International Journal of Structural and Civil Engineering Research

ISSN 2319 – 6009 www.ijscer.com
Vol. 3, No. 4, November 2014

Research Paper

AN EXPERIMENTAL INVESTIGATION ON STRENGTH PROPERTIES OF CONCRETE THROUGH FULL REPLACEMENT OF SAND BY COPPER SLAG

Syed Moizuddin Mahmood[1]* and S M Hashmi[2]

*Corresponding author: **Syed Moizuddin Mahmood** ✉ moiz90@ymail.com

Natural resources are depleting worldwide while at the same time the generated wastes from the industry are increasing substantially. The sustainable development for construction involves the use of nonconventional and innovative materials, and recycling of waste materials in order to compensate the lack of natural resources and to find alternative ways conserving the environment. The fine aggregates (sand) was replaced with percentages 0% (for the control mixture), 10%, 20%, 30%, 40%, 50%, 60%, 80%, and 100% of Copper Slag by weight. Tests were performed for properties of fresh concrete and Hardened Concrete. Compressive strength at 7 and 28 days. Tensile strength and Flexural strength were determined at 28 days. RCC beams Flexural strength tested @ 28 days. The results indicate that workability increases with increase in Copper Slag percentage. Test results indicate significant improvement in the strength properties of plain concrete by the inclusion of up to 100% Copper slag as replacement of fine aggregate (sand), and can be effectively used in structural concrete.

Keywords: Copper Slag, Concrete, Compressive strength, Tensile strength, Flexural strength, Beams

INTRODUCTION

Aggregates are considered one of the main constituents of concrete since they occupy more than 70% of the concrete matrix. In many countries there is scarcity of natural aggregates that are suitable for construction while in other countries there is an increase in the consumption of aggregates due to the greater demand by the construction industry. 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. Without

[1] Student, Department of Civil Engineering (Mtech Structural), Khaja Banda Nawaz College of Engineering, Gulbarga, India.
[2] Head Of the Department, Department of civil Engineering (Mtech Structural), Khaja Banda Nawaz College of Engineering, Gulbarga, India.

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. Such large consumption of natural aggregates will cause destruction to the environment.

The beneficial use of by-products in concrete technology has been well known for many years and significant research has been published with regard to the use of materials such as coal fly ash, pulverized fuel ash, bottom ash, blast furnace slag and silica fume as partial replacements for Portland cement or as fine aggregate.

Need of Replacement of Natural Resource in Concrete

In concrete, the cement with water forms a binder phase while the aggregate phase is mainly a filler phase which occupies about 75% of volume of concrete of which the fine aggregate is about 28 to 40% of this volume. In concrete construction, usually the prime source of fine aggregate is naturally available river sand which, possess a problem of its non-availability during floods and in rainy reasons as well as due to huge need of construction industry. In order to solve this problem, reliable source and continuous supply of alternative material for these ingredients should be thought of and their use should be recommended. It is essential that this recommended alternative material should be eco-friendly and they should be available at cheaper cost without an interrupted supply on to the construction sites.

Copper Slag

Copper slag is a by-product obtained during the matter smelting and refining of copper. To produce every ton of copper, approximately 2.2-3.0 tons copper slag is generated as a by-product material. Utilization of copper slag in applications such as Portland cement substitution and/or as aggregates has threefold advantages of eliminating the costs of dumping, reducing the cost of concrete, and minimizing air pollution problems. Consequently, conducting researches on the application of these environmental pollutant wastes in the concrete industry is of the most important movement towards sustainable development.

Uses of copper slag

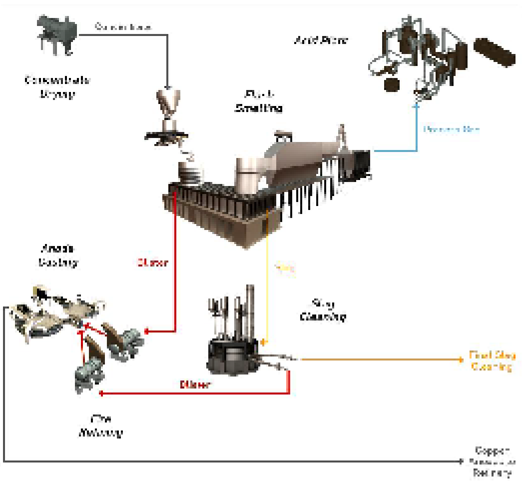
a) Copper slag has also gained popularity in the building industry for use as a fill material.

b) Contractors may also use copper slag in place of sand during concrete constructions.

c) Copper slag can also be used as a building material, formed into blocks.

d) Copper slag is widely used in the sand blasting industry and it has been used in the manufacture of abrasive tools.

Figure 1: Generating process of Copper Slag



e) Copper slag is widely used as an abrasive media to remove rust, old coating and other impurities in dry abrasive blasting due to its high hardness (6-7 Mohs), high density (2.8-3.8 g/cm^3) and low free silica content

LITERATURE REVIEW

The study of copper slag as a sand replacement both in normal and high performance concrete (Khalifa S Al-Jabri *et al*., 2009).

They explains that to examine the use of copper slag as a sand replacement, we have prepared specimens of normal and high performance concrete mixtures with various percentages of copper slag 5%, 20%, 40%,60%, 80%, and 100%. 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% 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% 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 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 (Wei wu *et al*., 2010).

SELECTION OF MATERIALS

Cement

Ordinary Portland Cement (OPC) is by far the most important type of cement. The OPC was classified into three grades, namely 33 grade, 43 grade and 53 grade depending upon the strength of the cement at 28 days when tested as per IS 4031-1988. If the 28 days strength is not less than 33 N/mm^2, 43 N/mm^2 and 53 N/mm^2 it called 43 grade and 53 grade cement, respectively. OPC of 53 Grade from Ultra Tech Cement brand conforming to IS: 8112-1989 and IS 12269-1987 is used in this experimental work. The different property of cement is shown in Tables 1 and 2. It conforms to various standard test as per IS recommendation.

Table 1: Physical Properties of Cement

Particulars	Results
Normal consistency	34%
Initial setting time	30 min
Final setting time	2:42mm
Specific gravity	3.15
Soundness	3 mm exp

Note: Compressive strength of cement for 28 days of curing 55.94N/mm2

Table 2: Properties of Cement Used in Experiment

Properties	Avg. Values of OPC used in current Experimental work	Standard values for OPC
Specific gravity	3.15	-
Consistency (%)	31.5%	-
Initial setting time (min)	48 (min)	>30
Final setting time (min)	225 (min)	<600
Soundness (mm)	2.8	<10
Fineness by Dry Sieving	8%	<10%
Compressive Strength of Cement		
3-days	28.7	>27
7-days	39.63	>37
28-days	55.94	>53

Coarse Aggregate

The aggregate size bigger than 4.75 mm, is considered as coarse aggregate. It can be found from original bed rocks. Coarse aggregate are available in different shape like rounded, Irregular or partly rounded, Angular, Flaky, etc. It should be free from any organic impurities and the dirt content was negligible. There has been a lot of controversy on subject whether the angular aggregate or rounded aggregate will make better concretes. They suggest that if at all the rounded aggregate is required to be used for economical reason it should be broken and then used. Dried angular coarse aggregate of 20 mm maximum size and 10 mm minimum size locally available was used for experimental work. Table 3 shows physical properties of coarse aggregate.

Fine Aggregate

The aggregate size is lesser than 4.75 mm is considered as fine aggregate. The sand particles should be free from any clay or inorganic materials and found to be hard and durable. Silt test is carried out to specify the limits of presence of organic matter and silt in fine aggregates. Table 4 shows physical properties of fine aggregate.

Table 3: Physical properties of Coarse Aggregate

Properties	Average Values
Water absorption	2.03
Fineness Modulus	6.17
Specific Gravity	2.78
Organic matter	Nil

Copper Slag

Copper slag is a by-product material produced from the process of manufacturing copper. As the copper settles down in the smelter, it has a higher density, impurities stay in the top layer and then are transported to a water basin with a low temperature for solidification. The end product is a solid, hard material that goes to the crusher for further processing. Table 5 shows physical properties of copper slag and Figure 2 represent copper slag.

Table 4: Physical Properties of Fine Aggregate

Properties	Average Values
Water absorption	2.52
Fineness Modulus	2.81
Specific Gravity	2.72
Silt content (%)	1.4
Organic matter	Nil

Table 5: Physical Properties of Copper Slag

Properties	Average Values
Water absorption	0.2% to 0.3%
Fineness Modulus	3.41
Specific Gravity	4.0
Bulk density (gm/cc)	2.20

Water

Water is an important ingredient of concrete, as it actively participates in the chemical reaction with cement. Since, it helps to form the strength giving cement gel and required workability to the concrete. The quantity and quality of water is required to be checked very carefully.

Figure 2: Copper Slag

SIEVE ANALYSIS AND MIX PROPORTIONS

The experimental work starts with the sieve analysis. IS specified sieves of varying sizes are used. The details of sieve analysis are shown in Table 6.

Table 7 shows mix proportion for M25 grade concrete used in this experiment.

Table 6: Sieve analysis of Coarse Aggregate, Fine Aggregate and Copper Slag

IS Sieve (mm)	Coarse Aggregates Cumulative% Retained	Fine Aggregates Cumulative% Retained	Copper Slag Cumulative% Retained
20.00	0.9	0.00	0.00
16.00	5.35	0.00	0.00
12.50	18.65	0.00	0.00
10.00	49.25	0.00	0.00
4.75	98.25	1.30	0.20
2.36	100	5.85	5.25
1.18	100	28.32	50.75
0.600	100	57.85	88.55
0.300	100	96.29	96.65
0.150	100	98.80	98.80
Fineness modulus	6.17	2.81	3.40

Table 7: Mix Proportion (Kg/ m³) and Mix Ratio for M25

Water	Cement	Fine Aggregate	Coarse Aggregate
176.8	410.65	539.7	1319.5
0.45	1	1.31	3.20

RESULTS AND DISCUSSION

Fresh Concrete

Workability (Slump Test)

A slump of 25 mm generally provides good workability of concrete. Throughout the project, no more extra amount of water needed to get the slump. Moisture content and absorption of the ingredients were taken into account for calculating the amount of water needed. Table 5.1 shows the measured slump and the amount of water needed to obtain the slump during the project. The water-to-cement ratio was kept at approximately 0.45. From the slump test results it was concluded that the amount of water to obtain the targeted slump in the concrete composites was the equivalent conventional concrete. Also, as the amount of Copper Slag increased, the amount of slump increased. Table 8 shows slump test results and Figure 3 represent slump test.

Table 8: Slump Test

MIX	w/c Ratio	Slump (mm)
Normal M-25	0.45	26
CS 10 %	0.45	28
CS 20 %	0.45	28
CS 30 %	0.45	30
CS 40 %	0.45	32
CS 50 %	0.45	32
CS 60 %	0.45	33
CS 80 %	0.45	34
CS 100 %	0.45	35

Figure 3: Slump test

Hardened Concrete Properties

Once water is added to a concrete mixture, pozzolonic reactions begin to take place that give strength to the concrete. These reactions continue for a long time however, the rate of reactions slows down as curing time increases. Several tests were performed on hardened concrete samples to evaluate the effects of using Copper Slag on hardened properties of the concrete composites. The tests performed on hardened concrete samples included: hardened concrete compression test, split tensile test and Flexural test. The results obtained from these tests are presented in the following sections.

Compressive Strength

Compression tests were performed on samples made during at various curing ages. As discussed earlier, a targeted compressive strength was used for this investigation.

Results from compression strength tests performed are presented in this section. Cube samples of size 150 x 150 x 150 mm, were prepared and tested at 7 and 28, of curing in water under controlled laboratory conditions. Three samples were tested at each curing age. Tables 5.2 and 5.3 shows the average compressive strengths of the concretes tested. Graph 5.1 shows the graphically compression test results.

From the test results, it can be seen that the compressive strength of Copper Slag concrete mixes with 10%, 20%, 30%, 40%, 50%, 60%, 80% and 100% fine aggregate replacement with Copper Slag, were higher than the control mix at all ages. It is evident from Table 5.2 and 5.3 and Graph 5.1, that compressive strength of all mixes continued to increase with the increase in age. From Graph 5.1, it can be seen that there is increase in strength with the increase in Copper Slag percentages; However, from Table 5.2 and 5.3 the highest compressive strength was achieved by 40% replacement of copper slag, which was found about 37.26 N/mm^2 compared with 28.62 N/mm^2 for the control mixture. This means that there is an increase in the strength of almost 30% compared to the control mix at 28 days.

Split Tensile Strength

Samples of size 150 x 300 mm , were prepared and tested for split tensile strength at 28-days of curing. At least 3 samples were tested at each curing age. The average tensile strengths of the concrete composites measured during this phase of the experiment are presented in Table 5.4 and graphically in Graph 5.2. The split tensile strength test results of concrete in Graph 5.2 shows the split tensile strength developed with age has variation of tensile strength with various percentages of Copper Slag. It is evident from Table 5.4, split

Table 9: Compressive Strength @ 7 & 28 Days

Mix proportions	Avg. Load (Tested on 3-Cubes) (tones)	Compressive strength (N/mm^2) @ 7 days	Avg. Load (Tested on 3-Cubes) (tones)	Compressive Strength (N/mm^2) @ 28 days
Nominal mix-M25	41.33	18.01	65.67	28.62
Cs 10%	43.16	18.81	70.16	30.58
Cs 20%	44.16	19.24	74.33	32.39
Cs 30%	45.16	19.68	77.00	33.55
Cs 40%	48.33	21.02	85.50	37.26
Cs 50%	46.00	20.02	78.83	34.35
Cs 60%	44.67	19.46	74.16	32.25
Cs 80%	43.33	18.85	70.16	30.51
Cs 100%	42.50	18.52	68.83	29.94

Table 10: Compressive Strength Gained @ 7 & 28 Days

Mix proportions	Avg. Load (Tested on 3-Cubes) (tones)	Compressive strength (N/mm^2) @ 7 days	Avg. Load (Tested on 3-Cubes) (tones)	Compressive Strength (N/mm^2) @ 28 days
Nominal mix-M25	18.01	——	28.62	———
Cs 10%	18.81	4.45	30.58	6.84
Cs 20%	19.24	6.88	32.39	13.17
Cs 30%	19.68	9.28	33.55	17.25
Cs 40%	21.02	16.71	37.26	30.20
Cs 50%	20.02	11.16	34.35	20.04
Cs 60%	19.46	8.05	32.25	12.92
Cs 80%	18.85	4.66	30.51	6.86
Cs 100%	18.52	2.83	29.94	4.83

Graph 1: Comparative Strength of Compressive Strength of concrete @ 7 & 28 days

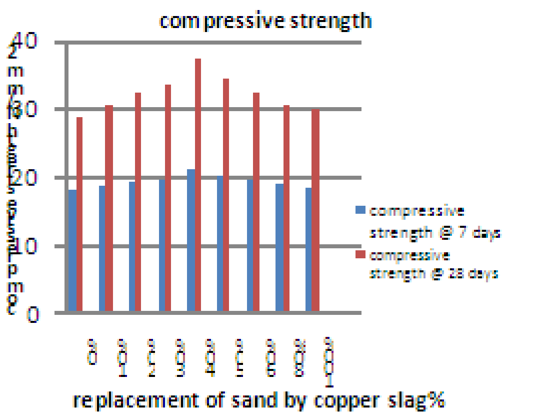


Figure 4: Compression Testing

tensile strength continued to increase with the increase in Copper slag percentages at 28 days, and there is significant increase in strength with that of strength of control mix. Maximum flexural strength is obtained at 40% replacement of copper slag, for 100% replacement results are almost similar to nominal mix.

Flexural Strength

Samples of size 500 x 100 x 100 mm, were prepared and tested for flexural strength at 28-

days of curing. At least 3 samples were tested at each curing age. The average flexural strengths of the concrete composites measured during this phase of the experiment are the flexural strength test results of concrete. In Graph 5.3 shows the flexural strength developed with age has variation of flexural strength with various percentages of Copper Slag. It is evident from Table 5.5. Flexural strength continued to increase with the increase in Copper slag percentages at 28 days, and there is significant increase in strength with that of strength of control mix. Maximum flexural strength is obtained at 40% replacement of copper slag, for 100% replacement results are almost similar to nominal mix.

BEAMS

Beams of size 700 x 150 x 150 mm were tested to determine the flexural strength and crack pattern. Beams designed are both over reinforced and under reinforced. The sand replace by copper slag by proportion 20%, 40%, 60%, 80% and 100%. For under reinforced beam 2-10 mm bar used in compression, 2-10 mm bar used in tension and 6 mm anchor bar at 150 mm. For over reinforced beam 2-10 mm bar used in compression, 2-12 mm in tension and 6 mm anchor bar at 150 mm. Figure 7 and 8 shows beam before and after casting.

The various test results of beams are shown in Tables 13, 14, 15, 16, 17 and 18 and their test results plotted graphs are 5, 6, 7, 8, 9 and 10.

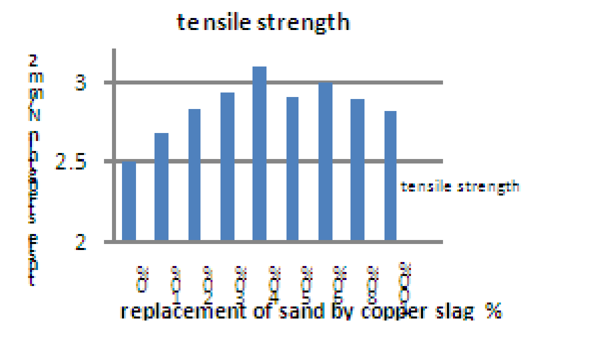
DISCUSSION OF BEAMS

1) The first crack in under reinforced Beam occur at 21.8 TN in control mix. For 20% copper slag @ 28 TN, for 40% copper slag @ 32.5 TN, for 60% 26.5, for 80% copper slag 24.6 TN, for copper slag 100% 23.2 TN.

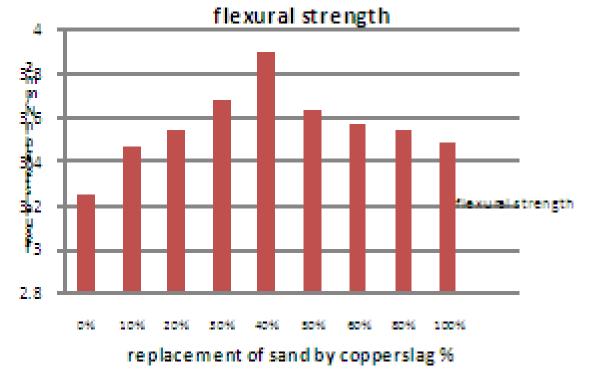
Table 11: Split Tensile Strength @ 28 days

Mix proportions	Avg. Load (Tested on 3-Cubes) (tones)	Tensile Strength (N/mm²)	Strength Gained %
Nominal mix-M25	18.33	2.50	–
Cs 10%	19.58	2.67	6.8
Cs 20%	21.08	2.88	15.2
Cs 30%	21.5	2.93	17.2
Cs 40%	22.25	3.10	24.32
Cs 50%	21.25	2.90	16.00
Cs 60%	22.00	3.00	20.00
Cs 80%	21.6	2.89	15.6
Cs 100%	20.58	2.81	12.4

Graph 2: Split Tensile Strength



Graph 4: Flexural Strength



Graph 3: Split Tensile Testing

Figure 5: Flexural Test on Prism Before Cracking

Table 12: Flexural strength @ 28 days

Mix proportions	Avg. Load (Tested on 3-Cubes) (tones)	Tensile Strength (N/mm^2)	Strength Gained %
Nominal mix-M25	0.830	3.25	–
Cs 10%	0.885	3.47	6.76
Cs 20%	0.905	3.54	8.92
Cs 30%	0.939	3.68	13.23
Cs 40%	0.996	3.90	20.00
Cs 50%	0.926	3.63	11.69
Cs 60%	0.912	3.57	10.98
Cs 80%	0.904	3.54	8.92
Cs 100%	0.888	3.48	7.07

Figure 6: Prism After Cracking

Figure 7: Beams Before casting

Figure 8: Beams After casting

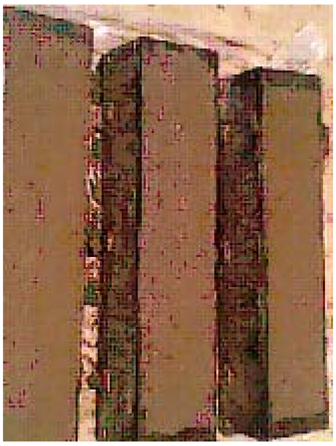
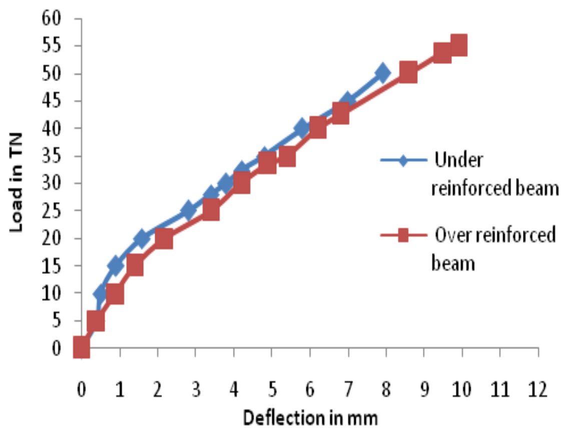


Table 13: Test Results of RCC Beams (Conventional concrete of grade M 25)

Under Reinforced Beam		Over Reinforced Beam	
Load (TN)	Deflection (mm)	Load (TN)	Deflection (mm)
0	0	0	0
5	0.3	5	0.3
10	0.4	10	0.8
15	0.7	15	1.2
20	1.2	20	1.6
21.8*	1.6	23.4*	2.1
25	2.8	25	2.5
27**	3.1	29**	3.3
30	3.4	30	3.5
35	4.5	35	4.8
39.8**	4.9	40	5.5
40	5.1	43.6**	6.2
		45	6.8

Note: * first crack. ** Ultimate crack.

Graph 5: Load vs deflection curve for convenient concrete copper slag of Grade M25



Graph 6: Load vs deflection curve for 20% copper slag beams of Grade M25

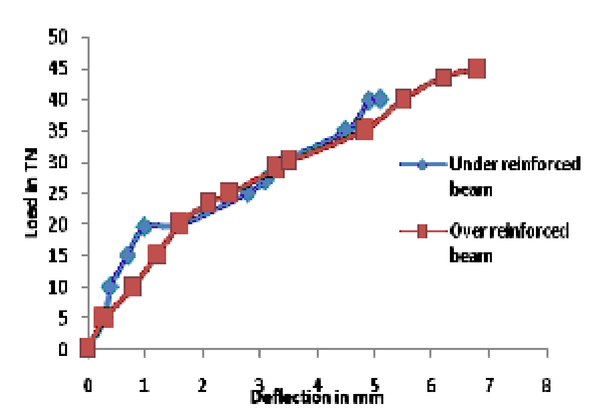


Table 14: Test results of RCC beams (Replacement of sand by copper slag 20%)

Under Reinforced Beam		Over Reinforced Beam	
Load (TN)	Deflection (mm)	Load (TN)	Deflection (mm)
0	0	0	0
5	0.4	5	0.4
10	0.5	10	0.9
15	0.9	15	1.4
20	1.6	20	2.2
25	2.8	25	3.4
28*	3.4	30	4.2
30	3.8	33.6*	4.9
32.4**	4.2	35	5.4
35	4.8	40	6.2
40	5.8	42.6**	6.8
44**	6.8	45	7.6
45	7.0	50	8.6
50	7.9	53.8**	9.5
		55	9.9

Table 15: Test results of RCC beams (Replacement of sand by copper slag 40%)

Under Reinforced Beam		Over Reinforced Beam	
Load (TN)	Deflection (mm)	Load (TN)	Deflection (mm)
0	0	0	0
5	0.4	5	0.5
10	0.6	10	0.8
15	0.9	15	1.2
20	1.6	20	1.9
25	2.7	25	2.8
30	3.8	30	4.1
32.5*	4.3	35	5.2
35	4.8	37.6*	5.8
40	5.9	40	6.4
43.6**	6.3	45	7.4
45	6.7	47.2**	7.9
50	7.6	50	8.5
55	8.7	55	9.6
58.3**	9.3	60	10.6
60	9.8	63.9**	11.2

Graph 7: Load vs deflection curve for 40% copper slag beams of Grade M25

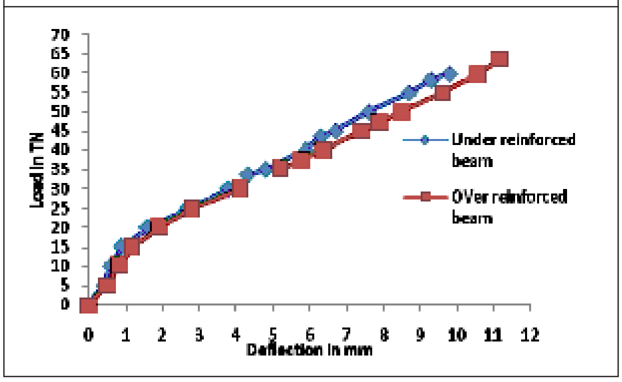


Table 16: Test results of R.C.C beams (Replacement of sand by copper slag 60%)

Under Reinforced Beam		Over Reinforced Beam	
Load (TN)	Deflection (mm)	Load (TN)	Deflection (mm)
0	0	0	0
5	0.4	5	0.4
10	0.5	10	0.5
15	0.9	15	1.0
20	1.9	20	2.1
25	2.8	25	2.8
26.5*	3.1	28.5*	3.7
30	3.8	30	3.9
34**	4.5	34.8**	4.7
35	4.7	35	4.9
40	5.6	40	5.9
45	6.7	45	6.9
48**	7.4	47.6**	7.7
50	7.9	50	8.2
55	9.0	55	9.4

Graph 8: Load vs deflection curve for 60% copper slag beams of Grade M25

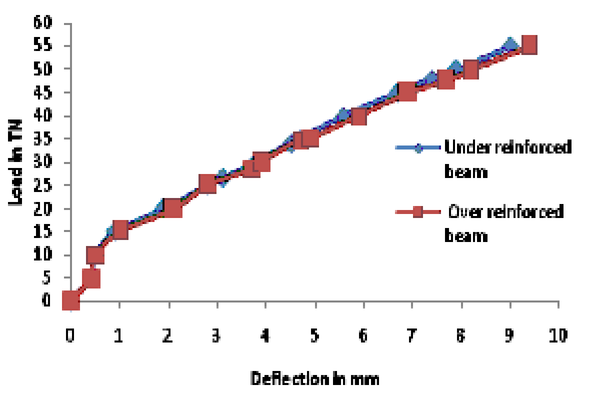


Table 17: Test results of R.C.C beams (Replacement of sand by copper slag 80%)

Under Reinforced Beam		Over Reinforced Beam	
Load (TN)	Deflection (mm)	Load (TN)	Deflection (mm)
0	0	0	0
5	0.3	5	0.3
10	0.9	10	0.8
15	1.2	15	1.2
20	1.8	20	1.9
24.6*	2.5	23.4*	2.4
25	2.7	25	2.8
30	3.6	30	3.3
33.8**	4.1	34.6**	3.9
35	4.4	35	4.2
40	5.3	40	5.2
41.4**	5.6	43.8**	6.1
45	6.4	45	6.7
50	7.4	50	7.8

Graph 9: Load vs deflection curve for 80% copper slag beams of Grade M25

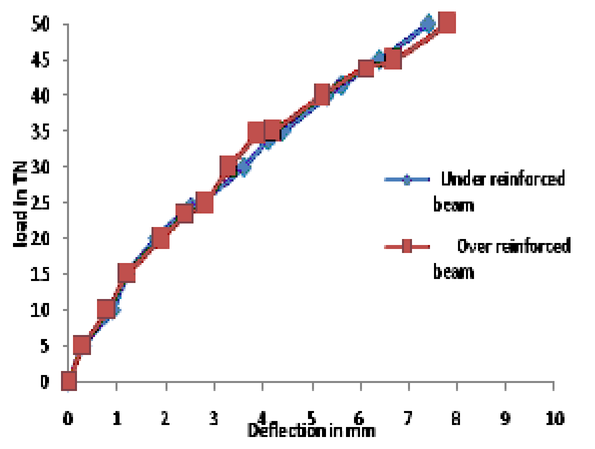
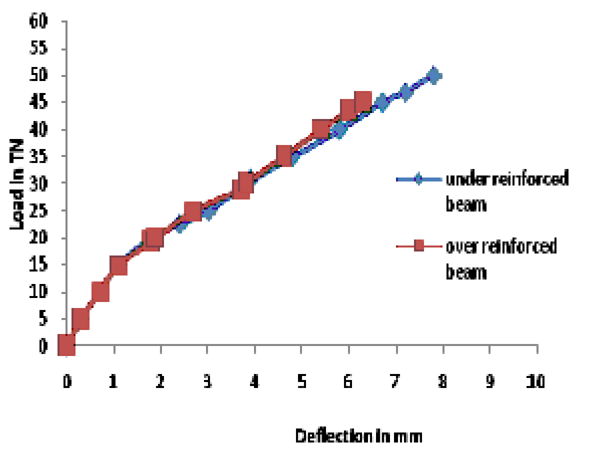


Table 18: Test results of R.C.C beams (Replacement of sand by copper slag 100%)

Under Reinforced Beam		Over Reinforced Beam	
Load (TN)	Deflection (mm)	Load (TN)	Deflection (mm)
0	0	0	0
5	0.3	5	0.3
10	0.7	10	0.7
15	1.1	15	1.1
20	1.8	19.4*	1.8
23.2*	2.5	20	1.9
25	3.0	25	2.7
30	3.8	29**	3.7
30.8**	3.9	30	3.8
35	4.8	35	4.6
40	5.8	40	5.4
45	6.7	43.6**	6.0
47**	7.2	45	6.3
50	7.8		

Graph 10: Load vs Deflection Curve for 100% Copper Lag



2) The first crack in over reinforced Beam occur at 23.4 TN in control mix. For 20% copper slag @ 33.6TN, for 40% copper slag @ 37.6 TN, for 60% 28.5, for 80% copper slag 23.4 TN, for copper slag 100% 19.6 TN.

3) The flexural strength of the beam increased by 6% to 49% while replacement of copper slag.

CONCLUSION

1) As the percentage of Copper Slag in concrete mix increases, the workability of concrete increases. This is because copper slag is unable to absorb the water in large proportion.

2) Maximum Compressive strength of concrete for a replacement of fine aggregate by 40%

3) It is observed that, the split tensile strength of concrete @ 28 days is higher for 40% of fine aggregate by copper slag. The split tensile strength is increased by 24%. Also split tensile strength is more than control mix in all percentage replacement.

4) It is observed that, the flexural strength of concrete at 28 days is higher than design mix (Without replacement) for 40% replacement of fine aggregate by Copper slag, the flexural strength of concrete is increased by 20%. This also indicates flexural strength is more for all percentage replacements that design mix.

5) The beam at 40% replacement of fine aggregate by copper slag shows high flexural strength and crack pattern.

REFERENCES

1. Al-Jabri K S, Taha R A, Al-Hashmi A, Al Harthy A S (2006), "Effect of copper slag and cement by-pass dust addition on mechanical properties of concrete", *Construction and Building Materials, Vol.* 20, pp. 322–331.
2. Alp H and Deveci H Sungun (2008), "Utilization of flotation wastes of copper slag as raw material in cement production", *Journal of Hazardous Materials*, Vol. 159, pp. 390-395.
3. Brinda D, Baskaran T and Nagan S (2010), "Assessment of Corrosion and Durability Characteristics of Copper Slag Admixed Concrete", *International journal of civil and structural engineering,* Vol. 1, No. 2, pp. 192 – 211
4. Khalifa S Al-Jabri, Makoto Hisada, Abdullah H. Al-Saidy S K. Al-Oraimi (2009), "Performance of high strength concrete made with copper slag as a fine aggregate", *Construction and Building Materials*, Vol. 23, pp. 2132–2140.
5. Khalifa S Al-Jabri, Abdullah H Al-Saidy, Ramzi Taha (2011), "Effect of copper slag as a fine aggregate on the properties of cement mortars and concrete", *Construction and Building Materials,* Vol. 25, pp. 933–938.
6. Meenakshi Sudarvizhi. S, Ilangovan. R, "Performance of Copper slag and ferrous slag as partial replacement of sand in Concrete", *International journal of civil and structural engineering, 2011, Volume 1*, pp. 918 – 927.
7. Najimi M, Sobhani J and Pourkhorshidi A R (2011), "Durability of copper slag contained concrete exposed to sulfate attack", *Construction and Building Materials,* Vol. 25, pp. 1895–1905
8. Wei Wua, Weide Zhang and Guowei Maa (2010), "Optimum content of copper slag as a fine aggregate in high strength concrete", *Materials and Design,* Vol. 31, pp. 2878–2883.