HBRC Journal (2014) **10**, 43–48

Housing and Building National Research Center

HBRC Journal

http://ees.elsevier.com/hbrcj

FULL LENGTH ARTICLE

Physico-mechanical properties of high performance concrete using different aggregates in presence of silica fume

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Received 12 February 2013; revised 29 May 2013; accepted 18 June 2013

KEYWORDS

Silica fume;
HPC;
Heavy weight aggregates;
Radiation shielding

Abstract Heavy weight high performance concrete (HPC) can be used when particular properties, such as high strength and good radiation shielding are required. Such concrete, using ilmenite and hematite coarse aggregates can significantly have higher specific gravities than those of concrete made with dolomite and air-cooled slag aggregates. Four different concrete mixes with the same cement content and different w/c ratios were designed using normal dolomite aggregate, air-cooled slag by-product and two different types of iron ore aggregates. High performance concrete (grade-M60) can be achieved using superplasticizer to reduce the water/cement ratio; the effect of SF on the performance of concrete was studied by addition of 10% silica fume to the total cement content. The physico-mechanical properties of coarse aggregates and hardened concrete were studied. The results show that, Ilmenite coarse aggregate gives higher physical and mechanical properties than the other aggregates. Also, addition of 10% silica fume developed a stronger and a denser interfacial transition zone (ITZ) between concrete particles and the cement matrix. Crushed air-cooled slag can be used to produce a high-strength concrete with better mechanical properties than corresponding concrete made with crushed hematite and ilmenite. Heavy density concrete made with fine aggregates of ilmenite and air-cooled slag are expected to be suitable as shielding materials to attenuate gamma rays.

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Introduction

Concrete is the most commonly used shield material as it is inexpensive and adaptable for any construction design [1,2]. The concrete shielding properties may vary depending on its composition. Different types of special concretes have been developed by changing the aggregate used for preparing concrete, depending on the available natural and artificial local materials [3–6].

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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.2013.06.002

Concrete has been used in the construction of nuclear facilities because of two primary properties: its structural strength and its ability to shield radiation [7]. Aggregates are the largest constituent (about 70 –80% of the total weight) of normal concrete. Different types of natural and artificial aggregates are used to enhance the properties of concrete. Heavy weight concretes have been widely used in building construction especially for critical buildings as it contains a mixture of light and heavy elements, which are ideal materials to shield radiation. Concretes with specific gravities higher than 2600 kg/m^3 are called heavy weight concrete and aggregates with specific gravities higher than 3000 kg/m^3 are called heavy weight aggregate according to TS EN 206-1 [8]. Concrete which is more effective for the attenuation of fast neutrons can be produced by increasing the water content through the use of hydrous aggregates such as limonite. For shields which are required to provide protection mainly against gamma radiations with limitations in regard to thickness, may be desirable to use heavy concretes with densities greater than ordinary concrete. For this purpose special heavy aggregates such as hematite, ilmenite may be used [9–11,5].

To meet such requirements, moderate compressive strength, low shrinkage and high durability are essential. In other words, a particular class of concrete is to be engineered in such a way to satisfy the above properties. HPC according to the definition of ACI [12], is a concrete meeting special combinations of performance and uniformity requirements that cannot be achieved routinely using conventional constituents and normal mixing, placing, and curing practices. HPC distinguishes itself from normal concrete mainly in the following properties: high compressive strength, high durability, high workability and reduced permeability.

The main objective of this investigation is to study the effect of SF on the hydration characteristics of high performance concrete containing iron ore aggregates as indicated from phase formation to produce heavy weight-high performance concrete with different densities and can be used for the attenuation of gamma rays and fast neutrons in nuclear facilities.

Experimental techniques

Starting materials

The materials used in this investigation for the preparation of high performance concrete (grade-M60) are ordinary Portland cement (OPC - CEM I – 42.5N), obtained from Suez Cement Company (Tourah Plant), Egypt and silica fume, provided from the ferrosilicon alloy Company, Edfo, Aswan governorate, Egypt. Two types of iron ores were selected for coarse aggregates, these were hematite (α-Fe_2O_3) and ilmenite ($FeTiO_3$), obtained from El- Bahariya Oasis, western desert of Egypt and Abu-ghosoon area, Red Sea governorate, Egypt, respectively. A third material that has been selected to be used as coarse aggregate was air-cooled slag that is extensively produced as a by-product through iron and steel production at the Egyptian Iron and Steel Company, Helwan, Egypt. Crushed dolomite [($CaMg(CO_3)_2$], obtained from Attaka area, Suez, Egypt has been used as coarse aggregate (reference material). Fine aggregate was local sand with a fineness modulus of 2.8, washed at the site to remove any deleterious materials and chloride contamination. In some concrete mixes, sand has been replaced by the fine aggregates of hematite, ilmenite and air-cooled slag to produce heavy density concrete.

The nominal maximum aggregate size were 19 mm. Both coarse and fine aggregates were graded according to the limits specified by the ESS 1109 [13]. High performance concrete should have low water / binder ratio. Hence, effective dispersion of the mix is necessary to achieve proper workability without increasing the unit water content. This has been achieved using a high range water-reducing superplasticizer (SP) - Type G with specific gravity of 1.195 kg/l compatible with ASTM C494 [14]. The chemical analyses of coarse and fine aggregates are given in Table 1.

Physical and mechanical properties of coarse aggregates and its fine portion carried out according to the limits specified by the ESS 1109 [13] and ASTM C637 [15] are given in Table 2. Results show that ilmenite has higher specific gravity and lower water absorption than hematite, air-cooled slag and natural dolomite.

Coarse aggregates were separated by manual sieving into various size fractions according to [13,15] for coarse aggregate of size 5 – 40 mm. The grading curves of coarse aggregates are shown in Fig. 1.

Casting and Curing

The procedure for mixing heavy concrete is similar to that for conventional concrete. In a typical mixing procedure, the materials were placed in the mixer with capacity of 56 dm^3 in the following sequence: Coarse aggregate was first added to the mixer, followed by approximately one third of mixing water and then the mixer was started. Fine aggregate, (cement + SF) and the remaining water were added to the running mixer in a gradual manner. The mixing time for mixtures was continued for 3 min., then followed by 2 min. for final mixing. Fresh mixes were tested for workability by slump test according to ASTM C143 [16], then all concrete specimens were cast into $10 \times 10 \times 10$ cm cubic steel moulds and then subjected to vibration. Following casting, concrete specimens were covered with plastic sheet and kept in the laboratory at room temperature for 24 h. After demolding, specimens were placed in water until time of testing. Curing was done according to ASTM C511 [17]. After curing, the cubes were exposed to compressive strength measurements at 7, 28 and 90 days. The crushed samples at each hydration time were first ground and then subjected to stopping of the hydration process using a mixture of acetone and methanol in the ratio of 1:1 by volume, followed by drying to 80 °C for 24 h to prevent further hydration and the dried samples were kept in a dissiccator for further analysis [18,19]. The density of fresh and hardened concrete was determined according to BS EN 12390-7 [20] as follow:

$$\rho = M/V \quad (A.1)$$

$$V = Ma - Mw/1000 \quad (A.2)$$

where M, weight of specimen; V, volume of specimen; Ma: weight of suspended specimen in air; Mw, weight of suspended specimen in water.

Four different high-performance concrete mixes were prepared from coarse aggregates of dolomite, hematite, ilmenite and air-cooled slag and using sand as fine aggregate in addition

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