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Research Article

Experimental Investigation on the Mechanical Properties of Reinforced Cement Concrete using Copper Slag as Partial Replacement for Fine Aggregates

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Abstract

India is one of the world's fastest growing economies and growth expected to continue at 7-7.5%. Infrastructure development is the backbone for the economic growth and prosperity of any nation. The exploitation of natural resources is a key factor in economic growth and development which have serious negative environmental and socioeconomic impacts. Steadily rising global demand for raw materials have been one of the main drivers of the depletion and degradation of natural resources. For sustainable development the use of alternate materials for cement and aggregates are being studied. The main opportunity zones for the use of sustainable materials in the Indian construction industry lie in using sustainable alternatives to aggregates. Copper slag is considered as one of the waste materials which can have a promising future in construction industry as partial or full substitute of either cement or aggregates. Only about 15% to 20% of copper slag generated is presently used for various purposes and remaining material is dumped as a waste. In this study M30 concrete is used to determine various mechanical properties by substituting copper slag for sand partially in concrete. For sand replacement, four test groups (including control mixture) were constituted with replacement of 0% (control specimen), 30%, 40% and 50% copper slag with sand in each series. Concrete cubes, cylinders, and RCC beams are cast and tested in laboratories. The optimum level of replacement of copper slag is found to be 40% and the results are better than that of control mix.

Keywords: *Copper Slag Concrete, Compressive Strength, Split Tensile Strength, Flexural Strength, Flexural Behaviour*

1. Introduction

All over the world rapid growth is being witnessed in construction industry in many countries. India is one of the fastest growing economy in the world. Infrastructure sector is a key driver for the Indian economy. Natural resources is being heavily exploited for the growth of infrastructure. This trend cannot continue forever. Without proper alternative aggregates being utilized in the near future, the concrete industry globally will consume 8–12 billion tons annually of natural aggregates after the year 2010 (Tu T-Y, Chen Y-Y, Hwang C-L 2006). Such large consumption of natural aggregates will cause destruction to the environment.

Alternate material need to be used instead of this natural materials. At the same time industrial waste is generated substantially (Al-Jabri, 2009) due to the growth of industrialization. In order to reduce dependence on natural aggregates as the main source of aggregate in concrete, artificially manufactured aggregates and artificial aggregates generated from industrial wastes provide an alternative for the construction industry. Therefore, utilization of aggregates from industrial wastes can be alternative to the natural and artificial aggregates.

In Concrete, fine aggregate acts as a filler material and workability agent. River sand is widely used as fine aggregate in concrete. There is a great demand of river sand for Concrete constructions. Sustainable Infrastructure is the need of the hour. Sustainable infrastructure refers to the designing, building, and operating of these structural elements in ways that do not diminish the social, economic and ecological processes required to maintain human equity, diversity, and the functionality of natural systems. The objective of this study is to find the feasibility of using copper slag as partial replacement of fine aggregate.

Copper slag is one of the industrial waste materials obtained during smelting and refining of copper. It has

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been estimated that approximately 24.6 million tons of slag are generated from the world copper industry (Gorai *et. al.*, 2003). In Tamil Nadu, the copper smelting unit of M/s Sterlite Industries Ltd., located at Tuticorin, produces about 1600 tons of copper slag per day.

The use of slag from copper smelting as a fine aggregate in concrete was investigated by many people all over the world. Based on above investigations, this research study is conducted to investigate the performance of concrete made with copper slag as a partial replacement for fine aggregate. Four test groups were constituted with replacement: 0%, 30%, 40% and 50% of copper slag with sand in each series. The following tests have been conducted to find the mechanical properties of concrete and structural members. i) Compressive strength test on mortal cubes, ii) Compressive strength test on concrete cubes, iii) Flexural strength test on concrete beam specimens and iv) Flexural strength studies on RCC beams.

2. Review of Literature

Bipra gorai *et al*, after reviewing the characteristics of copper slag concludes that judicial utilisation of copper slag is of prime importance in industrial waste management (Bipra gorai *et al*., 2003). Copper slag from Bahia, Brazil had been used as construction material by American concrete institute (Moura *et al*., 1999) and it was observed that the characteristic of the material is equivalent to the traditional ones or even better. Akihiko and Takashi investigated the use of slag from copper slag as fine aggregate (Akihiko and Takashi, 1996) in concrete and found from mortar strength tests with cement/slag/water ratio of 1/2/0.55 the ball milled slag gave higher strength. Najimi *et al*, investigated the application of copper slag and from the study emphasized the effectiveness of copper slag replacement (Najimi *et al*, 2011) in improving the concrete resistance against sulphate attack. Mechanical properties of high strength concrete incorporating copper slag as a fine aggregate has been investigated by Wei Wu and it is found that the smooth glassy surface texture and low moisture absorption, the excellent compressibility of copper slag can improve the workability (Wei Wu ,2010 a). Al-Jabri *et. al.*, has investigated the performance of high strength concrete (HSC) made with copper slag as a fine aggregate and found that addition of upto 50% of copper slag as sand replacement yielded comparable strength with that of the control mix (Al-Jabri *et. al.*, 2009). Chavan *et. al.*, investigated the effect of using copper slag as a replacement of fine aggregate on the strength properties. From the results obtained he concluded that the maximum compressive strength of concrete increased by 55% at 40% replacement of fine aggregate by copper slag, and up to 75% replacement, (Chavan *et. al.*, 2013) concrete gain more strength than control mix concrete strength. Al-Jabri *et al*., investigated the effect of using copper slag as a fine aggregate on the properties of cement mortars and concrete (Al-Jabri *et al*., 2011). A substitution of upto 40–50% copper slag as a sand replacement yielded comparable strength to that of the control mixture. M.V.Patil studied the properties and effects of copper slag in concrete, (M.V.Patil 2015) M30 grade concrete was used and the tests were conducted for various proportions of copper slag replacement with sand of 0%, to100 % in concrete. The results showed that the maximum compressive strength of concrete increased by 34 % at 20% replacement of fine aggregate.

3. Aim and Objective

The main aim of this research work was to investigate effective replacement of sand by copper slag in concrete and Reinforced Cement Concrete. To achieve this, an extensive study has been carried out to investigate the following using copper slag.

1. To find the optimum proportion of copper slag that can be used as a replacement/ substitute material for fine aggregate.
2. To evaluate compressive and tensile strength of copper slag admixed concrete specimens.
3. To investigate flexural strength and behaviour of copper slag replaced structural members.

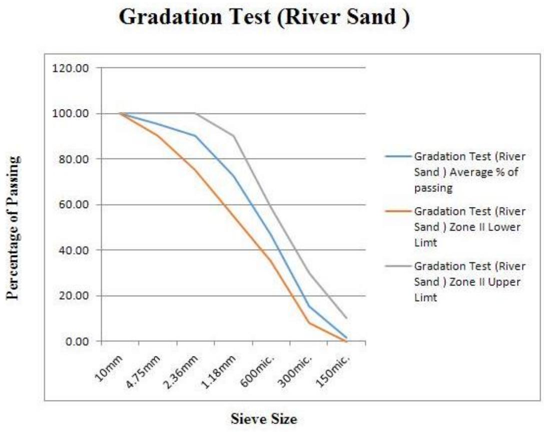
4. Materials Investigation and Mix Proportion

Cement: The following tests are conducted for cement in accordance with IS codes. Specific gravity (Le – Chatelier flask) (IS: 1727-1967) (Methods of test for pozzolanic materials), Standard consistency (IS: 4031 – 1988 Part 4) (Methods of physical tests for hydraulic cement: Part 4. Determination of consistency of standard cement paste). Initial setting time (IS: 4031 – 1988 Part 5), Final setting time (IS: 4031 – 1988 Part 5) (Methods of physical tests for hydraulic cement: Part 5. Determination of initial and final setting times).

Table 1 Tests on cement

1.	Specific Gravity	3.14
2.	**Setting Time**	
(i)	Initial Setting Time	104 min
(ii)	Final Setting Time	254 min
3.	Fineness	230
4.	Consistency	35

Fine Aggregate: The fine aggregate used in this investigation is clean river sand and the following tests are carried out on sand as per IS: 2386- 1968 (III). (Methods of Test for Aggregates for Concrete Part 3 Specific Gravity, Density, Voids, Absorption and Bulking).



Coarse Aggregate: Locally available crushed blue granite stone aggregate of size 20 mm and down, is used in this study and the various tests, carried out on the aggregates.

Copper Slag: Copper slag is black glassy and granular in nature and has a similar particle size range like sand. The copper slag used in the study was obtained from the copper smelting unit of M/s Sterlite Industries Ltd., located at Tuticorin in Tamilnadu.

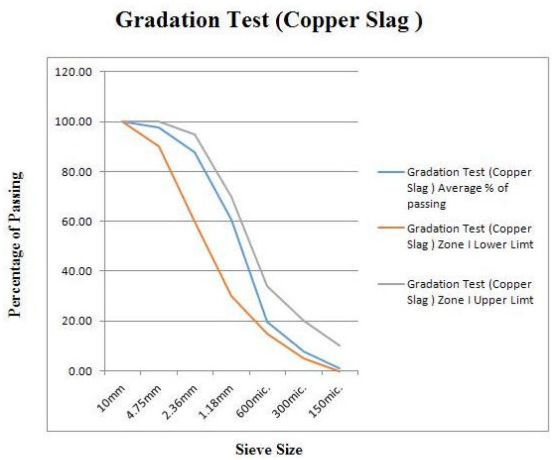


Table 2: Tests on fine aggregate Sand, Copper Slag and Coarse Aggregates

Sl.No	Desc.Prop.	Sand	Copper Slag	Coarse Aggregate
1	Specific Gravity	2.620	3.67	2.772
2	Fineness Modulus	2.780	3.254	7.479
3	Water absorption	0.609	0.372	0.67

5. Mix Design

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design.

The mix proportion chosen for this study is **1: 1.52: 2.63** with Water/Cement ratio of **0.45.** M30 concrete is used for this study. These basic mix proportions are modified in using copper slag as a partial replacement for sand. Totally four concrete mixtures are prepared with different proportions of copper slag ranging from 0% (for control mix) to 50% with sand named as CC, CS30, CS40 and CS50 .Each mixture contains three specimens. The following mix identifications are used for various proportions of copper slag with sand and cement.

CC - Control Concrete (0%)
CS30 - 30% of sand replaced by copper slag
CS40 - 40% of sand replaced by copper slag
CS50 - 50% of sand replaced by copper slag

Mix Proportion by weight:

For Controlled Concrete (CC) ⇨ 427:**649**:1121 (1:1.52:2.63)

For 30% replacement of Copper Slag Concrete (CS30) ⇨ 427:**727**:1121 (1:1.70:2.63)
[454.30 kg River Sand (70%)
272.70kg Copper Slag (30%)]

For 40% replacement of Copper Slag Concrete (CS40) ⇨ 427:**753**:1121 (1:1.76:2.63)
[389.40 kg River Sand (60%)
363.60kg Copper Slag (40%)]

For 50% replacement of Copper Slag Concrete (CS50) ⇨ 427:**779**:1121 (1:1.83:2.63)
[324.50kg River Sand (50%)
454.50kg Copper Slag (50%)]

6. Experimental Setup for Concrete Specimens

Four test groups were constituted with replacement of 0% (control specimen), 30%, 40% and 50% copper slag with sand in each series. Three specimens are prepared for every replacement percentage.

Concrete Cubes: To determine the compressive strength and durability effects of concrete, 150 mm × 150 mm × 150 mm size concrete cubes were cast and tested in accordance with IS: 516-1959. After 24 hours, the specimens are demoulded and cured for 28 days in potable water. After curing, the specimens are tested for compressive strength using compression testing machine of 2000KN capacity. The maximum load at failure was taken. The average compressive strength of concrete and mortar specimens is calculated by using the following equation.

$$\text{Compressive strength (N/mm}^2) = \frac{\text{Ultimate compressive load (N)}}{\text{Area of cross section of specimen (mm}^2)}$$

Concrete Cylinders: The size of cylinder used for split tensile strength and durability studies was 150mm diameter and 300mm height. This test was conducted in accordance with IS: 5816-1999. After 24 hours, the specimens are demoulded and subjected to curing for 28 days in portable water. After curing, the cylindrical specimens are tested for split tensile strength using compression testing machine of 2000kN capacity. The ultimate load is taken and the average split tensile strength is calculated using the equation given below.

$$\text{Split tensile strength (N/mm2)} = \frac{2P}{\pi LD}$$

Concrete Beams: Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending. It is measured by loading 150 x 150 mm concrete beams with a span length of at least three times the depth. Concrete beams of standard size 750 x 150 x 150 mm confirming to IS: 516-1959 are used for studying the flexural strength. The flexural strength is expressed as Modulus of Rupture (MR) in psi (MPa).

Reinforced Cement Concrete Beams: The flexural behaviour of RCC beams incorporating copper slag as partial replacement of sand is studied. (Replacement – 0 to 50%). Reinforced Cement Concrete beams of size 1100 x 150 x 150 mm are used for studying the flexural behaviour. Two 12 mm diameter bars are used for flexural reinforcement at bottom and two 10 mm rods were provided for top reinforcement. For each beam, 8 mm diameter mild steel bars are used as stirrups, spaced 150 mm c/c for shear reinforcement. Typical beam reinforcement details are illustrated in Figure 1.

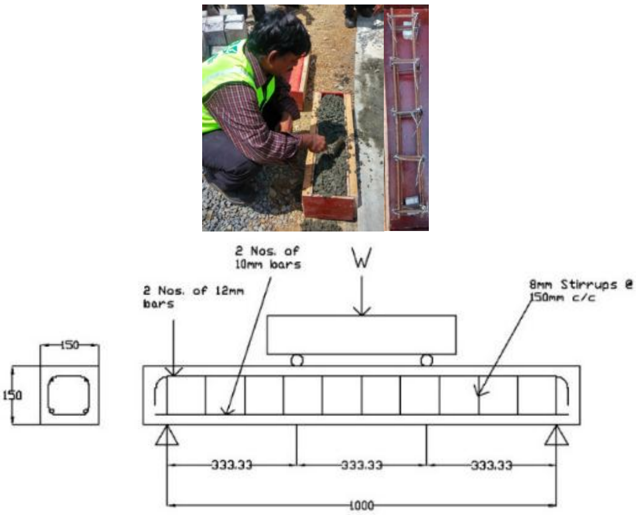


Figure 1 Beam reinforcement details

7. Results and Discussions

Compressive Strength Test on concrete cubes: The average 7 and 28 day cube compressive strength of concrete is given in Table 1. The effect of copper slag substitution as a fine aggregate on the strength of concrete is studied. The compressive strength values of concrete mixtures with different proportions of copper slag (from 0 to 50%) tested at 7 and 28 days are plotted in Figure 2.

The test results indicate that the compressive strength of concrete increased for mixtures prepared using upto 40% copper slag as replacement river sand. However, for mixtures with CS50 copper slag, the compressive strength decreased. Mixture CS40 yielded the highest 28 day compressive strength of 49.408 N/mm² compared with 38.37 N/mm² for the control mixture, whereas the compressive strength of CS 50 with 50% copper slag reduced to 46.148 N/mm². But the value is still greater than control mix. This reduction in compressive strength for concrete mixtures with high copper slag contents may be due to increase in the free water content that results from the low water absorption characteristics of copper slag in comparison with sand. The excessive free water content in the mixes with copper slag content causes the bleeding and segregation in concrete. This causes a considerable increase in the workability of concrete but leads reduction in the concrete strength.

Table 1 Comparison of Compressive Strength

Sl.No	Description of Sample	7 Days		28 days	
		Average Compressive Strength in N/Sqmm	% of increase in comp. strength	Average Compressive Strength in N/Sqmm	% of increase in comp. strength
1	CC	24.000		38.370	
2	CS30	28.444	18.517	45.556	18.728
3	CS40	30.222	25.925	49.408	28.767
4	CS50	28.000	16.667	46.148	20.271

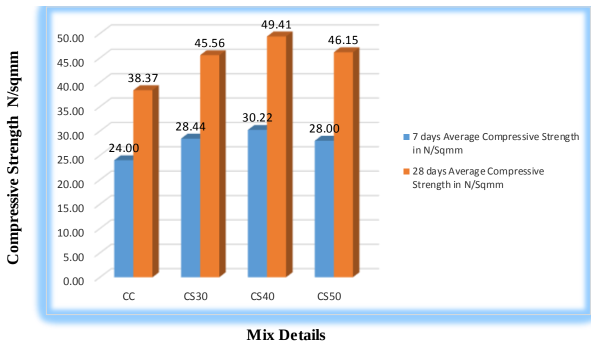


Figure 2 Compressive strength of concrete cubes

Split Tensile Strength Test on Concrete Cylinders: Split tensile strength is defined as a method of determining the tensile strength of concrete using a cylinder. The effect of copper slag substitution as a fine aggregate on split tensile strength of concrete is given in Table 2.

Table 2 Comparison of Split Tensile Strength

Sl.No	Description of Sample	7Days		28 Days	
		Average Split Tensile Strength in N/Sqmm	% of increase in strength	Average Split Tensile Strength in N/Sqmm	% of increase in strength
1	CC	**1.793**		**3.869**	
2	CS30	**2.052**	**14.445**	**4.600**	**18.894**
3	CS40	**2.312**	**28.946**	**4.883**	**26.208**
4	CS50	**2.194**	**22.365**	**4.695**	**21.349**

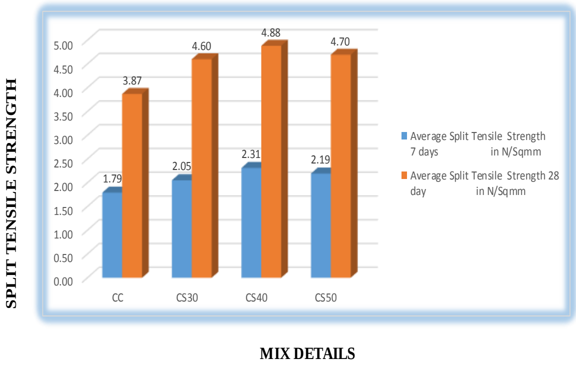


Figure 3 Split Tensile Strength of Concrete Cylinders

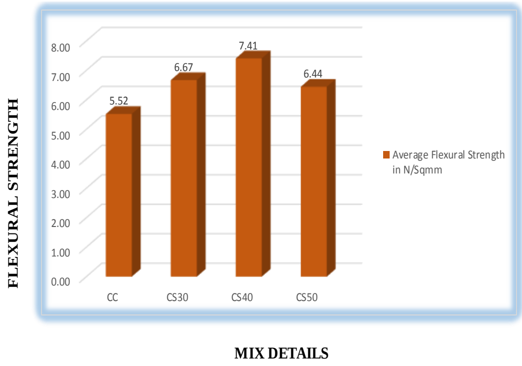


Figure 4 Flexural Strength of Concrete Beams

It can be seen from Table 6.2 that the 28 day split tensile strength of CS30, CS40 and CS50 specimens is 18.894 %, 26.208% and 21.349% higher than that of control specimens. 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.

Flexural Strength of Concrete Beams: One of the important strength property of concrete is the flexural strength of a concrete. Beams of size 750 x150 x150mm are cast. The beam specimens are fabricated and tested at 28 days of curing with and without copper slag addition in concrete for normal conditions. 12 numbers of concrete beam specimens are cast with replacement of 0%, 30%, 40% and 50%.

Table 3 Flexural strength test results on concrete beams

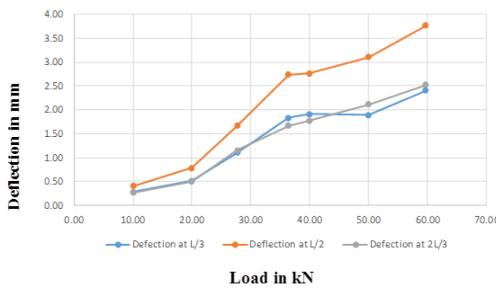
Sl.No	Description of Sample		Flexural Strength in N/Sqmm	% of increase in strength
1	Controlled Mix (100% sand)	Sample 1	5.330	
		Sample 2	5.670	
		Sample 3	5.560	
		Average	**5.520**	
2	Fine Aggregate 30% Copper Slag 70% River Sand	Sample 1	6.560	
		Sample 2	6.780	
		Sample 3	6.670	
		Average	**6.670**	**20.833**
3	Fine Aggregate 40% Copper Slag 60% River Sand	Sample 1	7.440	
		Sample 2	7.220	
		Sample 3	7.560	
		Average	**7.407**	**34.185**
4	Fine Aggregate 50% Copper Slag 50% River Sand	Sample 1	6.440	
		Sample 2	6.560	
		Sample 3	6.330	
		Average	**6.443**	**16.721**

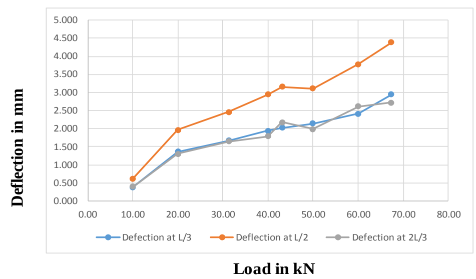
The 28 day average flexural strength (modulus of rupture) values for concrete are presented in Table 3. The flexural strength values for copper slag replaced concrete mixtures increase in all the samples upto 50% replacement with sand.

The experimental average flexural strength of CS40 concrete was 7.407 N/mm², compared with 5.520 N/mm² calculated from CC mixture. It is also worth mentioning that there was more than 34% improvement in the flexural strength of concrete beams with 40% copper slag replacement.

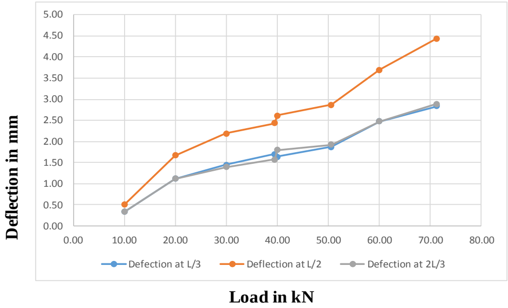
Flexural Behaviour of Reinforced Cement Concrete Beams : The main objective of this investigation is to study the flexure behaviour of RCC beams prepared with various proportions of copper slag with sand. Four mixtures of 12 specimens were prepared and tested at 28 days for various percentage of copper slag with sand.

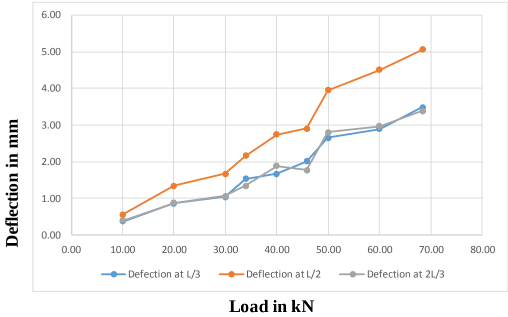
Totally 3 control beams and 9 slag sand specimens are casted and tested for flexure the specimens are designated as CC1,2,3, CS30 1,2,3 , CS40 1,2,3 and CS50 1,2,3 .Three dial gauges are used to measure the deflections at 1/3rd span, mid span and at 2/3rd span. Strain gauge are used to measure the top and bottom strain at mid span. The deflections are recorded up to failure load and compared with test values. The Load versus deflection curves of the test beams are presented below.





Load Vs deflection of CC beam Load Vs deflection of CS30 beam





Load Vs deflection of CS40 beam Load Vs deflection of CS50 beam

Figure 5 Load Vs deflection

All the reinforced concrete beam specimens were tested in a 500 KN capacity loading frame. As the load is increased the beam starts to deflect. Typical cracking, yield and ultimate load to which the beam is subjected and the deflection at those load value is also recorded.

Table 4 Comparison of copper slag replaced beams with control beams under flexure

Sl.No.	Parameter	CC	CS30	CS40	CS50
1	Initial Crack Load in kN	**27.100**	**31.000**	**39.600**	**33.100**
2	Initial Crack Deflection in mm	1.670	1.990	2.430	2.170
3	Initial Crack Width in mm	0.040	0.030	0.030	0.050
4	Yield Load in kN	**35.600**	**43.100**	**50.800**	**44.700**
5	Yield Deflection in mm (▲Y)	2.735	3.160	2.870	2.910
6	Yield Load Crack Width in mm	1.200	1.000	0.090	1.100
7	Ultimate Load in kN	**58.400**	**67.300**	**71.600**	**66.700**
8	Ultimate Load Deflection in mm (▲U)	3.765	4.390	4.440	5.060
9	Ultimate Load Crack Width in mm	1.400	1.600	2.100	2.200
10	Deflection Ductility (▲U/▲Y)	1.377	1.389	1.547	1.739
11	Percentage increase in Ultimate Load %		**15.240**	**22.600**	**14.210**

From the above results, it can be clearly seen that all the copper slag replaced flexure beams of size 1000 x 150 x 150mm show enhanced performance with respect to parameters such as initial cracking load, ultimate load, and yield load when compared with the control beams. When copper slag replaced more than 40%, the performance of RCC beams are slightly reduced with other replacement percentages. Still it was higher than control beams. CS30, CS40 and CS50 type RCC beams showed 15.24%, 22.60% and 14.21%, increase in ultimate load values respectively when compared with control beams.

Crack pattern and modes of failure

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 and as the load was increased the crack started propagating toward the neutral axis. Thereafter, as the load was increased more cracks started to form over the shear span on both sides of the beam. The mode of failure of all the beams were flexural failure. There was no horizontal cracks at the level of the reinforcement, which shows that there was no bonding failure.

Conclusion

M30 grade concrete is used in this study and the tests are conducted for various proportions of copper slag replacement with sand of 0%, to 50 % in concrete. Based on the experimental investigations, the following conclusions are drawn.

- The utilization of copper slag in cement and concrete provides additional environmental as well as technical benefits for all related industries.
- The behaviour of Copper Slag seems to be similar to river sand for its use as fine aggregate in concrete mixes. But due to the higher specific gravity minor adjustment/modifications have to be made.
- The optimum level of replacement of copper slag is found to be 40% and the results are better than that of control mix.
- The workability of fresh concrete increases with increase in the replacement of copper slag with same water cement ratio.
- The 28 days average compressive strength obtained for copper slag mix concrete shows 18.728% (CS 30) to 28.767% (CS40) increase in compressive strength when compared to control mix concrete. At 40% replacement it gives the maximum strength.
- The 28 days average split tensile strength obtained for copper slag mix concrete shows 18.894%(CS 30) to 26.208% (CS40) increase in split tensile strength when compared to control mix concrete and the maximum is obtained at 40% replacement.
- The 28 days average flexural strength obtained for copper slag mix concrete shows 16.721% (CS50) to 34.185% (CS40) increase in flexural strength when compared to control mix concrete and the maximum is obtained at 40% replacement.
- All the copper slag replaced flexure beams show enhanced performance with respect to parameters such as initial cracking load, ultimate load, and yield load when compared with the control beams .The CS30, CS40 and CS50 type RCC beams showed 15.24%, 22.60% and 14.21%, increase in ultimate

load values respectively when compared with control beams.

- Copper slag admixed RCC beams are stiffer than control beams.
- Replacement of copper slag in fine aggregate reduces the cost of making concrete.
- The improvement in the mechanical properties of concretes incorporating copper slag indicates that copper slag, a waste by-product of the copper industry, can be used beneficially as partial replacement for fine aggregate in concrete.

9. Limitations of the study

In the present study the partial replacement of copper slag by 30%, 40% and 50% of river sand is studied. Wider percentage of replacement have to be studied. Curing of the concrete samples was only considered up to 28 days due to limited time frame.

The study reported here is only meant to explore the feasibility of using copper slag as fine aggregates in concrete, and further efforts are needed to understand the long-term properties of concrete containing copper slag as replacement of fine aggregate. The chemical and durability aspects of the concrete is to be studied.

Further research work is needed to explore the effect of copper slag as fine aggregates on the properties of concrete with different cement types, silica fume sources and the degree of fines.

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