To Study Performance of Copper Slag as Partial or Fully Replacement to Fine Aggregate in Concrete

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Abstract- This paper presents the experimental investigation of properties of concrete using copper slag as replacement material of fine aggregates to increase the hardened concrete properties such as compressive strength, split tensile strength, flexural strength and ultrasonic pulse velocity of concrete. The present study encouraged the use of industrial by-product or waste copper slag as replacement material of fine aggregates in concrete. Mix proportion has to be done for M25 grade of concrete with water cement ratio 0.50. The fine aggregate is replaced with copper slag in proportions of 0%, 20%, 30%, 40%, 50%, 60%, 80%, and 100%. Tests were performed for properties of fresh concrete and hardened concrete. All concrete specimens were cured for 28 days before compression strength test, split tensile strength test, flexural strength test and ultrasonic pulse velocity test. The results indicate that workability and density of concrete increases significantly with the increase of copper slag content in concrete mixes. The results also demonstrated that the highest compressive strength, split tensile strength and flexural strength obtained were 41.53 N/mm^2, 3.86 N/mm^2 and 5.42 N/mm^2 for 40% replacement of fine aggregate by copper slag as compared to control mixture. The ultrasonic pulse velocity test indicated the excellent quality of concrete at all percentage replacement level. Therefore, it is recommended that 40% of copper slag can be used as replacement of fine aggregates. Also on the basis of obtained results the empirical relationships between the mechanical properties of concrete were established.
Keyword: Cement, Copper slag, Fine aggregate, concrete, ultrasonic pulse velocity, compressive strength, split tensile strength, flexural strength.

1. INTRODUCTION

The utilization of industrial waste or secondary materials has encouraged the production of cement and concrete in construction field. New by-products and waste materials are being generated by various industries. Dumping or disposal of waste materials causes environmental and health problems. Therefore, recycling of waste materials is a great potential in concrete industry. For many years, by-products such as fly ash, silica fume and copper slag were considered as waste materials. Concrete prepared with such materials showed improvement in workability and durability compared to normal concrete and has been used in the construction of power, chemical plants and under-water structures. Over recent decades, intensive research studies have been carried out to explore all possible reuse methods. Construction waste, blast furnace, steel slag, coal fly ash and bottom ash have been accepted in many places as alternative aggregates in embankment, roads, pavements, foundation and building construction, raw material in the manufacture of ordinary Portland cement pointed out by Teik thye lim et al (2006) [8]. Copper slag is an industrial by-product material produced from the process of manufacturing copper. For every ton of copper production, about 2.2 tonnes of copper slag is generated. It has been estimated that approximately 24.6 million tons of slag are generated from the world copper industry (Gorai et al 2002) [1]. Although copper slag is widely used in the sand blasting industry and in the manufacturing of abrasive tools, the remainder is disposed of without any further reuse or reclamation.

1.1 Background of Copper Slag

Sterlite Industries India Limited (SIIL), Tuticorin, Tamil Nadu is the principal subsidiary of Vedantha Resources public limited company (PLC), a diversified and integrated FTSE 100 metals and mining company, with principal operations located in India and Australia. The annual turnover of SIIL, Tutucorin, India is Rs.13, 452 crores. SIIL, a leading producer of copper in India, pioneered the manufacturing of continuous cast copper roads and established India's largest copper smelting and refining plant for production of world class refined copper. SIIL is the producer of copper slag (Figure 1.1) during the manufacture of copper metal. Presently, about 2500 tons of copper slag is produced per day and a total accumulation of around 1.5 million tons.

1.2 Production of Copper Slag

Copper slag is a by-product obtained during the matte smelting and refining of copper. The major constituent of a smelting charge are sulphides and oxides of iron and copper. The charge also contains oxides such as SiO_2, Al_2O_3 CaO and MgO, which are either present in original concentrate or added as flux. It is Iron, Copper, Sulphur, Oxygen and their oxides which largely control the chemistry and physical constitution of smelting system. A further important factor is the oxidation/reduction potential of the gases which are used to heat and melt the charge stated by Gorai et al (2002) [1]. As a result of this process copper- rich matte (sulphides) and copper slag (oxides) are formed as two separate liquid phases. The addition of silica during smelting process forms strongly bonded silicate anions by combining with the oxides.

1.3 Objectives of the paper

1. To find the optimum proportion of copper slag that can be used as a replacement/ substitute material for fine aggregate.
2. To evaluate the effect of copper slag replacement on the workability and density of concrete.
3. To evaluate compressive and tensile strength of copper slag replaced concrete specimens.
4. To investigate flexural strength of copper slag replaced Concrete beams.

2. LITERATURE REVIEW

Al-Jabri (2009 a) [3] investigated the effect of using copper slag as a replacement of sand on the properties of high performance concrete (HPC). Eight concrete mixtures were prepared with different proportions of copper slag ranging from 0% (for the control mix) to 100%. Concrete mixes were evaluated for workability, density, compressive strength, tensile strength, flexural strength and durability. The results indicate that there is a slight increase in the HPC density of nearly 5% with the increase of copper slag content, whereas the workability increased rapidly with increases in copper slag percentage. Addition of upto 50% of copper slag as sand replacement yielded comparable strength with that of the control mix. However, further additions of copper slag caused reduction in the strength due to an increase of the free water content in the mix. Mixes with 80% and 100% copper slag replacement gave the lowest compressive strength value of approximately 80 MPa, which is almost 16% lower than the strength of the control mix. The results also demonstrated that the surface water absorption decreased as copper slag quantity increases upto 40% replacement; beyond that level of replacement, the absorption rate increases rapidly.

Wei wu et al (2010) [4] investigated the mechanical properties of high strength concrete incorporating copper slag as fine aggregate. The workability and strength characteristics were assessed through a series of tests on six different mixing proportions at 20% incremental copper slag by weight replacement of sand from 0% to 100%. A high range water reducing admixture was incorporated to achieve adequate workability. Micro silica with a specific gravity of 2.0 was used to supplement the cementitious content in the mix for high strength requirement.

Al-Jabri et al (2006) [5] dealt with the effect of copper slag and cement by-pass dust addition on mechanical properties of concrete. Here in addition to the control mixture, two different trial mixtures were prepared using different proportions of copper slag (CS) and cement by-pass dust (CBPD). CBPD was primarily used as an activator. One mixture consisted of 5% copper slag substitution for Portland cement. The other mixture consisted of 13.5% CS, 1.5% CBPD and 85% Portland cement. Three water- to-binder ratios (0.5, 0.6 and 0.7) were studied. Concrete cubes, cylinders and prisms were prepared and tested for strength after 7 and 28 days of curing. The modulus of elasticity of these mixtures was also evaluated. The results showed that 5% copper slag substitution for Portland cement gave a similar strength performance as the control mixture, especially at low w/b ratios (0.5 and 0.6). Higher copper slag (13.5%) replacement yielded lower strength values. The results also demonstrated that the use of CS and CBPD as partial replacements of Portland cement have no significant effect on the modulus of elasticity of concrete, especially at small quantities substitution.

Caijun Shi et al (2008) [6] reviewed the characteristics of copper slag and its effects on the engineering properties of cement, mortars and concrete and they concluded that the utilization of copper slag in cement and concrete provides additional environmental as well as technical benefits for all related industries, particularly in areas where a considerable amount of copper slag is produced. When it is used as a cement replacement or an aggregate replacement, the cement, mortar and concrete containing different forms of copper slag have good performance in comparison with ordinary Portland cement having normal and even higher strength.

Al-Jabri et al (2011) [7] investigated the effect of using copper slag as a fine aggregate on the properties of cement mortars and concrete. Various mortar and concrete mixtures were prepared with different proportions of copper slag ranging from 0% (for the control mixture) to 100% as fine aggregates replacement. Cement mortar mixtures were evaluated for compressive strength, whereas concrete mixtures were evaluated for workability, density, compressive strength, tensile strength, flexural strength and durability. The results obtained for cement mortars revealed that all mixtures with different copper slag proportions yielded comparable or higher compressive strength than that of the control mixture. There was more than 70% improvement in the compressive strength of mortars with 50% copper slag substitution in comparison with the control mixture.

Teik-Thye Lim and Chu (2006) [8] conducted a study on the feasibility of using spent copper slag as fill material in land reclamation. The physical and geotechnical properties of the spent copper slag were first assessed by laboratory tests, including hydraulic conductivity and shear strength tests. The physical and geotechnical properties were compared with those of conventional fill materials such as sands. The potential environmental impacts associated with the use of the spent copper slag for land reclamation were also evaluated by conducting laboratory tests including pH and Eh measurements, batch-leaching tests, acid neutralization capacity determination and monitoring of long-term dissolution of the material. The spent copper slag was slightly alkaline, with pH 8.4 at a solid /water ratio of 1:1. The batch-leaching test results showed that the concentrations of the regulated heavy metals leached from the material at pH 5.0. They were significantly lower than the maximum concentration for their toxicity limits referred by United States Toxicity Characteristic Leaching Procedure. They finally suggested that the spent copper slag was a good fill material and it can be used as a fill material for land reclamation.

D.Brindhal et al (2011) [9] investigated the results of an experimental study on various corrosion and durability tests on concrete containing copper slag as partial replacement of sand and cement. For this research work , M20 grade concrete was used and the tests were conducted for various proportions of copper slag replacement with sand of 0%, 20%, 40%, and 60%, cement of 0%, 5%, 15% and 20% and combination of both (60% sand + 40% copper slag for fine aggregate and 85% cement+15% copper slag for cement) in concrete. Concrete mixes were evaluated for compressive strength, split tensile strength, acid and sulphate attack test, RCPT Test, Ultrasonic pulse velocity test etc. The result showed that, the compressive, split tensile strength test have indicated that the strength of concrete increases with respect to the percentage of slag added by weight of fine aggregate up to 40% of additions and 15% of ement.

Meenakshi Sudarvizhi.S and Ilangovan. R (2011) [10] investigated the Performance of Copper slag and ferrous slag as partial replacement of sand in Concrete. This work reports an experimental procedure to investigate the effect of using CS and FS as partial replacement of sand. The strength characteristics of conventional concrete and slag concrete such as compressive strength, tensile strength were found .Six series of concrete mixtures were prepared with different proportions of CS and FS ranging from 0% to 100%.

Mostafa Khanzadi and Ali Behnood (2009) [11] presented the results of a study undertaken to investigate the feasibility of using copper slag as coarse aggregates in high-strength concrete. The effects of replacing limestone coarse aggregate by copper slag coarse aggregate on the compressive strength, splitting tensile strength and rebound hammer values of high-strength concretes are evaluated in this work. Concrete mixtures containing different levels of silica fume were prepared with water to cementitious materials ratios of 0.40, 0.35 and 0.30.

Basil Johny et al (2014) [12] conducted study on the feasibility of using ground granulated blast furnace slag as an alternative for cement and recycled coarse aggregate for natural coarse aggregate. Experimental investigation is carried out with a conventional M30 mix, mixes by replacing with 40 percent, 50 percent and 60 percent of cement with ground granulated blast furnace slag (GGBS). Mix with 50 percent of cement when replaced with GGBS gave better performance compared to M30 conventional mix when tested for fresh and mechanical properties.

3. RESEARCH METHODOLOGY

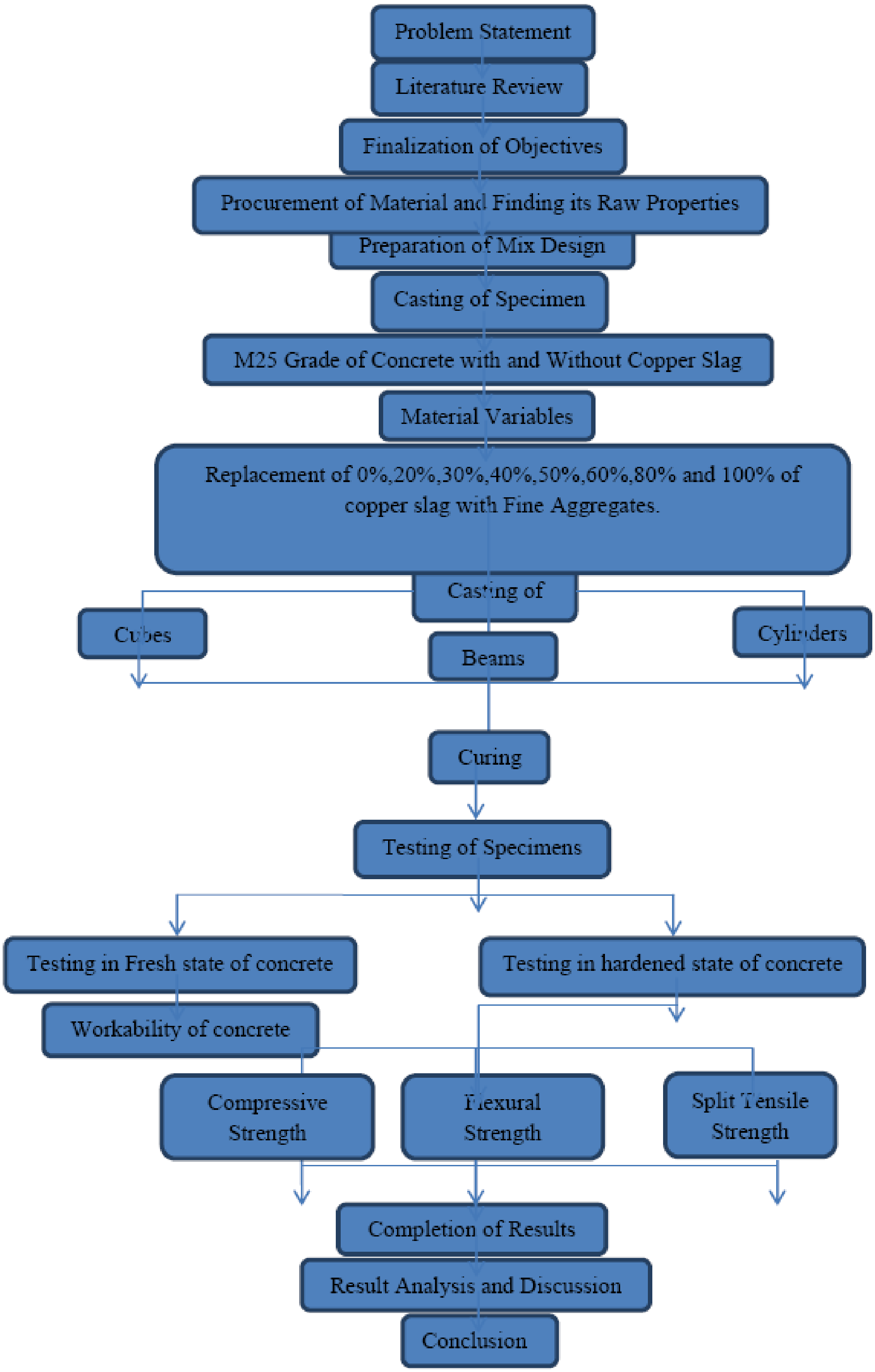


Figure 3.1:- Flowchart of methodology

Based on the investigations, this research study was conducted to investigate the performance of concrete made with copper slag as a partial replacement for fine aggregate. Eight test groups were constituted with replacement: 0%, 20%, 30%, 40%, 50%, 60%, 80%, and 100% of copper slag with sand in each series. The following tests have been conducted to find the fresh properties of concrete and mechanical properties of concrete.

i) Workability and density test on concrete.
ii) Compressive strength test on concrete cubes.
iii) Split tensile strength test on concrete cylinders.
iv) Flexural strength test on concrete beams.

4. RESULTS AND DISCUSSIONS

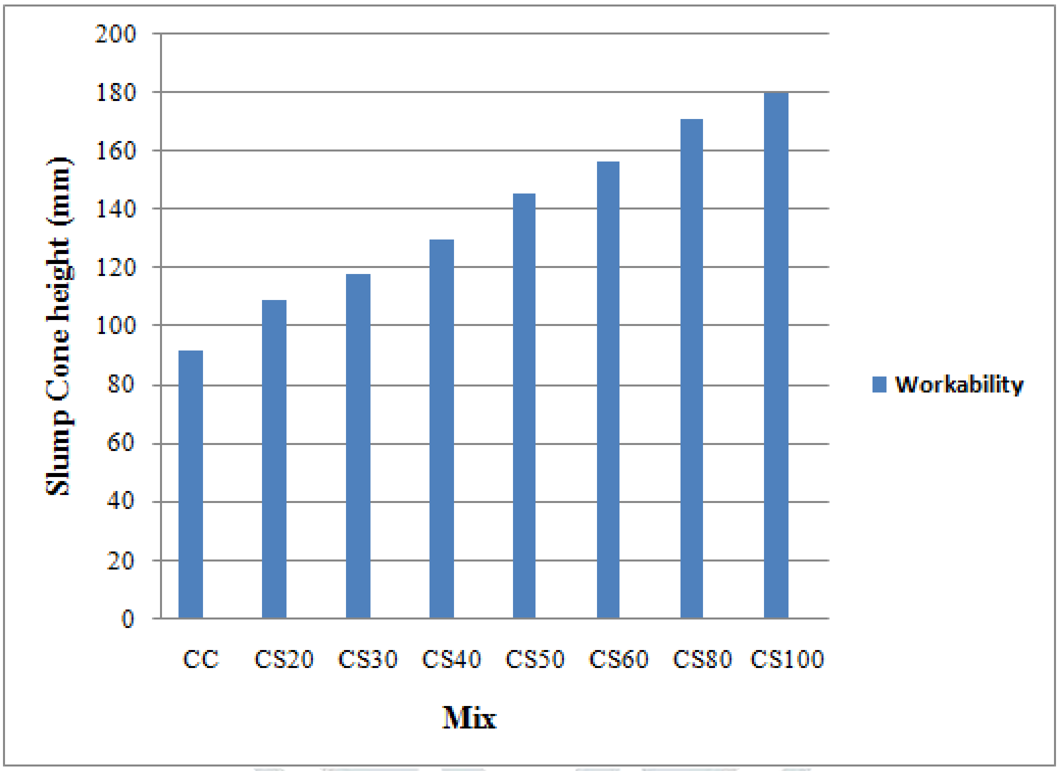
In this Paper, the test results obtained from various tests on concrete are presented and discussed in detail. The test results focuses the effect of copper slag on concrete when sand is replaced by copper slag materials in terms of compressive strength, flexural strength test and split tensile strength.

4.1 WORKABILITY

Workability of fresh concrete is checked immediately after mixing of water in dry concrete with the help of slump cone instrument. Table 4.1 shows results of workability of various sets of concrete. The slump value for each set is presented in graph 4.1.

Table 4.1:- Workability of Concrete Mixture

Mix	Slump (mm)
CC	92
CS20	109
CS30	118
CS40	130
CS50	146
CS60	157
CS80	171
CS100	180



Graph 4.1:- Workability Results

Graph 4.1 presents slump values as measurement for the workability of fresh concrete for all mixtures with different proportions of copper slag. The test results indicate that there is a substantial increase in the workability of concrete as copper slag content increases. The measured slump for the control mixture with 100% sand was 92 mm, while the measured slump for the concrete mixture with 100% copper slag substitution (CS100) was 180 mm. This significant increase in the workability was due to the low water absorption characteristics of copper slag compared with sand, where more free water remains in the concrete matrix after hydration. However, segregation and bleeding were observed in concrete mixtures with high copper slag contents (Mixtures CS80 and CS100).

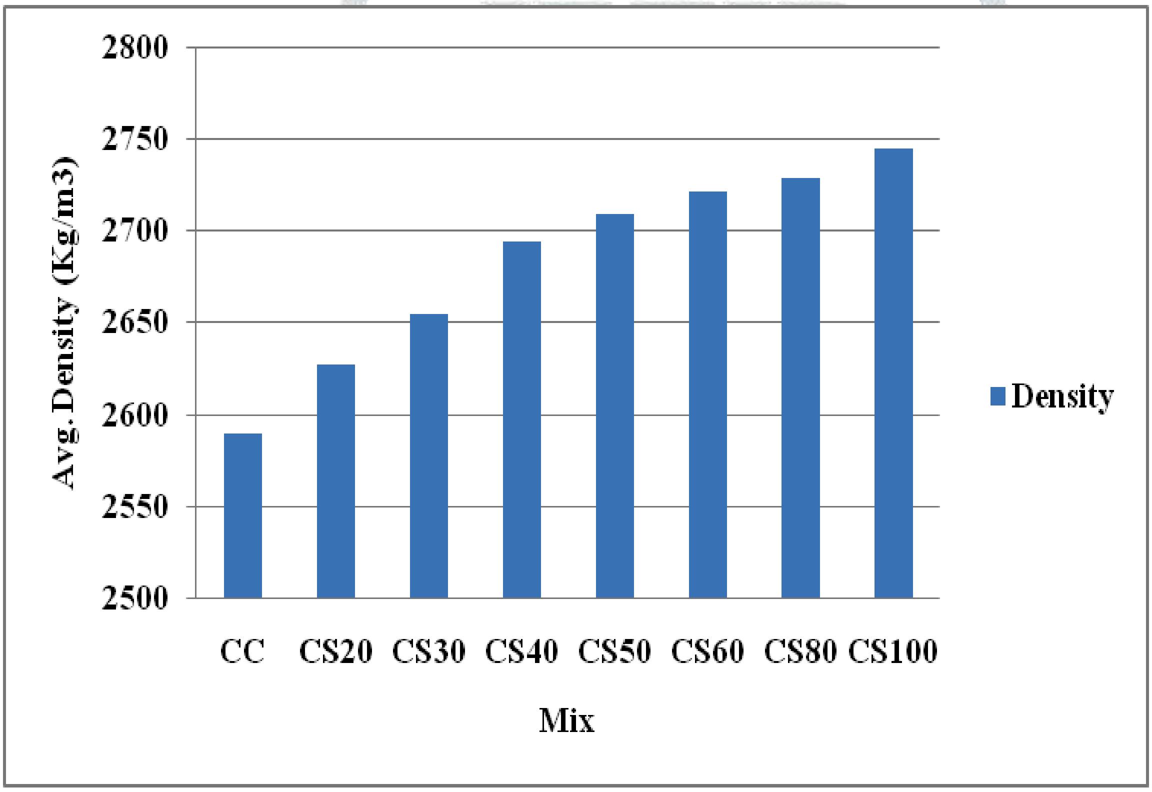
4.2 DENSITY OF CONCRETE

Weight of each concrete cube was measured after 28 days of curing as presented in table 4.2. The purpose of measuring weight is to find variations in density of concrete for each concrete mixture. The variation in average value of density for each set is presented in graph 4.2.

Table 4.2:- Density of Concrete Cube

CUBE		WEIGHT (KG)	DENSITY (KG/M^3)	AVG. DENSITY (KG/M^3)	(%) INCREASE IN DENSITY
MIX	SAMPLE NO.				
CC	A	8.724	2585.10	2590.20	-
	B	8.702	2578.32		
	C	8.799	2607.18		
CS20	A	8.860	2625.18	2627.31	1.43
	B	8.770	2598.70		
	C	8.971	2658.05		

CS30	A	9.014	2670.74	2654.48	2.48
	B	8.969	2657.58		
	C	8.893	2635.12		
CS40	A	9.021	2672.84	2694.28	4.02
	B	9.160	2714.28		
	C	9.098	2695.72		
CS50	A	9.078	2689.73	2708.67	4.57
	B	9.184	2721.19		
	C	9.163	2715.09		
CS60	A	9.141	2708.39	2721.12	5.05
	B	9.244	2739.08		
	C	9.166	2715.89		
CS80	A	9.186	2721.77	2728.95	5.36
	B	9.233	2735.73		
	C	9.211	2729.36		
CS100	A	9.261	2743.99	2744.73	5.97
	B	9.282	2750.12		
	C	9.247	2740.08		



Graph 4.2:- Density Results

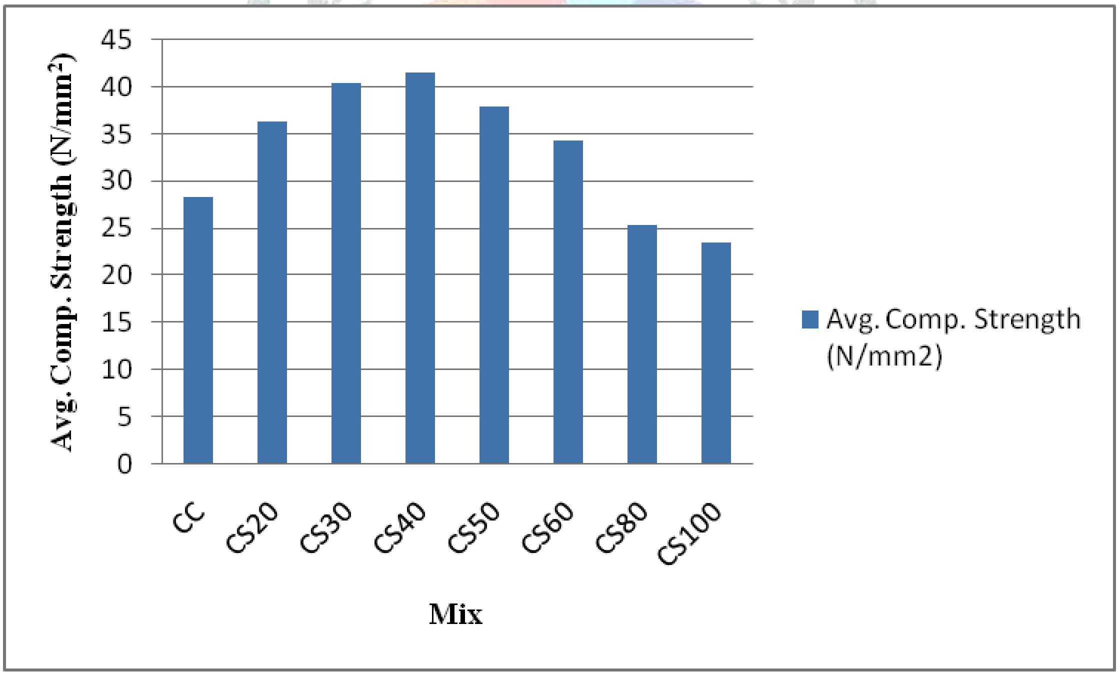
Graph 4.2 present the concrete density for all mixures with different proportions of copper slag. The test results indicate that there is a substantial increase in the density of concrete as copper slag content increases. Density of concrete was increased by 5.97% (for 100 % replacement), which is attributed to the high specific gravity of copper slag.

4.3 COMPRESSIVE STRENGTH TEST

The effect of copper slag substitution as a fine aggregate on the strength of concrete is given in table 4.3, which presents the average 28 day cube compressive strength of concrete. A total number of 24 concrete cube specimens were cast and tested. The unconfined compressive strength values of concrete mixtures with different proportions of copper slag tested 28 days are also plotted in graph 4.3.

Table 4.3:- Compressive Strength Results In Mpa

CUBE		COMPRESSIVE STRENGTH N/MM^2	AVG. COMPRESSIVE STRENGTH N/MM^2	% INCREASE IN STRENGTH AT 28 DAYS
MIX IDENTITY	SAMPLE NO.			
CC	A	27.38	28.46	-
	B	27.57		
	C	30.42		
CS20	A	36.95	36.38	27.83
	B	33.77		
	C	38.42		
CS30	A	43.12	40.42	42.02
	B	39.32		
	C	38.82		
CS40	A	40.67	41.53	45.92
	B	42.07		
	C	41.85		
CS50	A	36.25	38.01	33.56
	B	39.02		
	C	38.76		
CS60	A	31.38	34.37	20.77
	B	36.98		
	C	34.75		
CS80	A	24.47	25.36	-10.89
	B	27.42		
	C	24.19		
CS100	A	22.13	23.58	-17.15
	B	27.22		
	C	21.39		



Graph 4.3:- Average compressive strength values for each mix after 28 days curing

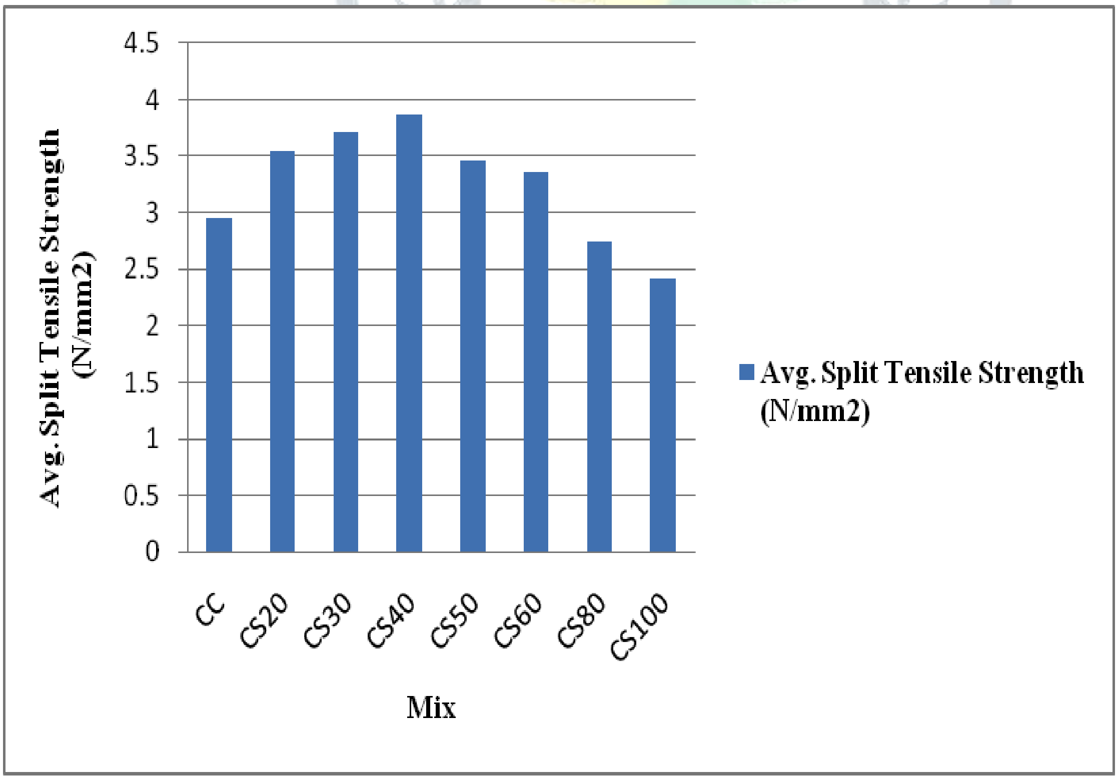
From graph 4.3 the test results indicate that for mixtures prepared using up to 60% copper slag replacement, the compressive strength of concrete is higher than that of the strength of the control mix with 100% sand. However, for mixtures with 80% and 100% copper slag (i.e. Mixtures CS80 and CS100), the compressive strength decreased rapidly below the strength of the control mixture. Mixture CS40 with 40% copper slag content yielded the highest 28 day compressive strength of 41.53 N/mm2 compared with 28.46 N/mm2 for the control mixture. This means that there is an increase in strength of almost 46% compared to the control mix at 28 days. Whereas the lowest compressive strength of 23.58 N/mm2 was obtained for Mixture CS100 with 100% copper slag. Here, the compressive strength yielded by Mixture CS100 is almost 17.15% lower than that of the control mix. This reduction in compressive strength for concrete mixtures with high copper slag contents is due to the increase in the free water content that results from the low water absorption characteristics of copper slag in comparison with sand. This causes a considerable increase in the workability of concrete and, thus, reduces concrete strength.

4.4 SPLIT TENSILE STRENGTH TEST

Split tensile strength is defined as a method of determining the tensile strength of concrete using a cylinder which splits across the vertical diameter. The effect of CS substitution as a fine agg. On split tensile strength of concrete is given in table 4.4.

Table 4.4:- Split Tensile Strength Results In Mpa

CYLINDER		SPLIT TENSILE STRENGTH N/MM^2	AVG. SPLIT TENSILE STRENGTH N/MM^2	% INCREASE IN STRENGTH AT 28 DAYS
MIX IDENTITY	SAMPLE NO.			
CC	A	2.8331	2.9594	-
	B	3.0411		
	C	3.0041		
CS20	A	3.2637	3.5440	19.75
	B	3.8624		
	C	3.5059		
CS30	A	3.7157	3.7157	25.56
	B	3.6012		
	C	3.8331		
CS40	A	3.9921	3.8621	30.50
	B	3.7642		
	C	3.8301		
CS50	A	3.2613	3.4624	17.00
	B	3.5619		
	C	3.5640		
CS60	A	3.6726	3.3656	13.73
	B	3.2362		
	C	3.1881		
CS80	A	2.8572	2.7381	-7.48
	B	2.5976		
	C	2.7596		
CS100	A	2.1909	2.4250	-18.06
	B	2.3881		
	C	2.6962		



Graph 4.4:- Average split tensile strength values for each mix after 28 days curing

From graph 4.4, the test results indicate that for mixtures prepared using up to 60% copper slag replacement, the Split tensile strength of concrete is higher than that of the strength of the control mix with 100% sand. However, for mixtures with 80% and 100% copper slag (i.e. Mixtures CS80 and CS100), the Split tensile strength decreased rapidly below the strength of the control mixture. Mixture CS40 with 40% copper slag content yielded the highest 28 day Split tensile strength of 3.8621 N/mm2 compared with 2.9594 N/mm2 for the control mixture. This means that there is an increase in strength of almost 30.5% compared to the control mix at 28 days. The reason for improvement of strength was, copper slag has a better compressibility than sand, which can partially relieve the stress concentration, if the sand is still as the dominant fine aggregate holding the concrete matrix together. It is known that the sand has good abrasion properties because of its rough surface, which can improve the cohesion between cement paste and coarse aggregate. However, the abrasion properties of sand is weakened with time after years of weathering causing sand particles to have rounded edges, which are detrimental to the interlocking properties of composite materials. The angular sharp edges of copper slag particles have the ability to compensate to some extent the adverse effects of sand and, thus, further improve the cohesion of concrete. His leads to improve the mechanical performance of copper slag admixed concrete. Whereas the lowest Split tensile strength of 2.4250 N/mm2 was obtained for Mixture CS100 with 100% copper slag. Here, the split tensile strength yielded by Mixture CS100 is almost 18.06% lower than that of the control mix. The maximum increase in strength was obtained at 40% replacement of copper slag with sand. This showed that the copper slag admixed concrete are not only increased the compressive strength of concrete but also increased the split tensile strength values.

4.5 FLEXURAL STRENGTH TEST

Flexural strength, also known as modulus of rupture, bend strength, or fracture strength, a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. The flexural strength represents the highest stress experienced within the material at its moment of rupture. The beam specimens were fabricated and tested with and without copper slag addition in concrete for normal conditions. The flexural strength (N/mm2) of rectangular cross-section using a three point flexural test technique is obtained by the formula,

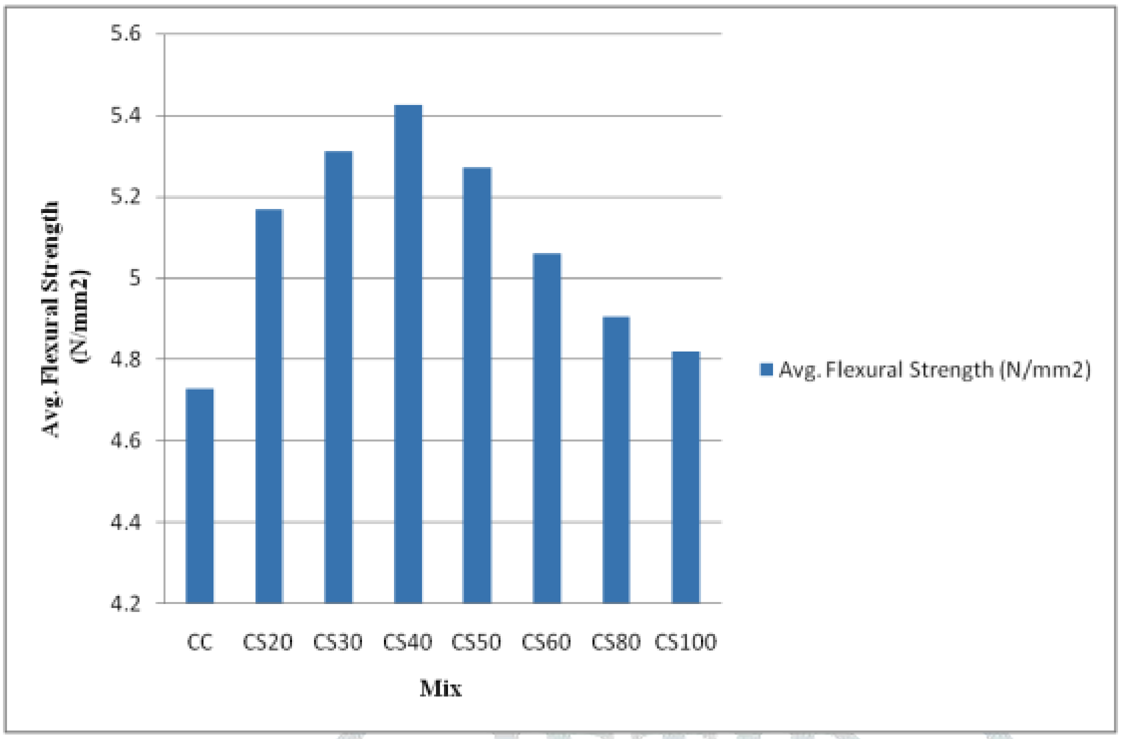
Flexural strength = $\frac{PL}{BD^2}$

Where, P=Ultimate load at failure (N), L=Length of specimen (mm), B=Breadth of specimen (mm) and D=Depth of specimen (mm)

The effect of copper slag substitution as a fine aggregate on the strength of concrete is given in table 4.5, which presents the average 28 day flexural strength of concrete. The unconfined flexural strength values of concrete mixtures with different proportions of copper slag tested 28 days are also plotted in graph 4.5.

Table 4.5:- Flexural Strength Results In Mpa

BEAM		FLEXURAL STRENGTH N/MM^2	AVG. FLEXURAL STRENGTH N/MM^2	% INCREASE IN STRENGTH AT 28 DAYS
MIX IDENTITY	SAMPLE NO.			
CC	A	4.8053	4.7288	-
	B	4.6523		
	C	4.7288		
CS20	A	5.160	5.1688	9.30
	B	5.1271		
	C	5.2195		
CS30	A	5.1893	5.3107	12.31
	B	5.4257		
	C	5.3173		
CS40	A	5.3368	5.4245	14.71
	B	5.4204		
	C	5.5164		
CS50	A	5.2408	5.2722	11.49
	B	5.3955		
	C	5.1804		
CS60	A	4.9902	5.0601	7.01
	B	4.9777		
	C	5.2124		
CS80	A	4.9902	4.9055	3.74
	B	4.9031		
	C	4.8231		
CS100	A	4.7946	4.8207	1.94
	B	4.9511		
	C	4.7164		



Graph 4.5:- Average Flexural strength values for each mix after 28 days curing

Graph 4.5 showed that the flexural strength of beam was found to be 4.7288 N/mm^2 at 0% fine aggregate replacement and of 4.8207 N/mm^2 at 100% fine aggregate replacement. This test results indicate that for mixtures prepared using up to 100% copper slag replacement, the flexural strength of concrete is higher than that of the strength of the control mix with 100% sand. Mixture CS40 with 40% copper slag content yielded the highest 28 day flexural strength of 5.4245 N/mm^2 compared with 4.7288 N/mm^2 for the control mixture. This means that there is an increase in strength of almost 14.71% compared to the control mix at 28 days.

CONCLUSION

The present study investigated the effectiveness of using copper slag (a waste material obtained from Bhosari MIDC, Pune) for the partial or full replacement of sand in concrete. Different tests are performed on the concrete in fresh and hardened state and results are explained. The conclusions based on entire experimental work are summarized as follows:

1. The utilisation of copper slag in concrete provides additional environmental as well as technical benefits for all related industries. Partial replacement of copper slag in fine aggregate reduces the cost of making concrete.
2. Water absorption of copper slag was 0.40% compared with 1.21% for sand. Therefore, the workability of concrete increases significantly with the increase of copper slag content in concrete mixes. This was attributed to the low water absorption and glassy surface of copper slag.
3. As the percentage of copper slag in design mix as replacement increases, the density of harden concrete observed to be increased. The density was increased by 5.97% when replacement of fine aggregate by 100% copper slag. This is because weight of concrete increases with copper slag.
4. Maximum Compressive strength of concrete increased by 46% at 40% replacement of fine aggregate by copper slag.
5. Maximum Split Tensile strength of concrete increased by 30.5% at 40% replacement of fine aggregate by copper slag.
6. Replacement of copper slag up to 60% will increase the Compressive and Split Tensile strength than control mix concrete strength, but beyond 60% replacement the strength started to reduce due to an increase of free water content in the mix. The Compressive and Split Tensile strength at 100 % replacement is reduced by 17.15% and 18.06% at 28 days.
7. It is observed that, the flexural strength of concrete at 28 days is higher than control mix concrete (Without replacement) for 40% replacement of fine aggregate by Copper slag, the flexural strength of concrete is increased by 14.71%. This also indicates flexural strength is more for all percentage replacements than control mix concrete.
8. Based upon the results obtained it was cocluded that 40% of copper slag can be used as replacement of fine aggregates.

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