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Studies on ultra high performance concrete incorporating copper slag as fine aggregate

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HIGHLIGHTS

- Alternate aggregate system for ultra high performance concrete (UHPC).
- Complete replacement of natural aggregate by waste copper slag in UHPC.
- Optimization of granular mixture by suitable separation and particle packing.

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ABSTRACT

This paper investigates the technical feasibility of using copper slag as fine aggregate replacement in ultra high performance concrete (UHPC). The studies demonstrated that it is possible to produce UHPC having compressive strength greater than 150 MPa by incorporation of copper slag. The complete replacement of standard sand by copper slag resulted in a maximum decrease in 28-day compressive strength of about 15–25% whereas, the flexural strength, fracture energy recorded was of the similar order. It can be concluded from the results that use of copper slag as fine aggregate in UHPC is technically viable.

1. Introduction

Natural resources are depleting worldwide at the same time new by products are being generated by various industries which could have a promising future in construction industry as partial or full substitute of either cement or aggregates. Copper slag, a waste resulting from the copper manufacturing process, is one of the promising industrial by products among them. To produce every tonne of copper, approximately 2.2–3.0 tonnes copper slag is generated as a byproduct material [1,2]. Current options of management of this slag are recycling, production of value added products and disposal in slag dumps or stockpiles. Copper slag is being used as a cement replacement material [2,3], fine aggregate replacement material [4–9] and coarse aggregate replacement material [10] in concrete depends upon the properties of the material. Slags containing <0.8% copper are either discarded as waste or sold cheaply [11,12]. Several studies have been reported by investigators from other countries on the use of copper slag in cement concrete and mortar [13–15] and few studies on high strength concrete and high performance concrete (HPC) [16–19]. However, there is not much research done in India concerning the incorporation of copper slag in high strength concrete.

During 1930's onwards much research work has been done, aimed at achieving cementitious matrix materials with high mechanical performance [20–23]. Research over the past decade has yielded a new classification of highly resilient concrete, called reactive powder concrete (RPC), with compressive strengths comparable to that of some steels. Now labeled and classified as ultra-high performance fiber reinforced concretes (UHPFRC), these materials address many of the durability performance deficiencies associated with both normal strength concrete (NSC) and HPC [24]. Several studies were reported on UHPC using different materials, its mechanical and durability properties as well as application [25–30]. In recent years, UHPFRC has been successfully applied to dam, repair, bridge deck overlays, coupling beams in high rise building and other specialized structures [31]. But in our country,

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so far, there are no applications for these concretes and their implementation is still exceptional, primarily because of their high cost. The sustainable development for construction involves the use of non-conventional and innovative materials, and reusing of waste materials in order to compensate the lack of natural resources and to find alternative ways for conserving the environment. Hence this research was performed to evaluate the potential use of copper slag as sand replacement in the production of UHPC, so that, UHPC may be made more affordable to a wider variety of applications.

2. UHPC constituents

The constituents of UHPC include Portland cement, silica fume, quartz powder, fine aggregate (Ennore sand, copper slag), steel fibers, superplasticizer and water. Each of the components in UHPC aids in optimizing the material properties, thus contributing to its extraordinary strength. The cement used in this study was 53 grade ordinary Portland cement conforming to IS: 12269: 1987 [32] equivalent to ASTM C 150/Type I. Densified silica fume conforms to ASTM C 1240-97 [33] with a specific gravity of 2.2 was used to supplement the cementitious content in the mix for the high strength requirement. Quartz powder is maximal for a particle size of between 5 and 25 μm and with a specific gravity 2.61. Ennore sand (ES) is the standard sand as per IS 650 – 1991 [34], grade I (2–1 mm), grade II (1–0.5 mm) and grade III (0.5–0.09 mm), with a specific gravity of 2.65 is used. Since no coarse aggregate is introduced into the mix, the sand contributes the largest particle size in the granular mixture. Copper slag (CS) used in this work was brought from Sterlite industries Ltd., Tuticorin. The fiber used in this study is straight brass coated steel fibers with 0.16 mm in diameter and 13 mm in length and having tensile strength of around 2000 MPa. Ordinary tap water was used for mixing and curing all the concrete specimens considered. The superplasticizer used in this study was Poly Acrylic Ester based high-range water-reducer (HRWR-Glenium 8045).

2.1. Physical and chemical properties of copper slag

The copper slag is a black glassy particle and granular in nature and has a similar particle size range like sand. The bulk density of granulated copper slag is varying from 1.9 to 2.15 g/cc. The free moisture content present in the copper slag was found to be less than 0.5% and the presence of silica is about 26%, which is desirable since it is one of the constituents of the natural fine aggregate used in normal concreting operations. Table 1 shows the physical properties of copper slag. The specific gravity and water absorption for copper slag and sand were determined as per IS 2386 Part III [35].

The higher specific gravity of copper slag compared to conventional sand results in production of UHPC with higher density, when used as sand substitution. Due to the low water absorption of copper slag would demand less water than that required by sand in the concrete mix. Therefore, it is expected that the free water content in concrete matrix will increase as the copper slag content increases which consequently will lead to increase in the workability of the concrete. Copper slag of different grades was prepared by sieving (similar to standard sand (Ennore sand) that grade I: 2–1 mm, grade II: 1–0.5 mm, grade III: 0.5–.09 mm). Fig. 1 shows the sieve analysis of copper slag done as per IS 383-1970 [36] .The fineness modulus was found to be 3.43.

Table 1
Physical properties of copper slag.

Physical properties	Copper slag
Particle shape	Irregular
Appearance	Black and glassy
Type	Air cooled
Specific gravity	3.37
Percentage of voids	43.20%
Bulk density	2.08 g/cc
Fineness modulus	3.43
Water absorption	0.3–0.4%
Moisture content	0.1%

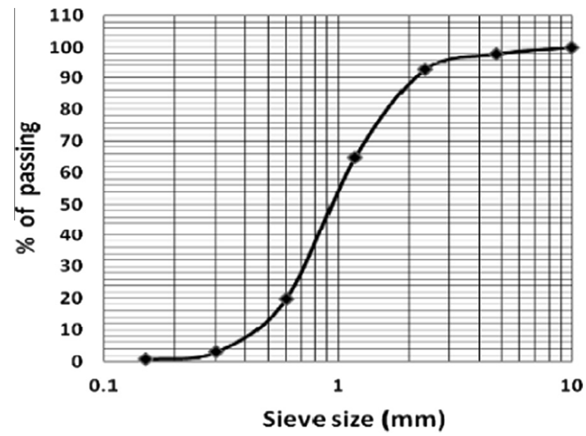

Fig. 1. Sieve analysis of copper slag.

Table 2
Chemical properties of copper slag.

Sl. no.	Chemical component	% of chemical component
1	SiO_2	25.84
2	Fe_2O_3	68.29
3	Al_2O_3	0.22
4	CaO	0.15
5	Na_2O	0.58
6	K_2O	0.23
7	LoI	6.59
8	Mn_2O_3	0.22
9	TiO_2	0.41
10	SO_3	0.11
11	CuO	1.20
12	Sulphide sulphur	0.25
13	Insoluble residue	14.88
14	Chloride	0.018

2.2. Chemical composition of copper slag

Copper slag samples were analyzed for constituent oxides including minor oxides and heavy elements besides mineral phases. The results of chemical analysis are shown in Table 2.

3. Research methodology

In the present investigation two types of UHPC were taken, one with local sand (standard sand) as aggregate system and the other with complete replacement of standard sand with copper slag as aggregate. A schematic representation of the methodology adopted is shown in Fig. 2.

3.1. Optimisation of granular materials

Advanced technologies like UHPC require a specific granulometric composition that reduces the void fraction in the dry mixture to obtain a harder and less porous concrete it will in turn