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Performance of alkali activated slag concrete mixes incorporating copper slag as fine aggregate

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ABSTRACT

In this present study, copper slag (CS) is proposed as an alternative to river sand as fine aggregate in alkali-activated slag concrete (AASC) mixes. The relative performance of alkali activated slag concrete mixes with CS as fine aggregate is compared to conventional Ordinary Portland Cement concrete (OPCC) mix in terms of their workability, strength and durability parameters. The results indicate that, AASC mixes with CS, as a replacement to sand upto 100% (by volume), show no marked loss in strength characteristics. AASC mixes with either sand or CS possess similar modulus of elasticity, lower total porosity, lesser water absorption and reduced chloride ion penetration as compared to OPCC. Strength-retention characteristics of AASC mixes with sand/CS on exposure to sulphate and acid-rich environment are also studied. Use of AASC mixes for structural application reduces carbon footprint, decreases water consumption and cost. Use of CS as fine aggregate reduces river sand consumption as an added benefit.

1. Introduction

Alkali Activated Slag Concrete (AASC) mixes are being deliberated as a potential alternate construction material to established Ordinary Portland Cement-based Concrete (OPCC). AASC mixes use large amounts of Ground Granulated Blast Furnace Slag (GGBFS), an industrial by-product from iron and steel industry, and hence can lead to reduced consumption of non-renewable resources like limestone, clay, coal, etc., in the manufacture of Ordinary Portland Cement (OPC). Along with lower energy ingestion and CO_2 discharge associated with the use of GGBFS, AASC mixes have also exhibited desirable properties like higher mechanical strengths at early ages, higher resistance to aggressive environments and greater resistance to elevated temperatures (Roy, 1999; Shi et al., 2006; Susan Ruby et al., 2011). These properties have made alkali-activated slag concretes, a very promising alternative to OPCC mixes, from both technical and market points of view (Provis and van Deventer, 2009; Van Deventer et al., 2010). Commercialization of alkali activation technology is advancing in many countries, and the development and study of AASC mixes is an active area of current research focus (Susan Ruby et al., 2011).

Sand mining mainly from river beds and open pits, is an age-old practice to extract sand, mainly from river beds and open pits. Sand is mined from beaches, inland dunes and is also dredged from ocean beds. With the launching of major infrastructure projects and continuous developments in construction industry, mostly based on concrete, there is an unprecedented increase in the demand for sand, in many developing countries including India. However, sand mining is becoming a severe ecological issue, in various parts of the world, due to the number of environment-related issues like reduction in water head leading to less recharging of water into the ground aquifers, wearing down of land, disturbance due to excavating of sand and lifting, devastation of flora and fauna in adjoining regions etc., associated with it (Ashwath, 2013).

Copper slag (CS) is a derivative obtained in the course of the manufacturing and decontaminating of copper. With manufacture of everyone ton of copper, nearly 2.2–3 tons of CS is produced as a by-product (Gorai et al., 2003), Even in India, about 3.5 million tons of copper slag is produced annually, which is used as an abrasive material to eliminate rust, timeworn coating and other impurities (Kambham et al., 2007), but most of them conventionally disposed off as an industrial waste. However, it can be valuably used as a partial replacement to sand as fine aggregate in production of concrete (Thomas and Gupta, 2013).

Even though the possible use of CS in concrete manufacture has attracted research attention in the past few years, it is quiet not clear about the optimal contents of CS to be used as fine aggregates

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Table 1
Chemical composition of GGBFS and CS (% by weight).

Constituent	GGBFS	CS
CaO	33.77	0.84
Al_2O_3	16.70	6.06
Fe_2O_3	1.20	49.30
SiO_2	32.43	32.74
MgO	9.65	0.20
Na_2O	0.16	0.14
K_2O	0.07	0.03
SO_3	0.88	0.13
Insoluble Residue	4.03	17.97
Loss of Ignition	0.04	0.25
Glass Content	92%	–

Table 2
Grading of fine aggregate materials.

IS sieve designation (mm)	Sand (% passing)	Copper slag (% passing)
10.0	100	100
4.75	99.0	100
2.36	96.4	99.6
1.18	75.7	76.8
0.60	53.5	48.8
0.30	14.3	11.9
0.15	2.8	1.0
FM	2.58	2.61

in concrete mixes (Wua et al., 2010). Since there is no research relating to the incorporation of CS as a fine aggregate to produce AASCs, the present research attempts to study the effect of using CS as fine aggregate on strength and durability characteristics of AASC mixes.

2. Experimental program

2.1. Materials

2.1.1. Cement

43 Grade Ordinary Portland Cement (OPC) conforming to IS 8112 – 2013 (equivalent to strength class of 42.5R of BS 12 – 1996), was used for preparing reference concrete mix. The cement was having a fineness of about 340 m^2/kg (as measured on Blaine's air permeability apparatus) and specific gravity of 3.14. Compressive strengths of cement at 7 and 28 days were 40.2 and 54.0 MPa, respectively.

2.1.2. Ground Granulated Blast Furnace Slag (GGBFS)

In the present investigation, GGBFS conforming to IS: 12089 – 1987 was used as the starting material to produce alkali-activated slag concrete mixes. The same was obtained from M/S Jindal Steel Works, Bellary, India. The slag had a Blaine's fineness of about 370 m^2/kg and specific gravity of 2.9. The chemical composition of GGBFS used is shown in Table 1. With a computed basicity coefficient [$K_b = (CaO + MgO)/(SiO_2 + Al_2O_3)$] of 0.88, it can be classified as an 'acidic slag' (Shi et al., 2006).

2.1.3. Alkali solution

Commercial grade Sodium Hydroxide (NaOH) flakes (97% purity) and Liquid Sodium Silicate (LSS) (14.7% Na_2O + 32.8% SiO_2 + 52.5% H_2O by mass, and density = 1570 kg/m^3), were used in the preparation of alkali activator solution.

The alkali activator solution used herein is a mixture of liquid sodium silicate and sodium hydroxide, with modulus, Ms (mass ratio of SiO_2/Na_2O) of 1.25 and Na_2O concentration of 4% (The mass of Na_2O in the alkaline activator is the sum of Na_2O present in sodium silicate and the mass of Na_2O equivalent in NaOH). The desired Ms was obtained by adding NaOH to appropriate amount of LSS. Tap water available in the institute laboratory was then added to bring the total water to binder ratio to 0.4, for all AASC mixes, taking into account the amount of water readily present in the LSS. Alkali solution was immediately transferred to a container with air tight cap, left for at least 24 h to cool, before using in a concrete mix.

2.1.4. Aggregates

Crushed granite chips of maximum nominal size of 20 mm were used as coarse aggregate. The specific gravity and water absorption of the coarse aggregate were 2.69 and 0.4%, respectively. The specific gravity, water absorption and fineness modulus (FM) of river sand used were 2.64, 1.50% and 2.58, respectively. The chemical composition of CS used in this study tested as per IS: 1727 – 1967 is shown in Table 1. The specific gravity, water absorption and fineness modulus (FM) of resulting CS used were 3.6, 0.50% and 2.61, respectively. The results of sieve-analysis of both sand and CS used as fine aggregates here in this study are compared with the four suggested standard grading zones shown in Table 2. The results show that both sand and CS conform to Zone II, as per IS: 383 – 1970.

2.1.5. Super plasticizers

A commercially available, chloride-free Naphthalene sulfonate-based admixture (Fosroc-Conplast SP 430) with 40% solids was used to increase the workability of the OPC-based control concrete mix.

2.2. Experimental program

2.2.1. Mix design and specimens preparation

The mix proportions of OPC-based concrete mix were designed following the guidelines specified in IS 10262 – 2009. The mix was proportioned to achieve an initial slump of 50–75 mm, with 440 kg

Table 3
Details of mix proportions of concrete mixes (All ingredient contents are in kg/m^3).

Mix ID	OPC	GGBFS	Fine Aggregates		Coarse Aggregate	LSS	NaOH	Added water	Total water	SP	Density
			Sand	CS							
OPCC	440	–	650	–	1178	–	–	174.4	176	2.64	2440
ACS-0	–	440	630	–	1141	67.1	10	140.8	176	–	2420
ACS-25	–	440	473	216	1141	67.1	10	140.8	176	–	2480
ACS-50	–	440	315	432	1141	67.1	10	140.8	176	–	2540
ACS-75	–	440	156	648	1141	67.1	10	140.8	176	–	2600
ACS-100	–	440	–	864	1141	67.1	10	140.8	176	–	2660

Note: OPCC – Portland cement based control mix; ACS-**X** – represents AASC mixes with X (% by volume) of sand replaced with copper slag, LSS – Liquid sodium silicate, SP – Super plasticizer.

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