in the chemical composition of the BOF slag [7]. The results in Table 2 indicate that, oxygenated slag has higher specific gravity and volumetric weight than natural sand whereas the percentage of clay

Table 1 Chemical composition and physical characteristics of cement (OPC-CEM I).

Oxides (mass, %)		Physical characteristics	
SiO_2	21.26	Specific gravity	3.15
Al_2O_3	4.49	Consistency	24%
Fe_2O_3	3.49	Blaine's specific surface (cm^2/kg)	2415
CaO	63.81	Initial setting time	103 min
MgO	2.02	Final setting time	211 min
SO_3^{--}	3.11		
Cl^-	0.03		
Na_2O	0.14		
K_2O	0.09		
TiO_2	–		
BaO	–		
P_2O_5	–		
L.O.I	1.57		
Total	99.98		

Please cite this article in press as: A.S. Ouda, H.A. Abdel-Gawwad, The effect of replacing sand by iron slag on physical, mechanical and radiological properties of cement mortar, HBRC Journal (2015), http://dx.doi.org/10.1016/j.hbrcj.2015.06.005