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Studies on Alkali Activated Slag Mortar with Copper Slag as Fine Aggregate

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Abstract: The over exploitation of natural river sand from the river beds for construction purposes has resulted in several environmental issues, leading to the need for identification of alternative sources for fine aggregates for mortar and concrete production. Hence, the present study is focused to evaluate the performance of Copper Slag (CS), which is a by-product obtained during the manufacture of copper, in Alkali Activated Slag (AAS) mortar mixes. The mix design for AAS mortar mixes is optimized and the river sand is replaced with CS fine aggregates at different replacements (0%, 25%, 50%, 75% and 100% by volume of total aggregate content). The compressive strength, water absorption, density, total porosity and abrasion resistance of AAS mixes with/without CS are evaluated and compared with conventional Ordinary Portland Cement (OPC) mortar mixes. The results indicated that the inclusion of CS in AAS mortar mixes did not have any adverse effects on the properties of AAS mixes.

Keywords: *Alkali Activated Slag, Mortar, Copper Slag, Waste Management.*

1. Introduction

Alkali activated binders are gaining wide attention in the current day research community due to its potential ability to replace conventional Ordinary Portland Cement (OPC). The alkali activated binders are well known for their environmental advantages such as reduction in CO_2 emissions, material recovery, decreased pollution and saving in energy sources as compared to OPC. Alkali activated slag (AAS) is one kind of the alkali activated binders which is mainly produced by activation of Ground Granulated Blast Furnace Slag (GGBFS), which is waste product obtained during the production of pig iron. Although the GGBFS has latent hydraulic properties, there a need to activate the GGBFS using strong alkaline solution in order to achieve sufficient strength properties within acceptable time duration necessary for construction. Several studies have been carried out to activate GGBFS by using different alkali metal hydroxides, silicates or carbonates, however, the combination of liquid sodium silicate and sodium hydroxide has provided the best results for activation of AAS [1-7]. Studies have shown that with higher concentration and dosage of alkali activator, the AAS develops higher mechanical properties [8-9]. AAS are believed have displayed better mechanical properties as compared to conventional OPC [10-12].

The mechanical and rheological properties of concrete and mortar mixes are greatly influenced by the type and properties of aggregates [13]. The various properties of aggregates such as surface texture, shape, specific gravity, toughness, strength etc. generally affect the strength of the mortar and concrete mixes in fresh and hardened state [14]. In India, natural river sand is the mostly widely used fine aggregates for construction purposes. However, over exploitation of natural sand from the river beds over the years have resulted in environmental and ecological concerns, leading to increased environmental restrictions on the use of natural sand for constructions. Due to this, the construction industry is forced to look upon alternative materials which can replace river sand in construction industry. The use of Copper Slag (CS), which is a by-product obtained during the manufacture of copper [15], as fine aggregates appears to be a promising alternative to river sand for the construction industry. Present day copper slag management processes include recycling, metal extraction from the slag, disposal in stockpiles etc. Copper slag is also widely used for manufacture of abrasion tools, cutting tools, railroad ballast, blended cement production and other purposes [16]. The use of CS for construction purposes is associated with concerns related to the content of toxic elements and the leaching from slag based products. However, the several organizations such as United States Environmental Protection Agency (USEPA). The United Nations (UN) Basel Convention on the Trans boundary Movement of Hazardous Waste and its Disposal, have ruled that CS to be a non-hazardous material [17].

The use of CS as aggregates is associated with certain advantages features such as high abrasion resistance, better stability, good soundness characteristics etc. Several investigations on the use of CS in cement mortar and concrete have been carried out over the years and the results have indicated the use of CS to be beneficial [18-20]

Studies carried out by researchers [21] have reported that CS when used as coarse aggregates met the grading requirements (according to ASTM C33) to be used in concrete. The studies reported CS to have lower water absorption and found to be harder as compared to limestone aggregate. The river sand when partially replaced with CS has found to satisfy the workability requirements along with reduction in bleeding and improvement in the compressive strength when tested in OPC concrete [22]. Studies carried out by researchers [23-24] reported that concrete containing CS displayed similar strength properties as that compared to conventional aggregates. The Ayano and Sakata [25] reported delayed in the setting time of the due to the presence of CS; however the durability was not affected by it.

The present work is conducted to explore the suitability of CS as fine aggregates in AAS mortars mixes. Mortars mix with CS, natural river sand and Indian standard Sand are prepared and various properties such as compressive strength, water absorption, total porosity, abrasion resistance are evaluated.

2. Experimental Program

2.1. Materials

Ordinary Portland Cement (OPC) 43 grade conforming to IS 8112 – 2013, was used for preparing reference concrete mix. Ground Granulated Blast Furnace Slag (GGBFS) procured from M/S Jindal Steel Works, Bellary, India conforming to IS: 12089 – 1987 was used as the starting material to produce alkali-activated slag concrete mixes. The GGBFS obtained had a specific gravity of 2.9 and fineness of 370 m^2/kg (Blaine). 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 was formulated to the required sodium oxide dosage (%Na_2O weight of binder) and activator modulus (ratio of SiO_2/ Na_2O) one day prior to mixing and stored in tight containers. Locally available river sand having a specific gravity of 2.64 and water absorption of 1.5% was used for the study. Copper slag fine aggregates obtained from Sterlite industries Tamil Nadu was used for the present study. It was observed that the CS, as-received from the industry consisted of 3.3% friable particles when tested as per ASTM C142-10. It can be expected that better bonding with paste and CS particles for better concrete properties may be realized by excluding of such weak particles [18]. Therefore, 20 kg of CS per batch was ground in a Los Angeles abrasion testing machine for 30 minutes, with 10 no of steel balls each weighing 390 to 445 gms, as the charge, along with 100 g of water to eliminate dust, while removing copper slag from the machine. The specific gravity, water absorption and fineness modulus (FM) of resulting CS used were 3.6, 0.50% and 2.61, respectively. Indian Standard IS: 383– 1970 classifies, the fine aggregate into four different zones on the basis of grading. The fine aggregate grading can vary between a ‘coarse’ for zone I to ‘fine’ for zone IV. 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. The chemical composition of GGBFS and CS used in this study is shown in Table 1.

Table 1: *Chemical composition of GGBFS and Copper Slag (% by weight)*

Constituent	GGBS	Copper Slag
CaO	33.77	0.84
Al_2O_3	16.7	6.06
Fe_2O_3	1.2	49.3
SiO_2	32.43	32.74
MgO	9.65	0.2
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 aggregates*

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
FM	2.58	2.61

2.2. Mix Design

The mix design for mortar mixes was done according to IS: 8112:2013. The volume ratio of paste to sand was maintained as 1.5 with a water/binder (w/b) ratio of 0.40 all the mixes (OPC and AAS). The AAS mixes were activated using a sodium oxide dosage (%Na_2O weight of binder) of 4% with a constant activator modulus (ratio of SiO_2/ Na_2O) of 1.25.Tap water available in the institute laboratory was added to the activator solution to bring the total water content as per required water/ binder ratio of 0.4, by taking into account the amount of water readily present in the LSS. With the known properties of all ingredients, AAS mortar mixes containing 25%, 50%, 75%, and 100% (% volume) of CS by replacing river sand were prepared. The total volume of fine aggregate comprising of sand/CS was kept constant in all AAS mortar mixtures. Details of mix proportions of all the trial mixes tested herein are presented in Table 3.

The ingredients were dry mixed properly and then the activator solution was poured. Care was taken to ensure proper mixing of the ingredients. Cubes of size (70x70x70) cm were cast by compacting in three layers on a vibrating table in order to evaluate hardened properties. The AAS cubes with/without CS were subjected to air curing at a RH of 85±5 % while the conventional OPC cubes were cured in water tank. The compressive strength, water absorption, total porosity and abrasion resistance were tested at different ages for all the mixes.

The abrasion test was conducted in accordance to IS: 1237-2012 which is used for determination of abrasion resistance of concrete flooring tiles. Specimens of size (70x70x70) cm were tested after 28 days of curing on rotating disc abrasion testing machine. IS: 1237-2012 provides an empirical equation for the calculation of depth of wear based on the loss due to abrasion.

***Figure 1**: Abrasion Testing Machine*

***Table 3:** Details of mix proportions of various mortars mixes (quantities in kg/m^3)*

Mix ID	OPC	GGBFS	River sand	Copper Slag	LSS	NaOH	Added Water	Total water
OPC	572	-	1584	-	-	-	229.0	229.0
AAS-0	-	516	1584	-	88.5	13.2	159.9	206.4
AAS-25	-	516	1188	540	88.5	13.2	159.9	206.4
AAS-50	-	516	792	1080	88.5	13.2	159.9	206.4
AAS-75	-	516	396	1620	88.5	13.2	159.9	206.4
AAS-100	-	516	-	2160	88.5	13.2	159.9	206.4

3. Results and Discussions

In the present section, the appropriate set of data has been collected and the obtained results have been discussed.

3.1. Compressive Strength of Mortar Mixes

The compressive strengths of all mortar mixes were evaluated according to IS:516:1959. The mortar cubes were tested at 3, 7, 28 and 90 days of curing and the results are presented in Table 4. An average of 3 specimens was tested for each mix. From the table it may be noticed that the OPC mortar cubes display lower compressive strength as compared to all the AAS mixes. The AAS mixes display high early strength as well as ultimate strength as compared to the conventional OPC based mortar mixes which may be mainly due to the presence of dense and refined microstructure and binder chemistry in the AAS mixes [26-27]. The compressive strength did not exhibit significant variation with the inclusion of CS in the AAS mixes. The replacement of river sand with CS in AAS mixes displays negligible effect on the compressive strength. The AAS mixes with more than 50% CS also display compressive in the similar range as that with AAS mix with 100% river sand. However, it was noticed that the density of the AAS mixes with CS fine aggregates was higher as compared to river sand AAS mix. With higher replacement of river sand with CS, the density of the AAS mixes increased which is mainly due to the higher specific gravity of CS aggregates.

***Table 4**: Compressive strength of mortar mixes*

Mix ID	Compressive strength (MPa)				Density (kg/m^3)
	3 days	7 days	28 days	90 days	
CC	24.2	43.7	61.4	67.1	2395
AAS-0	45.4	56.7	67.2	72.2	2385
AAS-25	43.7	55.8	63.7	71.7	2520
AAS-50	47.3	55.0	65.3	70.3	2670
AAS-75	44.7	54.6	62.0	73.0	2780
AAS-100	48.1	56.5	65.4	71.4	2920

3.2. Water Absorption and Total Porosity

The water absorption and total porosity for mortar mixes was evaluated according to the procedure suggested by ASTM C 642. The tests were carried out at 28 days of curing and the results are presented in Table 5. From the figure, it may be observed the OPC mortar mixes exhibit higher water absorption and total porosity as compared to AAS mixes (with/without CS). This may be mainly due to the formation of fine, tortuous and refined pore structure in AAS type binders which lead to reduction in the penetration of water [28]. The water absorption and total porosity of AAS mixes were not influenced by the inclusion of the CS fine aggregates AAS mixes. All the AAS mixes display similar water absorption and total porosity even with increasing content of CS.

Table 5*: Durability properties of mortar mixes*

Mix ID	Water Absorption (grams)	Total Porosity (%)	Abrasive wear (mm)
CC	79.0	12.1	0.45
AAS-0	68.5	11.0	0.35
AAS-25	65.7	11.3	0.34
AAS-50	63.2	11.1	0.31
AAS-75	65.5	11.0	0.36
AAS-100	64.8	10.9	0.33

3.3. Abrasion Resistance of Mortar Mixes

The abrasive wear of mortar mixes tested at 28 days of curing are presented in table .From Table 5, it can be observed that the OPCC specimen show higher loss of mass due to abrasion as compared to all AAS specimen. This may be attributed to the higher compressive strength of AASC as compared to OPCC. The compressive strength influences the loss due to abrasive wear loss in concrete; higher the compressive strength, higher is the abrasion resistance of concrete and mortar mixes [29, 30]. Incorporation of CS fine aggregates did not have significant influence on the abrasive wear of the AAS mixes. The AAS mortar mixes with CS fine aggregates display similar loss due to abrasive wear as that of normal aggregates which may be attributed to the similar compressive strength of AAS mortar mixes with/without CS fine aggregates.

The key conclusions drawn from the present investigation are as follows:

The AAS mortar mixes achieved high early and ultimate compressive strength as compared to OPC mortar mixes. The incorporation of CS as fine aggregates did not have any adverse effects on the compressive strength of AAS mortar mixes.

The OPC mortar mixes displayed higher water absorption and total porosity as compared to that with AAS mortar mixes with/without CS aggregates. The inclusion of CS did not have significant influence on the water absorption and total porosity. The AAS mixes with CS displayed similar water absorption and total porosity as that of AAS control mix.

The abrasion resistance of AAS mixes with/without CS fine aggregates was higher as compared to conventional OPC mortar mixes.

The performance of CS was found to be satisfactory to be used as fine aggregates in AAS mortar mixes. The utilization of CS will result in the reduction of mining of natural river sand, thus conserving the natural aggregates resources for future.

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