

# Effect of Partial Replacement of Copper Slag on Mechanical Properties in High Performance Alkaline Cement Concrete

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**ABSTRACT:** The study evaluates the technical possibility of the replacement of copper slag for fine aggregate in high performance alkali activated concrete (HPAAC). Further it demonstrated that, it is possible to produce HPAAC having compressive strength greater than 150 MPa by incorporation of copper slag. The compressive strength, flexural strength and split tensile strength of HPAAC have been evaluated. From the results obtained, it can be concluded that the use of copper slag as fine aggregate in HPAAC is quite possible.

**KEYWORDS:** Compressive strength, Copper slag, Split tensile strength, HPAAC

## I. INTRODUCTION

Ordinary Portland Cement-based Concrete (OPCC) is being altered potentially by adding Alkali Activated Slag Concrete (AASC) mixes. AASC mixes produced by blending the iron and steel industry by-product such as Ground Granulated Blast Furnace Slag (GGBFS), which can lead to reduced consumption of conventional resources viz., limestone, clay, coal, etc., in Ordinary Portland Cement (OPC) manufacture. In addition to lower energy ingestion and CO<sub>2</sub> discharge coupled with the use of GGBFS, AASC mixes also showed excellent properties like higher mechanical strengths at early ages, higher resistance to aggressive environments and greater resistance to elevated temperatures [1, 2]. With a view of above said properties, it is clear that AASC claims the role as a very promising alternative to OPCC mixes, in view of both technical and market application[3, 4] Sand mining is a very old technique to extract sand mainly from river beds and open pits. Nowadays, it is mined from beaches, inland dunes and is also dredged from ocean beds. However, C.Nagarajan et al [3,4,8] has studies sand mining leads to wearing down of land, reduction in water head leading to less recharging of water into the ground aquifers, devastation of flora and fauna in adjoining regions disturbance due to excavating of sand and lifting, etc., is becoming a severe ecological issue in various parts of the world [5].

The manufacturing and decontamination of copper gives copper slag (CS) as a waste product. Approximately 2 tons of CS is being produced in manufacturing of everyone ton of copper [6]. In India, nearly 4 million tons of copper slag is produced per annum, which is used as an abrasive material to remove rust, timeworn plating and other impurities [7]. In addition to these applications, it can also be effectively utilized as a partial replacement to sand as fine aggregate in production of concrete [8].

To the best of our knowledge, there is no research including to the addition of CS as a fine aggregate to produce HPAACs. Hence, the present study focuses to examine the effect of using CS as fine aggregate on strength and durability characteristics of HPAAC mixes.

## II. EXPERIMENTAL

### 1.1 Cement

OPC (43Gr) conforming to IS8112-2013 (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<sup>2</sup>/kg and specific gravity of 3.14. Compressive strengths of cement at 14, 28 and 56 days have been evaluated [9, 10].

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## 1.2 Copper slag

Copper slag conforming to IS: 12089-1987 obtained from M/S Star Trace Pvt. Ltd., Chennai, India was used as the starting material to produce alkali-activated slag concrete mixes in the present study. The slag had a Blaine's fineness of about 370 m<sup>2</sup>/kg and specific gravity of 2.9. The chemical composition of Copper slag used is shown in Table 1 [11].

**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	0.10%

**Table 2**  
Chemical properties of copper slag

S.No.	Chemical Composition	
1	Al <sub>2</sub> O <sub>3</sub>	3.01%
2	TiO <sub>2</sub>	0.60%
3	Fe <sub>2</sub> O <sub>3</sub>	68.29%
4	SiO <sub>2</sub>	35.00%
5	CaO	0.20%
6	MgO	0.90%
7	K <sub>2</sub> O	1.02%
8	Na <sub>2</sub> O	0.95%
9	CuO	0.42%
10	Mn <sub>2</sub> O <sub>3</sub>	0.22
11	Insoluble	14.88

## 1.3 Alkali solution

The alkali activator solution has been prepared by adding Commercial grade Potassium Hydroxide (KOH) (97% purity) with Liquid Potassium Silicate (LPS) (14.7% K<sub>2</sub>O + 32.8% SiO<sub>2</sub> + 52.5% H<sub>2</sub>O by mass, and density = 1570 kg/m<sup>3</sup>).

The prepared alkali activator solution is a mixture of liquid potassium silicate and potassium hydroxide with 1.25 Ms (mass ratio of SiO<sub>2</sub>/K<sub>2</sub>O) and 4% of K<sub>2</sub>O. The desired Ms was obtained by adding KOH to appropriate amount of LPS. Alkali solution was immediately transferred to a container with air tight cap and left for minimum 24 h to cool prior to use [12].

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### 1.4 Coarse aggregates

Coarse aggregates are actually obtained by crushing granite chips of maximum nominal size of 20 mm. Coarse aggregates have 2.69 specific gravity value and 4% of water absorption. The river sand having 2.64 of specific gravity, 1.5% of water absorption and 2.58 of fineness modulus (FM) were used. The chemical composition of CS used in this study tested as per IS: 1727-1967 is shown in Table 1. The CS (Fig. 1) used in the present study having the following properties viz., the specific gravity, water absorption and fineness modulus (FM) as 3.6, 0.50% and 2.61, respectively [12]. The output of sand and CS used as fine aggregates 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.



Fig. 1 Copper slag

### 1.5 Super plasticizers

A commercially available, poly ethylene glycol based admixture with 40% solids was used to enhance the workability of the OPC-based control concrete mix.

### 1.6 Mix ratio

The procedure for making mix was followed based on the recommendations of Bureau of Indian standards IS 10262 – 1982 in the prescribed ratio with view to know the test results of workability, specific gravity, water absorption and free surface moisture for the materials. Design is stipulated for good degree of quality control and mild exposure. The mix proportions for M20 grade, by weight are 1:1.5: 3 (cement: fine aggregate: coarse aggregate) with a water cement ratio of 0.42 [13]. The mix proportion for various concrete mixtures are tabulated and presented in Table 3.

**Table 3**  
Concrete Mix Design Details

S. No.	Cement (kg/m <sup>3</sup> )	% of slag added	F.A. (kg/m <sup>3</sup> )	Slag (kg/m <sup>3</sup> )	C.A. (kg/m <sup>3</sup> )	Water (l/m <sup>3</sup> )
1.	380.15	0	570.22	0	1140.45	159.66
2.	380.15	10	513.2	57.02	1140.45	159.66
3.	380.15	20	456.17	114.5	1140.45	159.66
4.	380.15	30	399.15	171.7	1140.45	159.66
5.	380.15	40	342.13	228.09	1140.45	159.66
6.	380.15	50	285.11	285.11	1140.45	159.66

### 1.7 Tests on Mechanical Properties

Indian standards have been adopted to test the fresh concrete properties. Cubical specimens of 150 size were prepared to study the compressive strength whereas cylindrical and prism specimens of size about 150 mm diameter

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with 300 mm height and 100 x 100 x 500 mm, respectively were designed to study the mechanical strength properties viz., compressive strength, split tensile strength and modulus of rupture according to Indian standards [14, 15].

### III. RESULT AND DISCUSSIONS

#### Effect on compressive strength

From the closest observation from the Fig. 2 and Table 4, it is clear that, the maximum compressive strength of concrete with 40% replacement of copper slag with or without chemical admixture has been found to be 26% and 56% higher than the conventional concrete. However the replacement of aggregate increasing up to 50% the concrete compressive strength has been significantly decreased when comparing with 40% replacing coarse aggregate with copper slag. Hence the replacement of 40% aggregate is found to be optimized and effective to attain the required strength of concrete.

#### Effect on split tensile strength

Fig. 3 and Table 4 shows the observation of split tensile strengths of different HPAAC mixes including CS in various proportions. All HPAAC mixes showed greater split tensile strengths than the OPCC (control) mix; hence, it is clear that the tensile strengths of HPAACs are not related to the replacement of fine aggregate with CS. The flexural strengths measured at various ages (14, 28 and 56 days) for HPAAC mixes are given in Fig. 4 and Table 4. The figure revealed the fact that, the HPAAC mix showed the enhanced flexural strength after the replacement of copper slag with fine aggregate compared to the control OPCC mix. Further, it is evident from the figure that, the replacing of copper slag with fine aggregate does not imply any marked changes in their flexural strengths of the concrete.

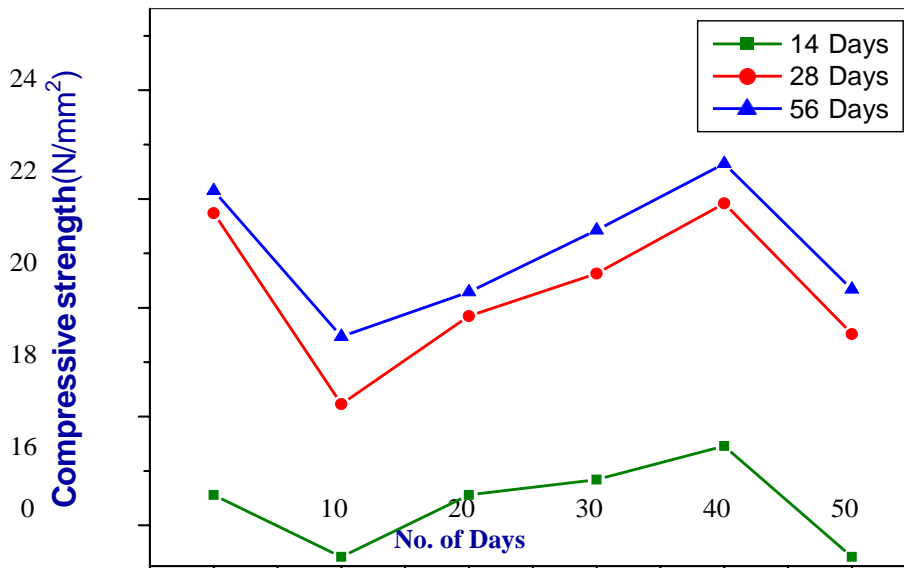


Fig. 2 Compressive strength of HPAAC

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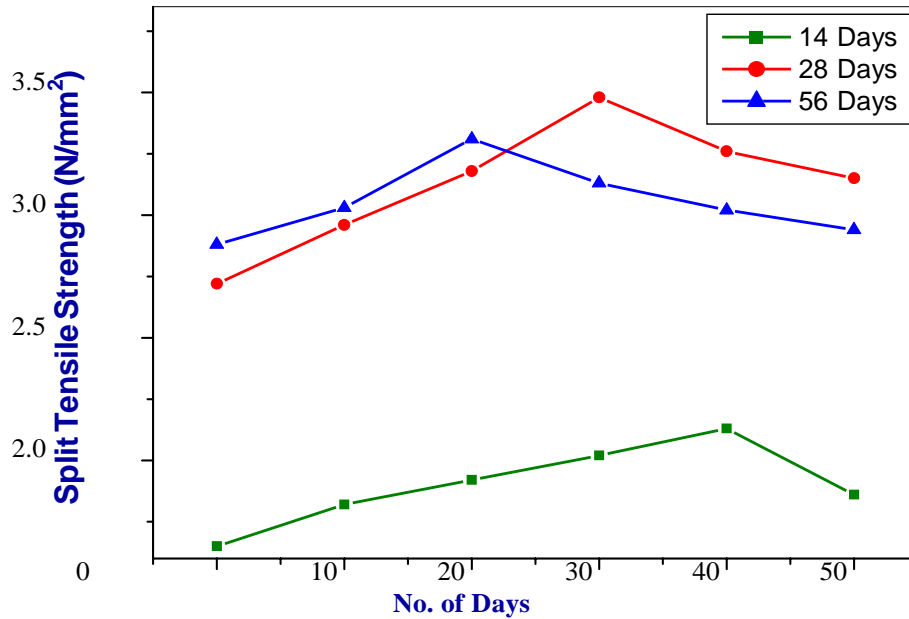


Fig. 3 Split tensile strength of HPAAC

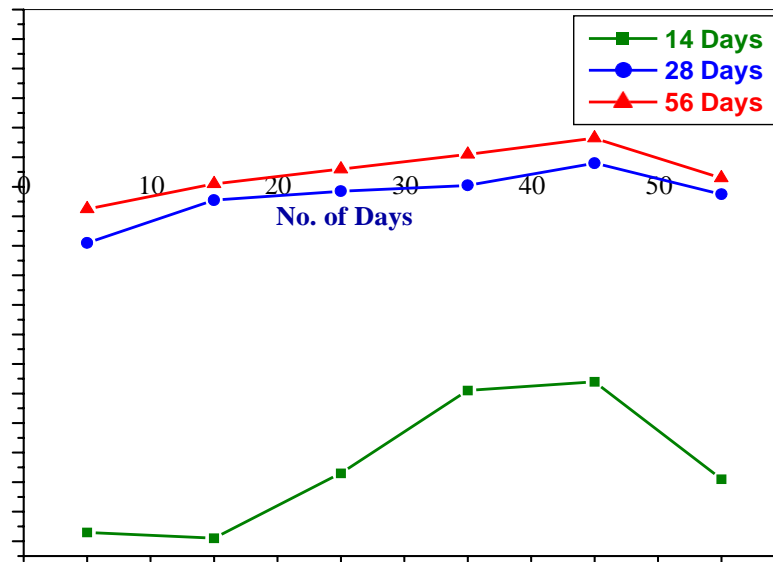


Fig. 4 Flexural strength of HPAAC

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**Table 4**  
Compressive, split tensile and flexural strengths

copper slag	Compressive strength (N/mm <sup>2</sup> )			Split tensile strength (N/mm <sup>2</sup> )			Flexural strength (N/mm <sup>2</sup> )		
	14 Days	28 Days	56 Days	14 Days	28 Days	56 Days	14 Days	28 Days	56 Days
0	16.56	21.74	22.15	1.65	2.72	2.88	1.46	3.42	3.65
10	15.42	18.23	19.47	1.82	2.96	3.03	1.42	3.71	3.82
20	16.56	19.85	20.29	1.92	3.18	3.31	1.86	3.77	3.92
30	16.84	20.63	21.43	2.02	3.48	3.13	2.42	3.81	4.02
40	17.46	21.92	22.65	2.13	3.26	3.02	2.48	3.96	4.13
50	15.42	19.52	20.34	1.86	3.15	2.94	1.82	3.75	3.86

## IV. CONCLUSIONS

The replacement of sand with CS in HPAAC showed no significant change in workability. HPAACs with CS show higher tensile strength properties than those of OPCC mix of similar compressive strength. Replacing CS even up to 50% did not show any represented loss in strength parameters. The compressive strength measurements showed that the strength of HPAAC mixes with CS showed no strength deterioration. The replacement of CS with fine aggregate enhanced the split tensile strength and flexural strength. Use of HPAAC mixes with CS as fine aggregates has seven fold advantages over OPCC namely (i) low energy consumption

(ii) less liberation of CO<sub>2</sub> (iii) cost-effective (iv) saving in water due to air curing (v) consumes industrial by product (GGBFS) which in turn saves conventional energy resources such as limestone, iron ore, coal etc., which are essential ingredients of cement (vi) uses industrial waste (waste management) (vii) reduction in copper slag stock piles, which or else would create environmental problems, with added economical benefits associated with the environment.

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