An Experimental Investigation Of Properties Of Concrete With Partial Or Full Replacement Of Fine Aggregates Through Copper Slag

Amit S. Kharade[1], Sandip V. Kapadiya[2], Ravindra Chavan[3]

[1] Assistant Professor, Department of Civil Engineering, TKIET Warana, INDIA
[2]Assistant Professor, Department of Civil Engineering, GTU, Ahmadabad, INDIA
[3]Post Graduate Student, Department of Civil Engineering, RIT, Sakharale, INDIA

Abstract

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. So, this paper presents the results of an experimental investigation carried out to evaluate the mechanical properties of concrete mixtures in which fine aggregate (sand) was replaced with Copper Slag. 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 and Flexural strength were determined at 7, 28 and 56days. 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 80% Copper slag as replacement of fine aggregate (sand), and can be effectively used in structural concrete. Also as percentage of Copper Slag increased the density of concrete increased. The workability of concrete increased with increase in percentage of copper slag. Toughness of copper slag is found to be more, which increases the compressive and flexural strength of concrete.

Keywords: Copper Slag, Concrete, Compressive strength, Fine Aggregate, Flexural strength, Replacement etc

1. 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 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.

1.1 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. On Indian scenario it is observed that at very few places good quality of sand may be available in plenty. All metro and mega cities in India are facing acute shortages of good quality of sand. At some places sand available is coarser than Zone I sand and hence not suitable for construction work.

1.2 Copper Slag

Copper slag is a by-product obtained during the matte 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.

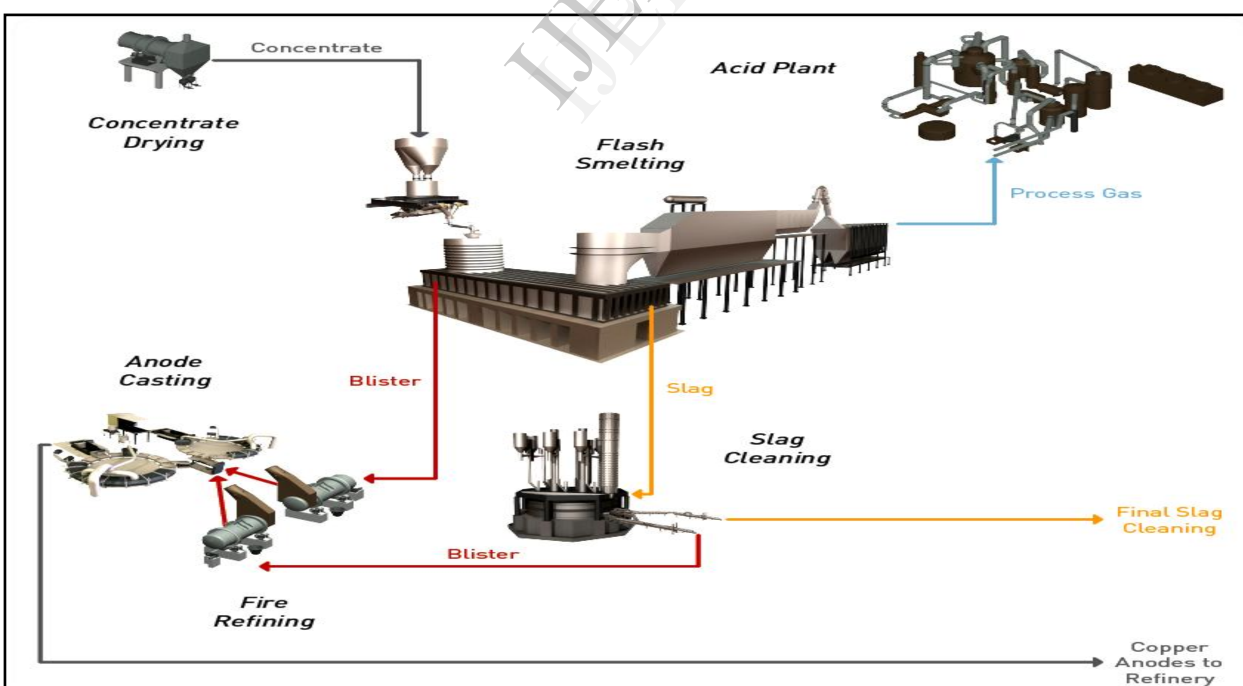
1.3 Uses of copper slag

Copper slag is widely used in the sand blasting industry and it has been used in the manufacture of abrasive tools. In general, the spent copper slag is suitable to be used as a fill material for land reclamation. 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/cm3) and low free silica content.

2 Selections of Materials

2.1 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 33N/mm^2, 43N/mm2 and 53 N/mm^2 it called 43 grade and 53 grade cement respectively. Ordinary Portland cement 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 Table 2.1. It conforms to various standard test as per IS recommendation
.



“**Figure 1.1** Process of generation of Copper Slag (www.google.com)

"**Table 2.1** 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

2.2 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. It was stored in open space free from dust and water. In our experiment fine aggregate can be found from bed of *Tapi River*. It conforms to IS 383 1970 comes under zone II.
Physical properties of a used fine aggregates workout in Table 2.2

"**Table 2.2** Physical properties of Fine Aggregate"

Properties	Average values
Water absorption	2.52
Fineness Modulus	2.80
Specific Gravity	2.76
Silt content (%)	1.4
Organic matter	Nil

2.3 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. But the angular aggregate are superior to rounded aggregate from following two points.

1. It exhibits a better interlocking effect in concrete.
2. The total surface area of rough textured angular aggregate is more than smooth rounded aggregate for the given volume.

Dried angular coarse aggregate of 20 mm maximum sized and 10 mm minimum size locally available was used for experimental work.
Physical properties of a used coarse aggregates workout in Table 2.3

"**Table 2.3** Physical properties of Coarse Aggregate"

Properties	Average values
Water absorption	2.03
Fineness Modulus	6.67
Specific Gravity	2.86
Organic matter	Nil

2.4 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. Portable water is used in concrete

2.5 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. Copper slag used in this work was brought from Birla Copper (The details are specify in references), the nature of copper slag used in experimental work shown in fig. 2.1.
Physical properties of copper slag workout in table 2.4

"Figure 2.1 Grinded copper slags from industry"

"**Table 2.4** Physical properties of Copper Slag"

Properties	Average values
Water absorption	0.2% to 0.3%
Fineness Modulus	3.38
Specific Gravity	4.0
Bulk density (gm/cc)	2.20

2.6 Chemical Composition of Cement and Copper slag

"Table 2.5 Composition of OPC and Copper"

Component	OPC	Copper Slag
SiO_2	20.85	33.05
Al_2O_3	4.78	2.79
Fe_2O_3	3.51	53.45
Cao	63.06	6.06
MgO	2.32	1.56
SO_3	2.48	1.89
K_2O	0.55	0.61
Na_2O	0.24	0.28
TiO_2	0.25	0.00
Mn_2O_3	0.05	0.06
CI	0.01	00.01
Loss on Ignition	1.75	0.00

3. Experimental work

3.1 Sieve Analysis

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 3.1

3.2 Mix design and sample preparation

1] Concrete mixtures

Concrete mixtures with different proportions of Copper slag used as a partial or full substitute for fine aggregates were prepared in order to investigate the effect of Copper slag substitution on the strength of normal concrete. Concrete mixtures were prepared with different proportions of Copper slag. The proportions (by weight) of Copper slag are added to concrete mixtures as follows,
0% (for the control mix), 10%, 20%, 30%, 40%, 50%, 60%, 80%, and 100%, the control mixture (with 0% Copper slag and 100% sand) was designed to have a target 28 day compressive strength of 30 N/mm^2 (M-30), using a water-to-cement ratio of 0.48. The mix proportion chosen for this study is given in Table 3.2

"Table 3.1 Sieve Analysis of fine, Coarse Aggregate, and Copper Slag."

IS Sieve (mm)	Coarse Aggregates	Fine Aggregates	Copper Slag
	Cumulative % Retained	Cumulative % Retained	Cumulative % Retained
20.00	0.7	0.00	0.00
16.00	4.15	0.00	0.00
12.50	15.85	0.00	0.00
10.00	48.75	0.00	0.00
4.75	97.25	1.17	0.20
2.36	100	5.68	4.75
1.18	100	28.14	50.65
0.600	100	57.07	88.25
0.300	100	95.39	96.15
0.150	100	98.68	98.00
FM	**6.67**	**2.8**	**3.38**

Note – FM – Fineness Modulus

"**Table 3.2** M 30 Mix proportions (Kg/m 3) and Mix ratio"

Cement	Fine Aggregate	Coarse Aggregate	Water
435	575	1216	208.8
1	1.32	2.79	0.48

ISSN: 2278-0181
Vol. 2 Issue 3, March - 2013

2] Sample Preparation

The samples were prepared in accordance with the IS standard relevant to each test. Table 3.3 samples for the tests. Cubes samples were used for compression testing and Rectangular moulds were used to prepare samples for flexural testing, these are shown in fig. 3.1 The specimens were prepared by two methods. First one is a tamping method and second one is a vibratory method. The tamping method consisted of filling the moulds in three layers, tamping each layer 25 times following by tamping the side of the mould 10 times. The vibratory method used, consists of use of a vibratory table and filling the moulds in two equal layers with each layer being vibrated for approximately 5 seconds as per IS standard. After this each sample was allowed to harden for a period of 24 ± 1 hour, the samples were removed from the moulds and placed into large curing tanks for curing.

"Figure 3.1 Steel cubes and moulds used in current experimental work"

"**Table 3.3**Sizes and Types of Moulds Used testing in experimental work in laboratory

Type of Test	Sample Type	Sample Size (mm)
Compression Test	Cube	150 × 150 × 150
Flexural Test	Rectangular	500 × 100 × 100

3] Curing Method

The strength of concrete is directly related to the curing age. Curing time is the time required under certain conditions to gain strength. Concrete continues to gain strength, with time, depending on curing conditions. The samples prepared were allowed to harden in the moulds for 24 ± 1 hour, and then removed from their moulds. The samples were then placed into large curing tanks, containing tap water kept at a constant temperature of 23 ± 3°C (73 ± 3°F) as per IS 456-2000 clause no.13.5 Curing.

At predetermined curing ages, different samples were removed from the tanks and tested for various properties. Compression testing was performed at curing ages of, 7, 28and 56-days and Flexural strength was tested at 28-days of curing.
Fig.3.2 displays some of the cubes and rectangular beams are put in water tank for curing purpose.

"**Figure 3.2** Curing tank with cubes and beams"

3.3 Testing Procedures

This paper entailed subjecting the designed concrete mixes to a series of tests to evaluate the strength, and other properties. For this experiment, it was important to monitor the strength development with time to adequately evaluate the strength of each concrete mix. For each test, 3 samples from each mix were tested at each curing age, and the average values were used for analysis. The following sections present the procedures used for the various tests.

1] Fresh Concrete Workability Test (Slump Test)

One of the initial concrete properties evaluated was the slump of the concrete. The slump directly relates to the workability of a concrete mix. The slump test was performed in general accordance with IS standard 456-2000 Clause no. 7.Before the test, the cone, base, and funnel were moistened lightly with oil to reduce friction between the apparatus and the fresh concrete. The funnel was placed on top of the cone and the cone was attached to the base with clamps. Once the apparatus had been prepared, the cone was filled in 3 layers with each layer tamped 25 times. Once the final layer had been tamped, the concrete was levelled at the top of the cone by using a trowel. The clamps were released and the cone was slowly pulled upward. After the cone was removed, the concrete in the cone settled, a ruler was used to measure the distance from the bottom of the handle (the same as the top of the cone when clamped) to the top of the concrete. The distance was recorded as the slump of the concrete.

ISSN: 2278-0181
Vol. 2 Issue 3, March - 2013

2] Compression Strength Test

One of the most important properties of concrete is the measurement of its ability to withstand compressive loads. This is referred to as a compressive strength and is expressed as load per unit area. One method for determining the compressive strength of concrete is to apply a load at a constant rate on a cube (150×150×150 mm), until the sample fails. The compression tests performed in this project were completed in accordance with IS standard 516 "Methods of Tests for Strength of Concrete". The apparatus used to determine the compressive strength of concretes in this experimental work was a universal testing machine (UTM). This machine is operated by hydraulics with a digital display monitoring the rate of loading and the peak load at the time of failure of the sample. The strain rate can be manually controlled by turning a valve either clockwise or counter clockwise. Fig. 3.3 shows the machine used for performing compression test. For this study samples were tested for compression testing at 7, 28, 56 days of curing. The compressive strength of the concrete in terms of pressure was then calculated using the Equation:

$$f_c = \frac{P}{A} \quad (1)$$

Where,
fc = Compressive Strength of Concrete, (Kpa or psi)
P = Maximum load applied (KN or lb), and
A = The cross-sectional area of sample (mm^2 or in^2)

"Figure 3.3 Compression Testing Machine"

3] Flexural Strength Test

Another important strength property of concrete is the flexural strength of a concrete. Samples were tested for flexural strength at 28 days of curing.
The testing machine apparatus used to measure the flexural strength of concrete in this experimental work is operated by hydraulics and has dial gauge displays for monitoring the rate of loading and the peak load on the sample at the time of failure. The strain rate was manually controlled by turning a knob either clockwise or counter clockwise. Fig. 3.4 shows the machine used for this test.
The flexural strength tests were performed in general accordance with IS standard 516 "Methods of Tests for Strength of Concrete" Third point loading entails subjecting a beam sample to a loading condition which ensures that no shear stresses in the middle third of the sample between the two loading points. The sample experiences pure bending forces in this region

"Figure 3.4 Flexural Strength Testing Machine"

To perform this test, each beam was measured and marked at the points of loading to ensure even loading on the sample. Lines were drawn at 2.5, 17.5, 32.5, and 47.5 from one end, to help placement of the sample in the proper position. The loading heads were cleaned and lowered onto the starting position and all gauges were zeroed. A static load was applied with a constant rate until failure occurred. The peak load was obtained from the digital display and recorded.
The flexural strength was then calculated using Equation:

$$f_{cr} = \frac{Pl}{bd^2} \quad (2)$$

Where,
f_{cr}= Flexural Strength of Concrete, (kpa or psi)
P = Maximum load applied (KN or lb),
l= Length of the specimen between the supports in (mm or in),
b = Width of the beam (mm or in), and
d = Depth of the beam (mm or in)

3.4 Specimen details used in experimental work

The details of cubes and beams required in the experimental work with replacement of fine aggregate by copper slag are listed in Table 3.4

"Table 3.4 Specimen Details of the work in laboratory"

Description	Compressive strength test	Flexural strength test
Specimen	Cubes	Beams
Size	150×150×150 mm	100×100×50 mm
No of specimens	3	3
Days of testing	7, 28 and 56	28
Total no of specimens for one series	9	3
Vol. of each specimen (m^3)	0.003375	0.015
Vol. of all specimen (m^3) for one series	0.030375	0.045
Total specimens for all series	72	24
Total vol. for all series (m^3)	0.243	0.36
Total vol. of concrete	0.600 + 0.075 (Normal) = 0.678	

4. Tests and Results

The different tests conducted in laboratories are shown in fig. 4.1 to fig. 4.3 It consist mixing of concrete in the laboratory by replacing Copper Slag as fine aggregate with proportions (by weight) of Copper Slag added to concrete mixtures were as follows: 0% (for the control mix), 10%, 20%, 30%, 40%, 50%, 60%, 80%, and 100%. Concrete samples were prepared and cured in the laboratory, and are tested, to evaluate the concrete fresh and harden properties like workability of concrete, compressive strength and flexural strength requirements.

"Figure 4.1 Measurement of Slump of concrete mix"

"Figure 4.2 Compressive strength tests for Cube"

"Figure 4.3 Flexural strength tests for beam"

4.1 Fresh Concrete Workability (Slump Test)

A slump of 25mm 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 4.1 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 0.48. 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 4.1** Workability Test (Slump Test)"

MIX	w/c ratio	Slump (mm)
Normal M-30	0.48	25
CS 10 %	0.48	25
CS 20 %	0.48	26
CS 30 %	0.48	28
CS 40 %	0.48	30
CS 50 %	0.48	30
CS 60 %	0.48	32
CS 80 %	0.48	33
CS 100 %	0.48	35

Note - CS = Copper Slag

4.2 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 and Flexural test. The results obtained from these tests are presented in the following sections.

4.2.1 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, 28, and 56-days of curing in water under controlled laboratory conditions. 3 samples were tested at each curing age. Tables 4.2 show the average compressive strengths of the concretes tested. Fig. 4.2 and 4.3 graphically display the compressive strength of concrete composites tested. Table 4.3 shows the total strength gained by concrete with content of different proportions of copper slag.

"**Table 4.2** Compressive strengths test result"

MIX	Compressive strength (Mpa)		
	7 days	28 days	56 days
Normal M-30	26.97	38.27	38.27
CS 10 %	30.73	40.97	39.10
CS 20 %	36.33	48.13	49.37
CS 30 %	33.27	40.83	45.47
CS 40 %	28.43	38.80	44.43
CS 50 %	28.87	39.43	44.90
CS 60 %	29.53	43.33	45.17
CS 80 %	28.01	35.17	38.43
CS 100 %	22.30	32.07	35.70

"**Table 4.3** Compressive strengths test result"

MIX	7 Days	Strength Gained at 7 days	28 days	Strength Gained at 28 days
Normal	26.97	100.00	38.27	100.00
CS-20%	36.33	134.73	48.13	129.01
CS-40%	28.43	105.44	38.80	116.11
CS-60%	29.53	109.52	43.33	118.03
CS-80%	28.01	103.83	35.17	100.44
CS-100	22.30	082.69	32.07	093.29

From the test results, it can be seen that the compressive strength of Copper Slag concrete mixes with 10%, 20%, 30%, 40%, 50%, 60%, and 80% fine aggregate replacement with Copper Slag, were higher than the control mix at all ages. It is evident from Table 4.3 and Fig.4.6, that compressive strength of all mixes continued to increase with the increase in age. From Fig. 4.6, it can be seen that there is increase in strength with the increase in Copper Slag percentages; However, from Table 4.3 the highest compressive strength was achieved by 20% replacement of copper slag, which was found about 36.33 Mpa compared with 26.97 Mpa for the control mixture. This means that there is an increase in the strength of almost 34% compared to the control mix at 7 days. However, mixtures with 100% replacement of copper slag gave the lowest compressive strength 22.30 Mpa which is almost 17% lower than the strength of the control mix.

4.2.2 Flexural Strength

Samples of size 500 x 100 x 100mm, 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 presented in Table 4.4 and graphically in Fig.4.4

“**Table 4.4** Flexural Strengths of Concrete at 28 days

Mix Proportions	Flexural Strength (Mpa)
Normal – M30	4.19
CS – 10 %	4.32
CS – 20 %	4.81
CS – 30 %	4.35
CS – 40 %	4.40
CS – 50 %	4.50
CS – 60 %	4.28
CS – 80 %	4.22
CS – 100%	4.20

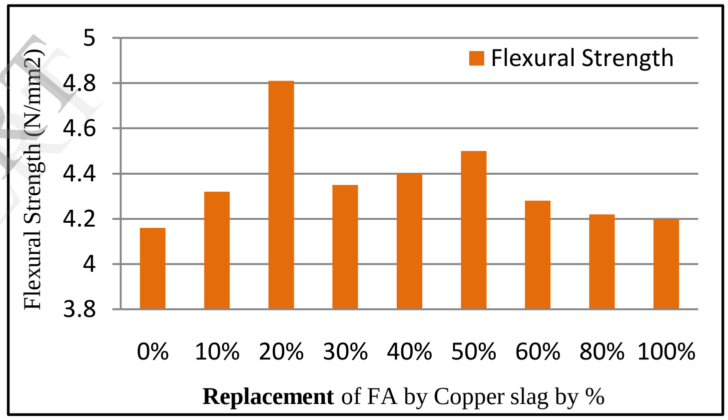
The flexural strength test results of concrete in Fig. 4.4 shows the flexural strength developed with age has variation of flexural strength with various percentages of Copper Slag. It is evident from Table 4.4. Flexural strength continued to increase with the increase in Copper slag percentages at 28 days, and there is significant increase in strength with that of strength of control mix. Maximum flexural strength is obtained at 20% replacement of copper slag, for 100% replacement results are almost similar to nominal mix.

4.2.3 Density

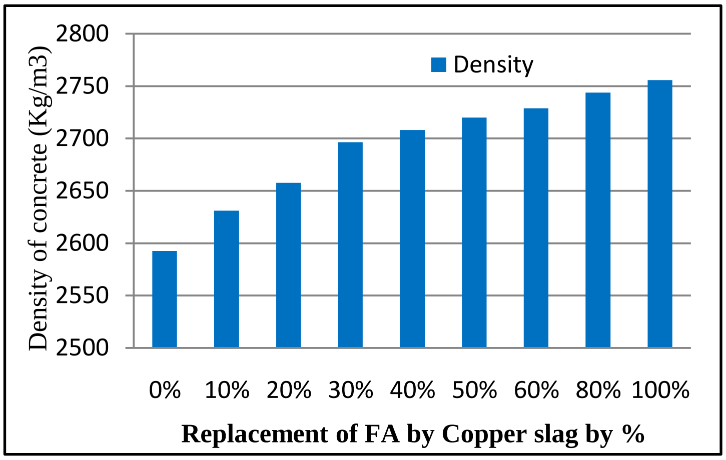
The density of hardened concrete at saturated-surface dried condition was measured at the age of 28 days. From the results in Table 4.5, it can be seen that the density of hardened concrete increased with the increase of the Copper Slag as sand content. This is due to the higher specific gravity of the Copper Slag, which was 4.0 compared to 2·72 of the natural sand. However, compared with the large difference in the specific gravity of the Copper Slag and the natural sand, it increased density of concrete. Fig.4.5 graphically presents the density graph.

“**Table 4.5** Densities of Concrete at 28 days

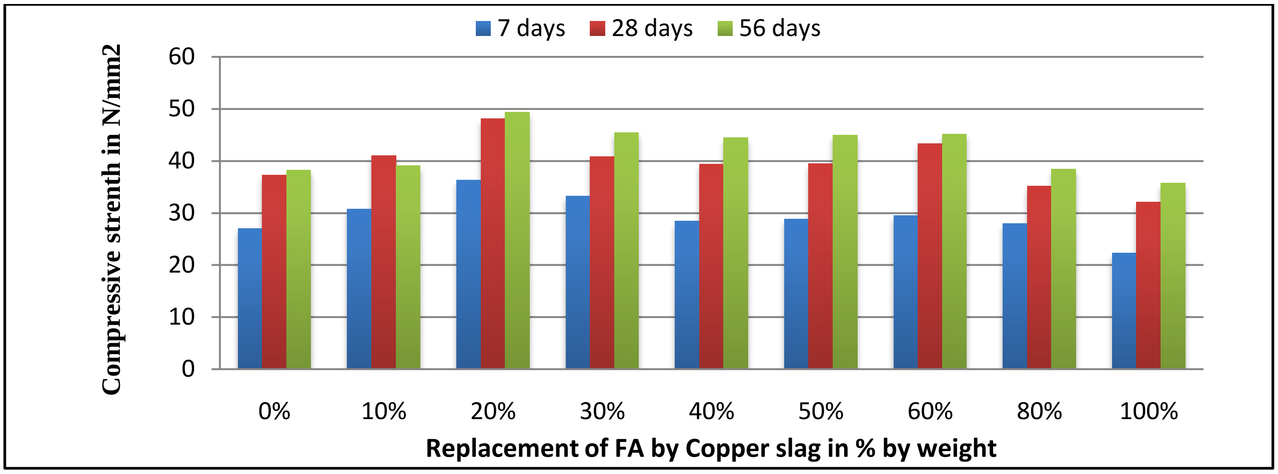
Mix Proportions	Density (Kg/m^3)
Normal – M30	2592.59
CS – 10 %	2631.11
CS – 20 %	2657.78
CS – 30 %	2696.30
CS – 40 %	2708.15
CS – 50 %	2720.00
CS – 60 %	2728.89
CS – 80 %	2743.70
CS – 100%	2755.56



“**Figure 4.4** Flexural strength results of beams”



“**Figure 4.5** Density of concrete at 28 days”



"Figure 4.6 Comparative results of compressive strength of concrete at 7, 28 and 56 days"

5. Conclusions

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 20% of copper slag increased by 34% at 7 days and increased by 29% at 28 days. Similar increase is observed at 56 days strength.
3) Replacement of copper slag up to 80% will increase the strength of design mix, but beyond 80% replacement the strength started to reduce. The strength at 100 % replacement is reduced by 7% at 28 days.
4) It is observed that, the flexural strength of concrete at 28 days is higher than design mix (Without replacement) for 20% replacement of fine aggregate by Copper slag, the flexural strength of concrete is increased by 14%. This also indicates flexural strength is more for all percentage replacements than design mix.
5) Compressive strength and Flexural strength was increased due to the high toughness property of Copper slag.
6) 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 7% when replacement of Fine aggregate by 100% copper slag. This is because weight of concrete increases with copper slag.

6. References

[1] Al-Jabri K.S., Taha R.A., Al-Hashmi A., Al Harthy A.S.,"Effect of copper slag and cement by-pass dust addition on mechanical properties of concrete", *Construction and Building Materials,2006, Volume no. 20*, pp.322–331.

[2] Alp, H. Deveci, H. Sungun, "Utilization of flotation wastes of copper slag as raw material in cement production", *Journal of Hazardous Materials,*2008, *Volume no. 159,* pp.390–395.

[3] Brindha D., Baskaran.T, Nagan.S, "Assessment of Corrosion and Durability Characteristics of Copper Slag Admixed Concrete", *International journal of civil and structural engineering,2010, Volume 1, No 2*, pp.192 - 211

[4] Khalifa S. Al-Jabri , Makoto Hisada , Abdullah H. Al-Saidy , S.K. Al-Oraimi, "Performance of high strength concrete made with copper slag as a fine aggregate", *Construction and Building Materials, 2009 , Volume no. 23*, pp.2132–2140.

[5] Khalifa S. Al-Jabri, Abdullah H. Al-Saidy, Ramzi Taha, "Effect of copper slag as a fine aggregate on the properties of cement mortars and concrete", *Construction and Building Materials, 2011,* Volume no.25, pp.933–938.

[6] M. Najimi, J. Sobhani, A.R. Pourkhorshidi,, "Durability of copper slag contained concrete exposed to sulfate attack", *Construction and Building Materials, 2011, Volume no.25,* pp. 1895–1905

[7] 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

[8] Wei Wua, Weide Zhang a, Guowei Maa,, "Optimum content of copper slag as a fine aggregate in high strength concrete", *Materials and Design, 2010, Volume no. 31*, pp. 2878–2883