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Experimental Study on the Flexural Behavior of Reinforced Concrete Beams as Replacement of Copper Slag as Fine Aggregate

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ORIGINAL ARTICLE

ABSTRACT: Researchers studied and developed waste management strategies to apply for advantages for specific needs. Owing to the scarcity of fine aggregate for the preparation of mortar and concrete, partial replacement of Copper Slag with sand have been attempted. The effects of replacing fine aggregates by copper slag on the compressive strength of cubes, split tensile strength of cylinders and flexural strength of beams are evaluated in this study. Copper slag is obtained as waste product from the sterlite industries. Investigations were carried out to explore the possibility of using copper slag as a replacement of sand in concrete mixtures. The test results of concrete were obtained by adding copper slag to sand in various percentages ranging from 0%, 20%. 40% 60%, 80% and 100%. All specimens were cured for 28 days before compression strength test, splitting tensile test and flexural strength. The highest compressive strength obtained was 35.11MPa (for 40% replacement) and the corresponding strength for control mix was 30MPa. This results of the research paper showed that the possibility of using copper slag as fine aggregate in concrete. The results showed the effect of copper slag on RCC concrete elements has a considerable amount of increase in the compressive, split tensile, flexural strength characteristics and energy absorption characteristics.

Keywords: Copper Slag Concrete, Compressive Strength, Split Tensile Strength, Flexural Strength, Energy Absorption Capacity

INTRODUCTION

Large amounts of industrial waste or by-products accumulate every year in the developing countries. Sustainability and resource efficiency are becoming increasing by most important issues in today's construction from industry. Therefore, nowadays utilization of secondary materials is being encouraged in construction field. For the production of cement and concrete, very high amount of energy is needed. Harmful effects of concrete can be reduced by producing good and durable concrete by using Industrial byproducts. Copper slag is one of the materials that is considered as a waste material which could have a promising future in construction industry as partial or full substitute of either cement or aggregates. Sterlite industries (India) ltd, Tuticorin, Tamil Nadu,India produces 4 lakh tons of copper per year . For every ton of copper production, about 2.2 tons of copper slag is generated. Therefore, in India 8 lakh tons of copper slag is generated every year. Copper slag have been widely used for abrasive tools, roofing granules, cutting tools, abrasive, tiles, glass, road base construction, rail road ballast and cement and concrete industries. Tixier et al. (1997) studied,Up to 50% by weight of copper slag was used as a Portland cement replacement together with up to 1.5% of hydrated lime as an activator to pozzolanic reaction. Result indicated a significant increase in the compressive strength. Li .F(1999) also reported that concrete containing copper slag as fine aggregate exhibited similar mechanical properties as that containing conventional sand and coarse aggregates.The pozzolanic activity and hydration of cement of copper slag was been investigated by O.Pavez et al(2003). Caliskan et al(2004)conducted experiemtnal investigation on the compressive strength of normal strength Concrete containing Copper Slag as coarse aggregate and showed that the compressive strength of Copper Slag coarse aggregate concrete was marginally higher than that of limestone aggregate concrete.A study carried out by central Road Research Institute (CRRI), 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 without 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. Khalifa al Jabri(2009) from his research study says that the reason for the use of iron waste in construction is because it is useful both for the economy and the environment, and he explains that there is an increase in industrial and technological by-products which are hazardous both for the environment and human health if not properly disposed of. Moreover, these byproducts are the main cause for the evaporation of CO_2 and other harmful gases which cause global warming and the destruction of the ozone layer which protects the planet earth from harmful cosmic rays. Moreover, industrial waste and by-products can be used as substitute materials in concrete and construction, which in itself is a better alternative to dumping such wastes as it will protect the environment and alleviate the exhaustion of perishable natural resources. The research study explains that to examine the use of copper slag as a sand replacement, prepared specimens of normal and high performance concrete mixtures with various percentages of copper slag 5 per cent, 20 per cent, 40 per cent, 60 per cent, 80 per cent, and 100 per cent. After the specimens were kept in water for 28 days to cure, laboratory tests were conducted to decide the volume of water absorption which is an important measure for concrete sustainability. Laboratory tests have demonstrated that the addition of about 50 per cent of copper slag as a sand replacement has yielded similar strength and sustainability as normal and high performance concrete totally prepared with sand. Moreover, it has been noticed that the addition of more than 50 per cent of copper slag has resulted in a gradual decrease in the density and workability of the concrete due to the increase in water percentage to the cement mixture, and to the fact that copper slag has a lesser capacity to absorb water than sand, which results in the increase of water percentage in that kind of cement mixture. The study concluded that 5 per cent copper slag substitution for cement gave a similar strength performance as normal concrete whereas 50 per cent copper slag can be used as replacement of sand in order to obtain concrete with good strength and durability requirements. There are many research studies that have been reported on the use of copper slag in cement concrete, not much research has been carried out in India concerning the incorporation of copper slag in concrete. Therefore, this paper presents the study of the effect of copper slag as a partial and full replacement of fine aggregate in concrete member like RCC beams and RCC columns. In this research studies the flexural behavior and strength calculation of RCC beams was investigated for the various proportion of copper slag as a sand substitute in concrete.

EXPERIMENATAL PROGRAMME

Materials

Cement

Ordinary Portland cement from Ramco Cement Company was used for this study. This cement is the most widely used one in the construction industry in India. Specific gravity of cement is 3.5.

Coarse and fine aggregates

Coarse aggregate of 20mm size and fine aggregates of zone 2 were procured from Arani area of Tamil Nadu .Specific gravity of fine aggregate is 2.65.Bulk density of Fine aggregate 1.457 g/cc and copper slag 1.978 g/cc. Fineness value of fine aggregate is 5.09, Table 1, shows the fineness value.

Copper slag

Copper slag from Sterlite Industries of India limited (SIIL), Tuticorin, Tamil Nadu, India was used for this research work. Table 2 shows the fines test on copper slag. Fineness modulus of copper slag is 4.90 and Bulk density of copper slag 1.978 g/cc.

Physical properties of copper slag

The slag is black glassy particle and granular materials in nature and has a similar particle size range like sand. The specific gravity of the slag is 3.91. The bulk density of granulated copper slag varies from 1.9 to 2.15 kg/m^3 which is almost similar to bulk density of convectional fine aggregate. The hardness of the slag lies between 6 and 7 in Moh scale. This is almost equal to the hardness of gypsum. The pH of aqueous solution of aqueous extract as per IS 11127 varies from 6.6 to 7.2. The free moisture content present in slag was found to be less than 0.5%.The presence of silica in slag is about 26% which is desirable since it is one of the constituents of the natural fine aggregate used in normal concreting operations. The fineness of copper slag was calculated as125 m^2 /kg. The following table shows the physical properties of copper slag.

Chemical properties of copper slag

The chemical properties of Copper slag samples were shown in Table 3.

Concrete mix proportions

The mix proportion for this study is given Table 4. The following mix proportion is adopted as per IS-10262.

The experimental program was designed to the study of mechanical properties of concrete with partial replacement of fine aggregate by the copper slag for M20 grade of concrete. The compressive strength of the cubes after replacing the fine aggregate by 20% 40% 60% 80% 100% with copper slag is studied for 28days shown in Table 2. For test specimens 53 grade port land cement, natural river sand and coarse aggregate, copper slags from plant are being utilized. The maximum size of coarse aggregate was limited to 20mm. Workability of concrete mix is given in Table 5.A sieve analysis of conforming to IS 383 – 1970 was carried for both fine and coarse aggregate. The concrete mix proportion of M20 with water cement ratio of 0.55 was used. The concrete mix design was proposed to achieve the compressive strength of 20MPa after 28 days curing in case of cubes. The flexural strength and spilt tensile strength of the specimen were also tested. The concrete cubes of (150x150x150mm) concrete beams(700x150x150mm) concrete for convectional as well as other mixes were casted. Each layer was compacted within 25 blows using 16mm diameter rod. The specimens were demoulded after 24 hours, cured in water and then tested at room temperature at the required age.

Test setup, compression test, split tensile strength and flexural strength test of concrete specimens

To determine the compressive strength, cube moulds of size 150x150x150 mm were used. 18 cubes were caste with different proportions of copper slag. Same as determine the split tensile strength, cylinder moulds of diameter 150mm and length 300mm were casted. Totally, 18 cylindrical specimens were casted with different proportions of copper slag.

Table 1. Fineness value of fine aggregate

Sieve size In (mm)	Weight retained(b)g	Cumulative weight retained (g)	Sand retained(n)g	Sand passing % of soil
4.75mm	32	3.2	3.2	96.8
2.36mm	58	5.8	9	91
1.18mm	234	23.4	32.4	67.6
600micron	348	34.8	67.2	32.8
300micron	273	27.3	94.5	5.5
150micron	52	5.2	99.7	0.3
75micron	3	0.3	100	100
Pan	0	0	100	100

Table 2 . Fineness test on copper salg

Sieve size In (mm)	Weight retained(b)g	Cumulative weight retained (g)	Slag retained(n)g	Slag passing % of soil
4.75mm	4	0.4	0.4	99.6
2.36mm	17	1.7	2.1	97.9
1.18mm	225	22.5	24.6	75.4
600micron	433	43.3	67.9	32.1
300micron	281	28.1	96	4
150micron	37	3.7	99.7	0.3
75micron	3	0.3	100	0
Pan	0	0	100	0

Table 3. Physical and Chemical properties of Copper Slag

Sl.No	Physical properties	Copper slag	Chemical components	% of chemical component
1	Particle shape	irregular	SiO_2	25.84
2	Appearance	Black & glassy	Fe_2O_3	68.29
3	Type	Air cooled	Al_2O_3	0.22
4	Specific gravity	3.91	CaO	0.15
5	Percentage of voids	43.20%	Na_2O	0.58
6	Bulk density	2.08g/cc	K_2O	0.23
7	Fineness modulus of copper slag	3.47	Lol	6.59
8	Angle of internal friction	51.20	Mn_2O_3	0.22
9	Hardness	6-7mohs	Tio_2	0.41
10	Water absorption	0.3% to 0.4%	SO_3	0.11
11	Moisture content	0.1%	CuO	1.20
12	Fineness of copper slag	125m^2/kg	Sulphide sulphur	0.25

Table 4. Concrete Mix With Different Proportions of Copper Slag

Mix Materials	100% Sand Kg/m^3	20% Kg/m^3	40% Kg/m^3	60% Kg/m^3	80% Kg/m^3	100% Kg/m^3
Cement	372	372	372	372	372	372
Copper slag	0	113.99	252.92	432.6	614.54	867.3
water	178.3	182.42	179.4	175.2	172.98	168
FA	656.7	455.94	379.39	288.4	153.63	0
CA	1201.76	1201.76	1201.76	1201.76	1201.76	1201.76

Table 5. workability of concrete with copper slag of various mix proportions

Composition of copper slag in concrete	Slump in (mm)	Indian Standard IS: 456- 2000	Remarks
CC(Complete sand)	105 mm	75 mm to 125 mm for Column	Thus 40% of composition of copper slag achieves the IS Standard (IS:456-2000)
CS20(20 % copper slag)	90 mm		
CS40(40% copper slag)	122 mm		
CS60(60% copper slag)	105mm		
CS80(80% copper slag)	100 mm		
CSF(100% copper slag)	120 mm		

Table 6 . Compressive strength test conducted on cube specimens at 28 days.

Sl.No	Replacement of Copper slag (%)	Ultimate load (kN)	Average Load(kN)	Ave.Compressive strength at 28 days strength(N/mm^2)	% of increase in compressive strength
1	CC	678 685 675	679	30.20	---
2	CS20	740 730 745	738.33	32.81	8.60
3	CS40	785 790 795	790.00	35.11	16.25
4	CS60	475 480 485	480	21.33	30.00
5	CS80	450 475 455	460	20.44	33.00
6	CSF	440 445 465	450	20	33.33

Table 7 . Split tensile strength test on cylinder at 28 days

Sl.No	Replacement of Copper slag (%)	Ave. Load at 28 days (kN)	Ave.Split tensile strength at 28 days (N/mm^2)	Increase in split tensile strength(%)
1	CC	109.56	1.55	---
2	CS20	158.34	2.24	44.52
3	CS40	202.16	2.86	84.52
4	CS60	173.18	2.45	58.06
5	CS80	141.37	2.00	12.00
6	CSF	113.09	1.60	3.22

Table 8. Flexural strength test and deflection of test beam

Sl.No	Replacement of Copper slag (%)	Ave. Ultimate load (tones)	Flexural Strength (N/mm^2)	Increase in Flexural strength(%)	Deflection in (mm)	Energy absorption capacity of the beam (Kn m)	Nature of Failure
1	CC	8.00	18.95	---	4	5.00	Flexure
2	CS20	9.72	23.04	21.58	5	6.50	Flexure
3	CS40	10.64	25.22	33.10	6	7.75	Flexure
4	CS60	11.80	27.97	47.60	6.5	8.25	Flexure
5	CS80	12.10	28.68	51.35	7	9.00	Shear
6	CSF	12.15	28.80	51.97	10	10.75	Shear

Flexural strength of beams

The size of beam specimens is 900 x150 x150mm. The beam specimens were cast and tested with and without copper slag for normal conditions. 18 Nos of beam specimens were cast using the same reinforcement shown in Figure. The beams were divided into six series CC, CS20,CS40,CS60,CS80 and CSF. Series CC consisted of three beams designated as CC1, CC2 and CC3. These beams were treated as control specimens and were not replaced with copper slag. Series CC20 consisted of three beams designated as CS20-1, CS20-2 and CS20-3. 20% of copper slag was replaced for fine aggregate in concrete. Similarly, series CS40, CS60,CS80 and CS100 consisted of CS40-1, CS40-2, CS60-3, CS60-1, CS60-2, CS60-3, CS80-1,CS80-2, CS80-3 and CSF-1,CSF-2 and CSF-3 beams replaced with 40% ,60% 80% and 100% of copper slag. The test was carried out in the Universal testing machine of capacity as 40 Tonne. Two distance pieces were kept at the one third distances from both the ends , three deflectometers were placed on the bottom side of the beam. Two point loading system was adopted for the test. Figure 2 and Figure 3 shows the reinforcement details and test setup of the test beam.

EXPERIMENTAL RESULTS AND DISCUSSION

Effects on compression test with copper slag concrete

The results show that the compressive strength of concrete is increased as copper slag quantity increases up to 40%, beyond that compressive strength was significant decreases due to increases free water content in the mixes. The excessive free water content in the mixes with copper slag content causes the bleeding and segregation in concrete. Therefore, it leads reduction in the concrete strength. The highest compressive strength was achieved with 40% replacement of copper slag, which was found about 35.11N/mm^2. This indicates that there is an increase of compressive strength of more than 30% compared to the control mix. However concrete mix with 60% replacement of copper slag gave the low compressive strength when compare to 40%. In 100% replacement of sand with copper slag shows the compressive strength of 20Mpa. From the results it showed that the uses of copper slag as a replacement of sand in concrete mixes resulted high compressive strength of about 30% in the mix ratio of 40% replacement. The average 28 days compressive strength for different mix proportions of concrete mixes shown in Table 6 and its graphical representation shown in Figure 4 .

Split Tensile Strength of Copper Slag Concrete

Totally 18 cylindrical specimens were tested for finding split tensile The split tensile strength of concrete is calculated by using the following formula,

$$f_{st}=2P/\pi ld$$

where: P-maximum load at failure, l-length of cylindrical specimen in mm, d-diameter of cylindrical specimen in mm.

The tensile strength of concrete showed similar behavior to the compressive strength. The results show that the split tensile strength is increased as copper slag quantity increases up to 40% addition, beyond that the split tensile strength value reduces but still more than 40% compared with control mix. The results showed that the use of copper slag in concrete increases the tensile strength of about 85% with that of control mixture. The results from the splitting tensile test at 28 days are presented in Table 7 and its graphical representation shown in Figure 5.

Flexural strength and energy absorption capacity of RCC beams with copper slag

Eighteen beams were tested for flexural strength under two point loading conditions. Out of the 18 specimens CC, were treated as control specimens, remaining set of specimens incorporating copper slag at a percentage of 20%, 40%, 60%,80% and 100%(CFS) with that of sand.
The average modulus of rupture (flexural strength) was determined using the following expression

$$F_{cr}=FL/BD^2$$

Where F_{cr}=modulus of rupture, F=ultimate load in KN, L=length of beam in m, B=Average width of specimen in m, D=Average depth of specimen in m.

The bending moment, obviously , induce compressive stress at the top and tensile stress at the bottom of beam. The beam fails in tension. The first cracks formed between the locations of the maximum bending moment. Thereafter, as the load was increased more cracks started to form over the shear span on both sides of the beam. Flexural beams replaced with copper slag gives more flexural strength compared to the control specimens. From Table 8 of results showed the significant increase of flexural strength of beams when copper slag was added for the replacement of sand.

From the Figure 6 load(% of copper slag concrete)Vs deflection curve it is clearly understand that the copper slag replaced concrete specimens are withstanding for higher loads. The energy absorption of these beams was calculated as the area under the load Vs deflection curves. From the values, it was observed that the copper slag replaced beams showed an increase in energy absorption values shown in Table 8. Due to this increasing energy absorption of beams could be attributed to the ductile of the copper slag beams.

Figure 1. Copper slag

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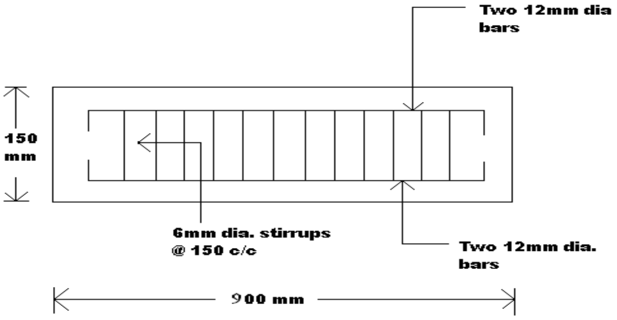

Figure 2. Reinforcement details of test beam
(Longitudinal section)

Figure 3. Experimental set up

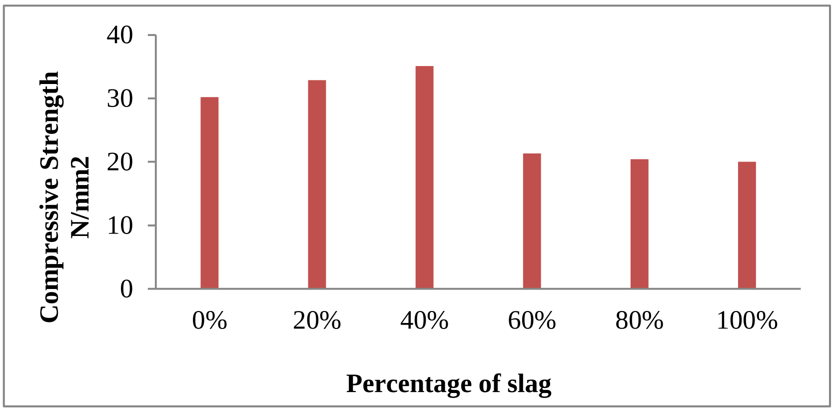

Figure 4. Compressive strength of concrete and different mix ratio of copper concrete cubes

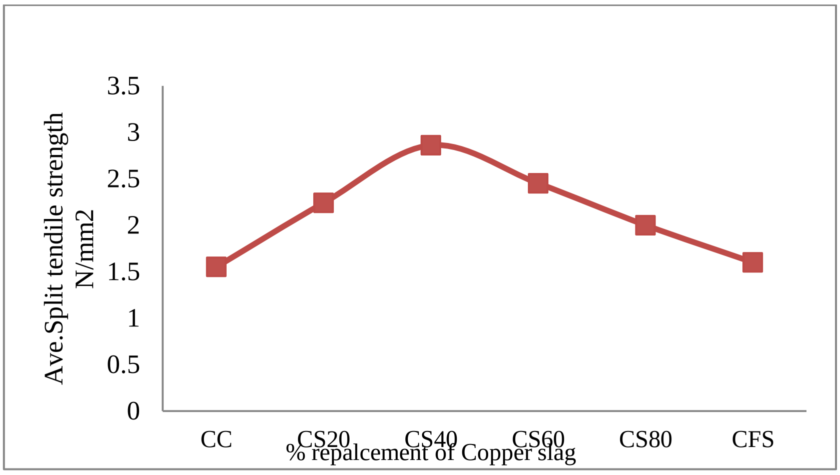

Figure 5. Ave.split tensile strength with different % of copper slag concrete

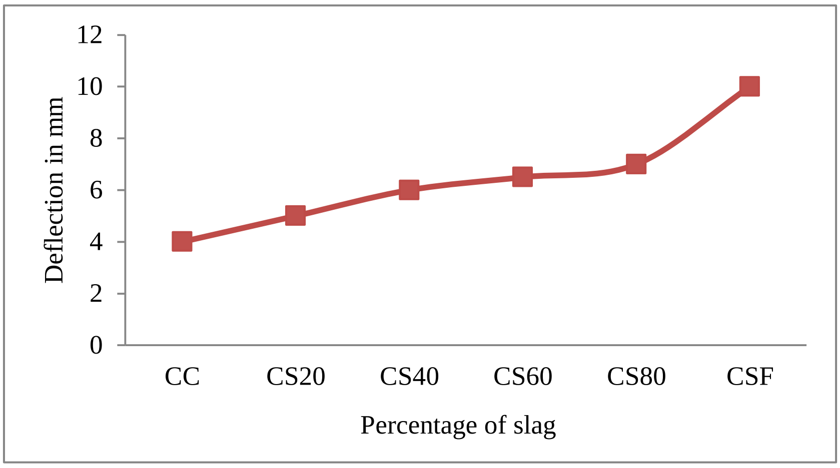

Figure 6. %of copper slag concrete Vs deflection

CONCLUSION

A following conclusion were obtained from this research study with replacement of sand to copper slag on the concrete properties

1) The addition of copper slag has improved the compressive strength, split tensile strength and flexural strength of concrete.
2) While replacement of copper slag in concrete increases the density of concrete.
3) The slump value of copper slag concrete lies between 90 to 120 mm.
4) The flexural strength of the beam increased by 21% to 51% while replacement of copper slag.
5) The uses of copper slag as a partial replacement for sand strength increasing up to 40% replacement level. Higher level replacement leads to segregation and bleeding due to less water absorption capacity of copper slag.
6) It was also observed that the sand replaced copper slag beams showed an increase in energy absorption capacity.

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