Cement & Concrete Composites 31 (2009) 483–488

Contents lists available at ScienceDirect

Cement & Concrete Composites

journal homepage: www.elsevier.com/locate/cemconcomp

Copper slag as sand replacement for high performance concrete

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ARTICLE INFO

Article history:
Received 30 June 2008
Received in revised form 11 April 2009
Accepted 14 April 2009
Available online 24 April 2009

Keywords:
High performance concrete
Copper slag
Waste material
Industrial by-products
Strength
Durability

ABSTRACT

This paper reports on an experimental program to investigate the effect of using copper slag as a replacement of sand on the properties of high performance concrete (HPC). Eight concrete mixtures were prepared with different proportions of copper slag ranging from 0% (for the control mix) to 100%. Concrete mixes were evaluated for workability, density, compressive strength, tensile strength, flexural strength and durability. The results indicate that there is a slight increase in the HPC density of nearly 5% with the increase of copper slag content, whereas the workability increased rapidly with increases in copper slag percentage. Addition of up to 50% of copper slag as sand replacement yielded comparable strength with that of the control mix. However, further additions of copper slag caused reduction in the strength due to an increase of the free water content in the mix. Mixes with 80% and 100% copper slag replacement gave the lowest compressive strength value of approximately 80 MPa, which is almost 16% lower than the strength of the control mix. The results also demonstrated that the surface water absorption decreased as copper slag quantity increases up to 40% replacement; beyond that level of replacement, the absorption rate increases rapidly. Therefore, it is recommended that 40 wt% of copper slag can used as replacement of sand in order to obtain HPC with good strength and durability properties.

1. Introduction

Many countries are witnessing a rapid growth in the construction industry which involves the use of natural resources for the development of the infrastructure. This growth is jeopardized by the lack of natural resources that are available. Natural resources are depleting world wide while at the same time the generated wastes from the industry are increasing substantially. The sustainable development for construction involves the use of non-conventional and innovative materials, and recycling of waste materials in order to compensate the lack of natural resources and to find alternative ways for conserving the environment.

Aggregates are considered one of the main constituents of concrete since they occupy more than 70% of the concrete matrix. In many countries there is scarcity of natural aggregates that are suitable for construction while in other countries there is an increase in the consumption of aggregates due to the greater demand by the construction industry. In order to reduce dependence on natural aggregates as the main source of aggregate in concrete, artificially manufactured aggregates and artificial aggregates generated from industrial wastes provide an an alternative for the construction industry. Therefore, utilization of aggregates from industrial wastes can be alternative to the natural and artificial aggregates. Without proper alternative aggregates being utilized in the near future, the concrete industry globally will consume 8–12 billion tons annually of natural aggregates after the year 2010 [1]. Such large consumption of natural aggregates will cause destruction to the environment.

In the last few decades there has been rapid increase in the waste materials and by-products production due to the exponential growth rate of population, development of industry and technology and the growth of consumerism. The basic strategies to decrease solid waste disposal problems have been focused at the reduction of waste production and recovery of usable materials from waste as raw materials as well as utilization of waste as raw materials whenever possible [2]. The beneficial use of by-products in concrete technology has been well known for many years and significant research has been published with regard to the use of materials such as coal fly ash, pulverized fuel ash, blast furnace slag and silica fume as partial replacements for Portland cement. Such materials are widely used in the construction of industrial and chemical plants because of their enhanced durability compared with Portland cement. The other main advantage of using such materials is to reduce the cost of construction.

Copper slag is one of the materials that is considered as a waste material which could have a promising future in construction industry as partial or full substitute of either cement or aggregates. It is a by-product obtained during the matte smelting and refining of copper. To produce every ton of copper, approximately 2.2–3.0 tons copper slag is generated as a by-product material. In Oman approximately 60,000 tons of copper slag is produced every year.

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doi:10.1016/j.cemconcomp.2009.04.007

Also, the production of approximately 0.36, 0.244, 2.0, and 4.0 million tons of copper slag is reported in Iran, Brazil, Japan and the United States, respectively [3]. Utilization of copper slag in applications such as Portland cement substitution and/or as aggregates has threefold advantages of eliminating the costs of dumping, reducing the cost of concrete, and minimizing air pollution problems.

High performance concretes (HPC) can be designed to have the desired higher workability, higher mechanical properties and/or greater durability than those of conventional concretes. Production of HPC that possesses good properties may involve enhancements of the following: ease of placement without segregation, long-term mechanical properties, early-age strength, toughness, volume stability, and life in severe environments. Therefore, HPC should have both high-strength and high-durability properties pertinent to an application. A HPC using cement alone as a binder requires high paste volume, which often leads to excessive shrinkage and large evolution of heat of hydration, besides increased cost. A partial replacement of cement by mineral admixtures, such as, fly ash, ground granulated blast furnace slag (GGBS), silica fume, metakaolin, rice husk ash or fillers such as limestone powders in concrete mixes would help to overcome these problems and lead to improvement in the durability of concrete. This would also lead additional benefits in terms of reduction in cost, energy savings, promoting ecological balance and conservation of natural resources, etc. [4–7]. Although there are some studies that have been reported on the effect of copper slag as aggregates on the performance of normal strength concrete, there has been little research concerning the incorporation of copper slag as fine aggregates to produce high performance concrete (HPC). Thus this research was performed to evaluate the potential use of copper slag as sand replacement in the production of high performance concrete (HPC).

2. Materials

2.1. Cement

The cement used in this study was ordinary Portland cement (OPC) purchased from Oman Cement Company. This cement is the most widely used one in the construction industry in Oman.

2.2. Fine aggregates

Fine aggregates (i.e. 10 mm) and fine sand were purchased from a nearby crusher in Al-Khoudh area, which are typically the same materials used in normal concrete mixtures. The gradation test conducted on aggregates showed that they met specifications requirements.

2.3. Copper slag

Copper slag is a by-product material produced from the process of manufacturing copper. As the copper settles down in the smelter, it has a higher density, impurities stay in the top layer and then are transported to a water basin with a low temperature for solidification. The end product is a solid, hard material that goes to the crusher for further processing. Copper slag used in this work was brought from Oman Mining Company, which produces an annual average of 60,000 tons.

2.4. Silica fume

The silica fume used in the production of high-strength concrete was supplied and added to the mix in a powder form (Elkem Emsac 500s).

2.5. Superplasticizer

In order to improve the workability of high-strength concrete, superplasticizer in the form of a polynaphthalene sulphonate-based admixture (conplast SP430) was used. This had 40% active solids in solution.

3. Laboratory testing program

3.1. Mix design and sample preparation

The mix proportion chosen for this study is given in Table 1. Eight concrete mixtures with different proportions of copper slag ranging from 0% (for the control mix) to 100% were considered as shown in Table 2. The constituents were weighed in separate buckets. The materials were mixed in a rotating pan in accordance with ASTM C192-98 [8]. The overall mixing time was about 4 min. The mixes were compacted using vibrating table. The slump of the fresh concrete was determined to ensure that it would be within the design value and to study the effect of copper slag replacement on the workability of concrete. The specimens were demoulded after 24 h, cured in water and then tested at room temperature at the required age.

To determine the unconfined compressive strength, six cubes ($150\ \text{mm} \times 150\ \text{mm} \times 150\ \text{mm}$) were cast for each mix and water-to-binder ratio, and three samples were tested after 7- and 28-days of curing. Three 150 mm diameter $\times$ 300 mm long cylinders were prepared for each mix in order to determine the 28-day tensile strength of concrete. Also, to determine the flexural strength (modulus of rupture) for each mix, three $100\ \text{mm} \times 100\ \text{mm} \times 500\ \text{mm}$ prisms were cast and tested after 28-days of curing. Two more ($150\ \text{mm} \times 150\ \text{mm} \times 150\ \text{mm}$) cubes were prepared and tested after 28-days in order to assess the durability of the HPC using the initial surface absorption test.

3.2. Testing procedure

After curing, the following tests were carried out on the concrete specimens:

- 7- and 28-day cube compressive strength test was conducted in accordance with BS 1881: Part 116 [9] using a loading rate of 2.5 kN/s;
- 28-day cylinder tensile (splitting) strength test was done in accordance with ASTM C496-96 [10] using a loading rate of 2 kN/s;
- 28-day flexural strength test was conducted in accordance with ASTM C78-94 [11] using a simple beam with third point loading at a loading rate of 0.2 kN/s; and
- the initial surface absorption test was conducted on two samples after 28-days of curing in accordance with BS 1881: Part 208 [12].

All strength tests were conducted using a DARTEC compression machine.

4. Results and discussion

4.1. Chemical analyses and physical properties

Chemical analyses of OPC and copper slag are presented in Table 3. It can be seen from Table 3 that free and combined limes contribute to nearly 63% of the chemical composition of OPC whereas copper slag has a very low lime content of approximately 6%. This indicates that copper slag is not chemically a very reactive material