Replacing river sand with granulated copper slag in cement

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Abstract— Copper Slag is generated as a by-product material during production of copper metal from its ore. Utility of Copper Slag at present ranges from land-filling to grit blasting and these are not very high value added applications. When Copper Slag is produced granular form, behaviour of Granulated Copper Slag (GCS) seems to be similar to river sand and hence GSC was investigated as sand replacement material in the study presented in this paper. The test data shows that since the GCS has higher fineness modulus (indicating coarser average particle size), it may be preferable to avoid its use as the only fine aggregate in mortar and concrete mixes. Compared to the control mix, the Granulated Copper Slag based concrete showed an increase in the density up to 19%, whereas the workability was found to be often better for the mixes investigated in the present study. The highest compressive strength obtained was 52MPa (100% replacement), the corresponding strength for control concrete was 44MPa. However, with GCS as fine aggregate, the Ultra High Performance Concretes (UHPCs) can reach compressive strength of about 150 MPa. From the studies the recommended mix proportions obtained by absolute volume method for M25 and M40 grade concretes for different replacements (25-75%) of Granulated Copper Slag in fine aggregate are presented

Index Terms— Blasting, compressive strength, fineness modulus, replacements, performance concretes, granulated, copper slag.

1 Introduction

Every year large quantities of different industrial by-products are being produced by various industries and governments are seeking ways to reduce the dual problem of disposal and health hazard from the accumulation of by-products. Some of these by-products, such as, fly ash, ground granulated blast furnace slag and silica fume are already being used to produce high value added products, such as, concrete [Rajamane, 2003; Malhotra, 1993] and masonry products. It may be noted here that rapid rate of growth of concrete utility in developing countries has created a huge demand for sand, which cannot be met by the available resources. For instance, it is estimated that the current rate of extraction of sand (236 Mm3/year can meet only 9% of the Chinese requirement per year [Leeuw, 2002]. 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, which is byproduct of the manufacture of copper, is one of the promising industrial byproducts among them. To produce every ton of copper, approximately 2.2–3.0 tons Copper Slag is generated as a by-product material [Caliskan, 2004]. This slag is currently being used for many purposes ranging from land-filling to grit blasting, which are not very high value added applications. These applications utilise only about 15% to 20% of the copper slag generated and the remaining material is dumped as a waste, which requires large areas of land, a fast diminishing high value asset. In addition, there are apprehensions that the material could also cause environmental pollution. Alternative use of it as partial or complete substitute for fine aggregates and cement will eliminate these problems. The main objective of study presented in this paper is to determine the feasibility of use of Granulated Copper Slag (GCS) as fine aggregate in cement concrete and mortar.

2 LITERATURE ON COPPER SLAG IN CONSTRUCTION INDUSTRY

Caliskan [2004] investigated the compressive strength of normal-strength concrete containing copper slag coarse aggregate and showed that the compressive strength of copper slag coarse aggregate concrete was marginally higher than that of limestone aggregate concrete.

Several works reported that the compressive and tensile strengths of concrete specimens made with copper slag as fine and coarse aggregates are almost the same as that of normal concrete or even significantly more than control mixtures [Caliskan, 2004], [Ayano, 2004], [Hwang, 1989], [Shoya, 2003]. It was noticed that the use of copper slag as fine aggregate could greatly increase the abrasion resistance of the cement mortar [Tan, 2000].

Li [1999] and Zong [2003] also reported that concrete containing copper slag as fine aggregate exhibited similar mechanical properties as that containing conventional sand and coarse aggregates. Ayano [2000] critically reviewed the characteristics of copper slag and its effects on the engineering properties of cement, mortars and concrete. They reported that the shrinkage of specimens containing copper slag fine aggregate is similar or even less than that of specimens without copper slag. Hwang [1989] reported that the amount of bleeding of mortar made with copper slag is comparatively less than that using natural sand. However, the heavy specific weight and the glass-like smooth surface properties of irregular grain shape of copper slag aggregates are effective for characteristics of bleeding. Shoya [1997] observed that the amount and rate of bleeding increased by using copper slag fine aggregate depending on the water to cement ratio, the volume fraction of slag and air content. They recommended using less than 40% copper slag as partial replacement of aggregate to control the amount of bleeding to less than 5 l/m².

Studies by Alnuaimi [2005] indicated that replacement of fine aggregate (sand) by copper slag does not have an adverse effect on the load carrying capacity of the concrete columns.

Rojas [2008] had reported that copper slag exhibits pozzolanic activity, although only in the longer term, since at early stages (under 90 days) it fixes only small amounts of lime. The pozzolanic activity of copper slag is similar to that of fly ash. Further, Roper et al. [1983] reported that copper slag does not need to be completely glassy for significant hydration of cement to occur [Roper, 1983].

Good performance of copper slag as fine and coarse aggregates in normal concrete is the basis for researchers to evaluate its possible use in producing special concrete such as self-consolidating concrete [Shoya, 2003], high-performance concrete [Al-Jabri et al, 22] and high-strength concrete [Khanzadi, 2009]. One province in China published technical guidelines for the use of copper slag as sand for mortars and concrete. Khalifa, [2009] report that the use of copper slag as sand substitution improves strength and durability characteristics of high strength concrete at same workability and produces concrete that meets strength and durability design requirements.

Khanzadi [2009] observed that there is stronger bonding between copper slag aggregate and the cement paste matrix in cement concrete and this leads to higher strengths in concretes. Tixier [1997] showed that the densification of the microstructure in the capillary pores of hydrated cement is evident in the analysis of test data from mercury intrusion porosimetry when copper slag grains are added to the cement mixes.

A study carried out by Central Road Research Institute, New Delhi has shown that copper slag can be used as a partial replacement for sand as fine aggregate in concrete up to 40% in pavement grade concrete with out any loss of cohesiveness and the compressive and flexural strength of such concretes is about 20% higher than that of conventional cement concretes of the same grade [CRRI, 2006].

3 DETAILS OF EXPERIMENTAL WORK

3.1 Materials

The cement used in this study was 53 grade ordinary Portland cement (OPC).

TABLE 1 PROPERTIES OF ORDINARY PORTLAND CEMENT (OPC)

Sl. No	Descriptions	Ordinary Portland Cement
1	Fineness	274 m²/kg
2	Normal Consistency	29.0 %
3	Setting Time Initial Final	185 minutes 300 minutes
4	Compressive Strength 7 Days 28 Days	36 MPa 48 MPa

Aggregates used for control concrete were natural river sand and crushed granite aggregate. Coarse aggregates (i.e. 60% of 20 mm and 40% of 10 mm) have a specific gravity of 2.76, bulk density 1.6 g/cc respectively.

TABLE 2 PROPERTIES OF RIVER SAND

Specific gravity (Saturated Surface Dry): 2.53, Bulk density (SSD): 1.60 gm/cc
Water absorption: 0.83%, Fineness modulus: 2.27, No Deleterious Materials present

IS Sieve No	Weight Retained gm	Cumulative Wt retained, gm	Cumulative % Wt Retained	Cumulative % Passing
4.75mm	0	0	0	100
2.36mm	0.89	0.89	0.18	99.82
1.18mm	9.26	10.15	2.03	97.97
600 microns	205.00	215.15	43.03	56.97
300 microns	207.00	422.15	84.43	15.57
150 microns	67.00	489.15	97.83	2.17
% Passing	10.55	500.00	100.00	0.00

Granulated Copper Slag is a by-product material produced from the process of manufacturing copper. Granulated Copper Slag used in this work was brought from Sterlite Industries (I) Ltd, Tuticorin, Tamil Nadu, India

FIG. 1 VIEW OF GRANULATED COPPER SLAG

TABLE 3 PHYSICAL PROPERTIES OF GRANULATED COPPER SLAG

Specific gravity (Saturated Surface Dry): 4.12, Bulk density (SSD): 2.31 gm/cc Fineness modulus: 3.40, Deleterious Materials: Not present				
Sieve analysis				
IS Sieve No	**Wt retained gm**	**Cumulative Wt retained, gm**	**Cumulative % Wt Retained**	**Cumulative % Passing**
4.75mm	-	-	-	-
2.36mm	85.00	85.00	17.00	83.00
1.18mm	154.00	239.00	47.80	52.2
600 microns	166.00	405.00	81.00	19.00
300 microns	72.00	477.00	95.40	4.60
150 microns	16.42	493.42	98.684	1.316
% Passing	6.58	500.00	100.00	0.00

TABLE 4 CHEMICAL PROPERTIES OF GRANULATED COPPER SLAG

Composition	% by mass
Fe_2O_3	55 - 60%
Fe_3O_4	<10%
SiO_2	27 - 33%
CaO	1 - 3.5%
S	0.2 - 1.5%
Cu	<1%
Al_2O_3	<3%

3.2 Sample Preparation

The mix proportions of the control concrete mixes with 100% river sand, which were used for this study are given in Table 5. These basic mix proportions were modified for using Granulated Copper Slag as a partial replacement for sand. Fifteen concrete mixes with different proportions of Granulated Copper Slag ranging from 0% (for the control mix) to 100% were considered. All the mixes were proportioned by the method of absolute volumes considering the specific gravity of the constituent materials. The materials were weighed using a digital balance. The materials were mixed in a pan mixer. The mixes were compacted using vibrating table. The slump of the fresh concrete was determined to study the effect of Granulated Copper Slag replacement on the workability of concrete. The specimens were demoulded after 24 h, cured in water and then tested in saturated surface dry condition at the required age.

3.3 Testing

To determine the compressive strength, eight cubes (150 mm × 150 mm × 150 mm) were cast for each mix, and four samples each were tested after 7 and 28-days of curing. 7 and 28day cube compressive strength test was conducted in accordance with IS: 516-1959. All strength tests were conducted using 2000kN compression testing machine.

TABLE 5. UNIT CONTENTS OF CONTROL CONCRETE MIXES

Mix ID	w/c ratio	**Unit contents** kg/m^3				
		Cement	Sand	10 mm Agg.	20 mm Agg.	Water
C1	0.4	450	784	384	576	180
C2	0.46	413	788	384	576	190
C3	0.55	346	843	384	576	190

4. TEST RESULTS AND DISCUSSION

4.1 Physical properties

The specific gravity and density for Granulated Copper Slag and river sand were determined out in accordance with IS 2386 part III. Granulated Copper Slag has a specific gravity of 4.12 and bulk density of 2.31 g/cc which is higher than that for normal river sand (2.6, 1.53) which may result in production of concrete with higher density. Also, the measured water absorption for Granulated Copper Slag was 0.40% compared with 0.70% for sand. This suggests that Granulated Copper Slag has less apparent porosity and would demand less water than that required by sand in the concrete mix. Therefore due to higher free water content in concrete matrix and also due to the higher coarseness of Granulated Copper Slag will increase the workability of the concrete when the Granulated Copper Slag partially replaces sand, especially when the concrete is of higher grade. Fig. 1 shows sieve analysis as per IS 383: 1970 [9] test results conducted, it seems that river sand has higher fines content than Granulated Copper Slag.

4.2. Effect of Granulated Copper Slag on the workability and density of concrete

The effect of Granulated Copper Slag as fine aggregates on the workability and density of concrete is presented in

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6 for different proportions of Granulated Copper Slag. The workability of concrete was determined based on the measured slump of the fresh concrete. It is clear from Table 6 that the workability of concrete increases with the addition of Granulated Copper Slag in the concrete mixes. This increase in the workability with the Granulated Copper Slag is attributed to the low water absorption characteristics of Granulated Copper Slag. This increase in the workability may have beneficial effect on concrete in the sense that mixes with low water-to-cement ratios, for the same amount of sand replaced, concrete can be produced which may have good workability, greater strength than the conventional concrete. However, it should be noted that mixes with high contents of Granulated Copper Slag (i.e. Mixes 5, 10 and 15) showed signs of bleeding and segregation which can have detrimental effects on concrete performance. But this problem can be easily overcome by the addition of finer materials such as fly ash, quarry dust, which are also incidentally industrial wastes. In the case of higher percentage replacement, it is noticed that there is a comparative reduction in workability (but still, workability is higher than that in control mix) and this may be due to the poor packing effect.

Mix Id	Mix Type	Fresh concrete D	Slump (mm)	Strength (MPa)	
				fc7	fc28
C1	Control (100% S)	2430	20	31	44
C1U25	25% GCS+75% S	2612	85	33	47
C1U50	50% GCS+ 50% S	2670	75	34	46
C1U75	75% GCS+ 25% S	2790	60	37	50
C1U100	100% CS	2923	40	38	52
C2	Control (100% S)	2411	25	25	35
C2U25	25% GCS+75% S	2624	85	26	41
C2U50	50% GCS+ 50% S	2696	110	28	43
C2U75	75% GCS+ 25% S	2818	85	27	40
C2U100	100% CS	2920	35	26	41
C3C3	Control (100% S)	2405	25	17	25
C3U25	25% GCS+ 75% S	2620	150	18	27
C3U50	50% GCS+ 50% S	2711	65	21	29
C3U75	75% GCS+ 25% S	2815	45	21	31
C3U100	100% CS	2940	30	20	30

In the present study, all the mixtures were prepared without using superplasticizers. The slump values obtained for the mixes indicate that they require much less dosage of superplasticier to achieve the workability required for a pumpable concrete as in case of ready mix concrete. The slump retention would another major requirement of ready mix concrete would also be better in view of the higher initial workability.

In general there is an increase in the density of concrete with the increase of Granulated Copper Slag quantity. The density of concrete was increased by 9-22%. This is mainly due to the higher specific gravity of Granulated Copper Slag which was 4.12 compared with sand which has a specific gravity of 2.6.

The increased density of concrete mix should be taken into account in the design of formwork when it is to be used for structural applications.

4.3 Effect of Granulated Copper Slag on the strength of concrete

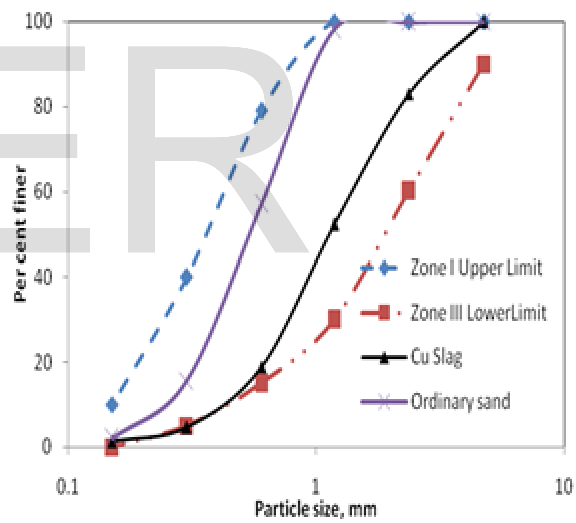

FIG. 2 SIEVE ANALYSIS OF SAND AND GRANULATED COPPER SLAG

The average 7 and 28 day compressive strengths for different concrete mixes are shown in Fig. 2. The expected target strengths are 31.6 MPa for M25 grade concrete and 48.25 MPa for M40 grade concrete assuming standard deviations of 4 MPa and 5 MPa, respectively vide Table 8 of IS: 456-2000 in the absence of sufficient experimental results to evaluate the standard deviation. It is seen from Table 6 and Fig. 2 that the mixes 1 to 3 and mixes 11 to 12 are marginally short of the target strength while all the remaining mixes meet the strength requirement. This may be attributed the lower cement strength and the higher than normal standard deviation used for determining the target strength. In actual practice, the standard deviation is likely to be much less when the sample size is larger and quality control is better. The cement strength is also likely to be much higher than that obtained in the present study.

The results also show that the compressive strength of Granulated Copper Slag concrete is slightly increased when compared to control concrete(around 24%), where as Granulated Copper Slag quantity increases the strength is often more or less same .

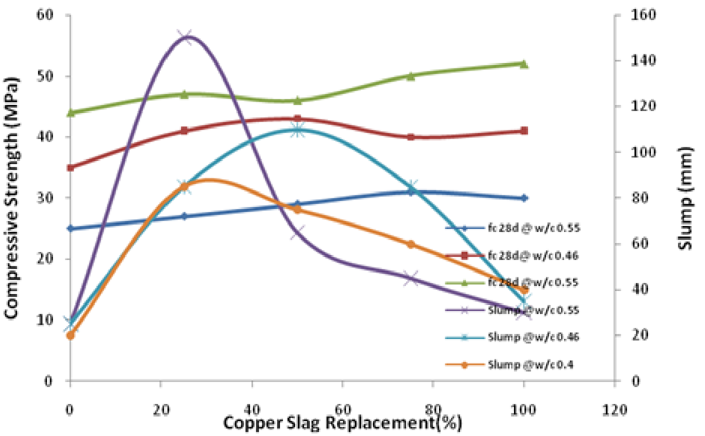

FIG. 3 EFFECT OF GCS ON WORKABILITY AND STRENGTH OF CONCRETE

As in the case of control concrete, for Granulated Copper Slag concrete when the water cement ratio increases the strength reduces. As seen from Fig. 3, irrespective of water-cement ratio, as the Granulated Copper Slag content increases, the compressive strength increases. The highest compressive strength was achieved by Mix 5 (Table 6) with 100% replacement of Granulated Copper Slag, which was found about 52 MPa compared with 44 MPa for the control mixture. The increase in the strength was 18% compared to the control mix. However, the increase in compressive strength of Granulated Copper Slag based concrete over control concretes was almost of the same order for all cooper slag contents investigated in the study. Therefore, if the concrete mixes are proportioned by absolute volume method and the percentage of replacement of river sand is by mass of the total fine aggregate, the compressive strength is influenced mainly by the water-cement ratio. The above observations are supported by the work of other researchers who studied the influence of copper slag as fine and coarse aggregates on the strength of both normal [Li, 1999; Zong, 2003; Avano, 2000; Tang, 2000] and high-strength concrete [Khanzadi, 2009]. The results indicated that the compressive strengths of concrete made with copper slag are slightly higher than that of the control mixtures. The compressive strength of mortars and concrete specimens containing copper slag as fine aggregate was investigated by Hwang [1989] and the study concluded that the mortars containing the larger amounts of copper slag with 20–80% substitution of copper slag as fine aggregate had the strengths higher than that of the control specimens. Investigations conducted by Khanzadi [2009] also showed that the use of copper slag aggregate compared to limestone aggregate resulted in a 28-day compressive strength improvement of about 10–15%. Therefore, copper slag can be beneficially used as partial replacement for river sand in concrete construction for normal structural grade concrete (M20-M40). Since the rate of strength development and the strength at 28 days are satisfactory and generally better than that of concretes with conventional sand, copper slag can be employed in the ready mix concrete with no significant modifications in the production process and the performance would meet all the necessary requirements.

5 ULTRA HIGH PERFORMANCE CONCRETE WITH GRANULATED COPPER SLAG [AMBILY, 2013A, 2013 B]

Ultra high performance concrete (UHPC) are concretes with compressive strength more than 200 MPa. The process of optimization of UHPC mix requires detailed evaluation of the relative effect of granular materials and pozzolanic additives on the various properties. In UHPC, Granulated Copper Slag acts as a fine aggregate and UHP mix consists of:

Cement = 31 parts by weight
Silica fume = 8 parts by weight
Water = 7 parts by weight
High range water reducing agent = 1 parts by weight.
Quartz powder = 13 parts by weight
GCS = 34 parts by weight
Micro steel fibers (brass coated) = 6 parts by weight

UHPC mixing in a high efficiency planetary mixer machine (Fig 6) of 10kg capacity is dine following steps:

Dry mix solid materials except steel fibres for 6-8 minutes at slow speed

Add 70% of water and continue mixing for 6-8 minutes at medium speed

Add balance water and SP and continue mixing for about 2-3 minutes

Add steel fibres slowly and continue mixing for about 2-3 minutes.

Mix the whole mixture at high speed for 1min.

The fresh UHPC was placed into steel moulds in 3 layers and each layer compacted on a vibrating table till a good compaction is ensured. Demoulding is done after 24 hrs of casting and kept in water for 3 day after which they were exposed to thermal regime at 150°C for duration of 48hours.The rate of rise in temperature was 2°C/min. After the hot air regime, the samples were then kept in water and continued water curing till the respective age of testing.

The 28 day compressive strength achieved was about 143 MPa without fibres and 152 MPa with fibers. In the flexural strength by four point bending test on beams of size 70 x 70 x 350mm, after cracking, a main crack expanding along the high direction of the beam was observed and until the last step of loading, beam was not broken. The mean flexural stress was 12.3 MPa without fibers, and 32.4 MPa with fibres. The mix without fibre showed a high E value compared to without fibres. Charge passed in RCPT was 'negligible' as per ASTM rating. Water ingress determined as per ASTM C1585-11 was only about 1%.

6 TEST RESULTS AND DISCUSSION

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8 CONCLUDING REMARKS

The following conclusions may be drawn from the present study:

(1) The behaviour of Granulated Copper Slag seems to be similar to river sand for its use as fine aggregate in mortar and concrete mixes. However minor adjustment/modifications may have to be made in view of the higher specific gravity and rough surface texture and the extent of Granulated Copper Slag proposed to be used.

(2) The Granulated Copper Slag, as it is, has higher fineness modulus indicating coarser average particle size. Therefore, it may be preferable to avoid the use of Granulated Copper Slag as the only fine aggregate in mortar and concrete mixes; it may be necessary to add conventional sand (and finer materials such as fly ash and stone dust) also in order to improve the particle size distribution of the concrete mix to get the cohesiveness and satisfactory workability. In cases of higher percentage of Granulated Copper Slag(of the order 60-75%), finer industrial wastes like quarry dust and fine ash may be gainfully utilized to achieve the necessary particle grading and exclude the possibility of bleeding and segregation.

(3) Compared to the control mix, the Granulated Copper Slag based concrete showed an increase in the density up to 19%, whereas the workability was found to be often better for the mixes investigated in the present study

(4) The highest compressive strength obtained was 52MPa (100% replacement), the corresponding strength for control concrete was 44MPa. The full replacement of sand by Granulated Copper Slag yielded higher compressive strength compared to that of the control mix. However, with different replacements the variation in strength was marginal.

(5) With higher levels of replacements (100%) there was a slight bleeding and segregation tendency and it is recommended that up to 75% of Granulated Copper Slag can be used as replacement of sand.

(6) With Granulated Copper Slag as fine aggregate, UHPCs can achieve compressive strengths of about 150 MPa.

(7) The use of Granulated Copper Slag as partial replacement for sand in ready mix concrete is beneficial of the better workability and strength it imparts upto 50% replacement level. Such applications are already reported in other countries. It has been found to be suitable for the production of self compacting concrete in a few studies.

(8) The studies show that total replacement of sand by Granulated Copper Slag is not advisable.

(9) The experience in the present study indicates that up to 50% of the fine aggregate can be made up of Cu Slag and the rest can be made up of conventional sand. However, the actual content of Cu slag depends upon the grade of concrete and the fineness modulus of sand available for use in concrete.

(10) From the studies the recommended mix proportions obtained by absolute volume method for M25 and M40 grade concretes for different replacements (25-75%) of Granulated Copper Slag in fine aggregate are presented in Table 2.7.

(11) These mix proportions are only indicative and are applicable to the materials used in the present study. In actual practice, he mix proportions have to be appropriately modified taking into account the properties of the available materials and trial mixes have to be prepared and if required some more adjustments may be made to achieve satisfactory workability and strength as per the specific project requirement. Further research work is needed to explore the effect of Granulated Copper Slag as fine aggregates on the durability properties of concrete.

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