International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 09, September-2018

STRENGTH AND DURABILITY PROPERTIES OF M30 GRADE CONCRETE ON REPLACING FINE AGGREGATE WITH COPPER SLAG

[1] Shaik Raheem, [2] Dr. K. Srinivasa Rao

[1] *M.Tech, Department Of Civil Engineering, Andhra University College of Engineering, Visakhapatnam, India.*
[2] *Associate Professor, Department of Civil Engineering, Andhra University College of Engineering, Visakhapatnam, India*

Abstract: In this present project work, M30 grade of concrete was used as reference mix. The fine aggregate is replaced with percentages 0% (for conventional concrete mixture), 30%, 40% and 50% of copper slag by weight and optimum dosage is found out for 7 and 28 days. Compressive strength, flexural strength and split tensile strength were determined at the age of 1, 3, 7, 28, 56 and 91 days respectively. The durability of concrete was also tested by subjecting the specimens to temperatures of 27, 100, 200, 300, 400 and 500^{o}C for durations of 1, 2 and 3 hours respectively.

Keywords: M30, Copper slag, optimum dosage, compressive strength, split tensile strength, flexural strength, durability, temperatures.

1. Introduction

Natural resources are depleting worldwide while at the same time the generated wastes from the industries are increasing substantially. The sustainable development for construction involves the use of non-conventional and innovative materials such as recycling of waste materials and using them in order to compensate the lack of resources and conserve environment by finding alternative materials. Copper slag is one of the waste materials which can be used in construction industry as partial replacement of fine aggregate i.e (river sand). The proper disposal as well as management of the copper slag is required to make the environment pollution free. Therefore, reusing it helps in the protection of our surroundings as well as in a stable management of waste materials. There are various uses of copper slag which include its use in blended cement, in replacement of cement and sand, in production of cement clinker. It is resistant for corrosion and also used as infill to stabilize expansive soils. It has been used in abrasive tools, in roofing granules in tiles and glass manufacturing. Copper slag is also used in pavements as an aggregate.

2. Literature Review

Patil et al (2013) studied properties and effects of copper slag in concrete. His work states that as percentage of copper slag concrete increases workability increased. Maximum compressive strength of concrete increases by 34% at 20% replacement of fine aggregate and up to 80% replacement concrete has more strength than normal concrete strength. Compressive and flexural strength increases due to high toughness of copper slag concrete. As percentage of copper slag concrete increases the density of concrete increases. His work also concluded that replacement of copper slag concrete in fine aggregate reduces cost of making of concrete.

Tamil Selvi P et al (2014): In this project work, the concrete grade M40 was selected and IS method was used for mix design. The various strengths of concrete like compressive, flexural and split tensile were studied and non-destructive tests such as rebound hammer test and Ultra sonic pulse velocity test were studied for the replacements of 0%, 20%, 40%, 60%, 80% and 100%. The maximum compressive strength of concrete attained at 40% replacement of fine aggregate at 7 and 28 days. The split tensile and flexural strength were also obtained higher strength at 40% replacement level at 28 days. The rebound hammer strength and pulse wave velocity test is higher for the 40% replacement of fine aggregate with copper slag.

Arivalagan (2015) Investigated the effects of replacing fine aggregates by copper slag concrete on the compressive strength of cubes, split tensile strength of cylinders and flexural strength of beams are evaluated in this study. Copper slag was obtained as waste product from the sterlite industries. Investigations were carried out to explore the possibility of using copper slag concrete as a replacement of sand in concrete mixtures. The test results of concrete were obtained by adding copper slag concrete to sand in various percentages ranging from 0%, 20%, 40%, 60%, 80% and 100%. All specimens were cured for 28days before compression strength test, splitting tensile test and flexural strength. The highest compressive strength obtained was 35.11MPa. This results of the research paper showed that the possibility of using copper slag concrete as fine aggregate in concrete. The results showed the effect of copper slag concrete on RCC concrete elements have a considerable amount of increase in the compressive, split tensile, flexural strength characteristics and energy absorption characteristics. The addition of copper slag concrete has improved the compressive strength, split tensile strength and flexural strength of concrete. While replacement of copper slag concrete in concrete increases the density of concrete. The slump value of copper slag concrete concrete lies between 90 to 120 mm. The flexural strength of the beam increased by 21% to 51% while replacement of copper slag concrete. The uses of copper slag concrete 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 concrete. It was also observed that the sand replaced copper slag concrete beams showed an increase in energy absorption capacity.

Jaivignesh and Gandhimathi,(2015) investigated experimentally on the properties of concrete by replacing fine aggregate with copper slag concrete to find out the optimum percentage for replacement. The main objective of their work was to find out alternative material for concrete to meet the demands of fine aggregate for the upcoming years, to provide adequate strength at minimum cost, to make the eco-friendly structures. This work described the optimum level of replacement for strength and durability of concrete by replacing different percentage of copper slag concrete by weight of fine aggregate for a mix M30 grade concrete for find out the optimum ratio of copper slag concrete. The compressive strength of Copper slag concrete concrete mixes with 20%, 40%, 60%, 80% and 100% fine aggregate replacement with Copper slag concrete, and were higher than the control mix at all ages of curing. The highest compressive strength was achieved by 40% replacement of copper slag concrete.

3. Experimental Investigation

3.1 Materials

3.1.1 Cement type

53 Grade Ordinary Portland cement (Ultratech Cement) was used. Physical properties of cement are shown in Table1

3.1.2 Coarse Aggregate

Crushed granite material with 60% passing 20mm and retained on 10mm sieve, 40% passing 10mm and retained on 4.75mm sieve having a specific gravity of 2.74 was used. The details about the coarse aggregate and their properties are shown in Table 2.

3.1.3 Fine Aggregate

River sand of zone-II was used as fine aggregate. The details of fine aggregate properties are shown in Table 3.

3.1.4 Water

Potable fresh water available at Andhra University, Visakhapatnam, which is free from concentration of acid or organic substances was used for mixing the concrete.

3.1.5 Copper slag

Copper slag is a by-product obtained during the matte smelting and refining of copper. Copper slag is also called as Ferro sand. Copper slag used in this work is brought from Sterlite Industries Ltd (SIL), SIPCOT Industrial Complex Madurai Bypass Road, Thoothukudi, Tamilnadu, India. SIL is producing copper slag during the manufacturing of copper metal. Currently in SIL itself 2600 tons of copper slag is produced per day and the total accumulation is around 1.5 million tons. Copper slag is a black glassy and granular in nature and has similar particle size range like sand. The specific gravity of the slag lies between 3.4 and 3.98. It is also found that the copper slag has less moisture content so it has less heat of hydration. The properties of copper slag are shown in Table 4 and 5.

Table 1 Physical properties of cement (ULTRA TECH OPC 53 GRADE)

S.NO.	Property	Value
1.	Specific Gravity	3.01
2.	Fineness of cement (By sieving)	2.75%
3.	Standard Consistency	31%
4.	Setting Time i) Initial setting time	115 min
	ii) Final setting time	253 min

Table 2 Physical Properties of coarse Aggregate

S.NO.	Property	Value
1.	Specific Gravity	2.74
2.	Fineness Modulus	6.76

Table 3 Physical Properties of Fine aggregate (Natural Sand)

S.NO.	PROPERTY	VALUE
1.	Grading of Sand	Zone II as per IS 383
2.	Specific Gravity	2.61
3.	Fineness Modulus	2.66

IJTIMES-2018@All rights reserved

Table 4 Physical Properties of copper slag (as suggested by the supplier)

S.NO	Physical properties	Suggested values by supplier
1.	Colour	Black
2.	Specific Gravity	3.77
3.	Fineness	3.44%

Table 5 Chemical Properties of copper slag

S.No.	Chemical component	% of chemical component
1	SiO_2	25.42
2	Fe_2	68.79
3	Al_2O_3	0.21
4	CaO	0.14
5	Na_2O	0.55
6	K_2O	0.22
7	MnO_3	0.24
8	TiO_2	0.39
9	SO_3	14.38
10	CuO	6.53

3.1.6 Mix Proportion

Mix design is a process of selecting suitable ingredients and determining their relative proportions with the objective of producing concrete of having certain minimum workability, strength and durability as economically as possible. The M30 grade concrete Mix design is made as per IS10262:2009. The Table 6 below shows the mix design.

Table 6 Mix Proportions

Water (Liters)	Cement (Kg/m^3)	Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)
171	380	694.95	1209.79 (725.87+483.91) (60%+40%)
0.45	1	1.82	3.18

4. Test Procedure

4.1 Slump cone Test

Slump cone test is a preliminary test conducted to determine the workability. In this thesis, slump test was conducted on the mix containing cement, fine aggregate, copper slag and coarse aggregate. The mix was prepared according to the proportions obtained from mix design. The prepared mix was then placed in slump cone in three layers with simultaneous tamping with a tamping rod for each layer. The slump cone is lifted and the change in slump is observed. The change in slump is measured with a steel rule and is noted down.

4.2 Compaction Factor Test

Compaction factor test is another test conducted to determine the workability of the prepared mix. In this test the mix is poured into the upper hopper of the compaction factor apparatus, and then the lever is pulled, which makes the mix fall down in to the lower hopper and then in to the cylinder under the action of gravity. Now the cylinder is weighed and the weight is noted down. The cylinder is now placed on the vibrator table and then compacted. The cylinder is again weighed and the weight of fully compacted cylinder is noted down. The compaction factor is found out with the help of the formula below.

$$\text{Compaction factor} = \frac{\text{Weight of partially compacted concrete}}{\text{Weihght of fully compacted concrete}}$$

4.3 Vee-Bee Consistometer Test

In this test, the mix is placed in the cone in three layers with simultaneous compaction. After the cone has been removed the circular glass plate attached to the apparatus is placed on the mix. The machine is switched on and the stopwatch is started. The time taken for the cone shaped to mix to transform into a cylindrical shaped mix is noted down. This time recorded is known as Vee-Bee time.

4.4 Compressive Strength Test

In this test, the cubes that have been cast in the cubical mould of dimensions 150mmx150mmx150mm, placed in curing tank for 1, 3, 7, 28, 56, and 91 days and then dried until it is free from moisture are tested in a compression testing machine. The cubes are placed in the machine and then load is applied until failure. The load obtained is recorded and the compressive strength is calculated using the formula below. Figure 2 depicts the placing of concrete cube in compression testing machine.

$$\text{Compressive strength}= \frac{P}{A} \ (\text{N/mm}^2).$$

Where,

P = load applied to the specimen.

A = Cross-sectional area of cube on which the load is applied (150mm x 150mm)

Fig 2. Testing of cube

4.5 Splitting Tensile Strength

In this test, cylinders of dimension 150mm x 300mm have been cast in cylindrical moulds, placed in curing tank for 1, 3, 7, 28, 56 and 91 days and dried until free from moisture. These cylinders are placed in the testing machine and the load is applied until failure. The ultimate load is recorded and then the splitting tensile strength is calculated according to the formula given below. The placing of the cylinder in the testing machine is depicted in Fig 3.

$$F_t = \frac{2P}{\pi \ x \ D \ x \ L} \ \text{N/mm}^2$$

Where, P= Maximum load applied to the specimen.
D = Cross sectional dimension of cylinder on which load is applied.
L = Length of specimen in mm.
F_t = Split tensile strength. (N/mm^2)

Fig 3. Testing of Cylinder

4.6 Flexural Strength

In this test, prisms of dimensions 500mm x 100mm x 100mm were cast in the appropriate moulds, placed in curing tank for 1, 3, 7, 28, 56 and 91 days, and then dried until free form moisture. Before the testing of these prisms, two lines with a gap of 5 cm from each of the ends are drawn. Now from this 5 cm lines, two more lines with a gap of 13.33 cm are drawn. This is for the purpose of three point loading. The prism is placed in the testing machine and then load is applied on the roller plate placed on the lines drawn on the prism. The prism is loaded until failure and the ultimate load is recorded. The flexural strength is calculated with the help of the formula given below. Fig 3 depicts the placing of the prism in the universal testing machine.

$$F_b = P\ x \frac{L}{B\ x\ D\ x\ D}\ N/mm^2 \text{ (when tensile crack length is greater than 13.33cm)}$$

$$F_b = \frac{3Pa}{B\ x\ D\ x\ D}\ N/mm^2 \text{ (when tensile crack length is between 11.0cm to 13.33cm)}$$

Where,

F_b = Flexural strength of the specimen.

P = maximum load applied to the specimen.

L = Length in mm of the span on which the specimen was supported.

B = width of the specimen.

D = depth of specimen.

Fig 4. Testing of Prism

4.7 Durability

Durability is defined as the ability of concrete to withstand factors of weathering, abrasive actions, and exposure to freeze and thaw characteristics.

Concrete will remain durable if:

- The cement paste structure is dense and of low permeability
- Under extreme condition, it has entrained air to resist freeze-thaw cycle.
- It is made with graded aggregate that are strong and inert

4.7.1 Temperature effect on concrete

The behavior of concrete at high temperatures is influenced by several factors, including the rate of temperature rise and the aggregate type and stability. It has been found that high temperature has negative impacts on later strength of concrete. Its reason is that at high initial rate of hydration, there is insufficient time available for the diffusion of the products of hydration away from the cement particle and for a uniform precipitation in the interstitial space. All this results in concentration of the products in the vicinity of the hydrating particles which causes subsequent retardation in hydration and effects strength. Fire resistance is purely characterized by the ability of structure to sustain and withstand the effects of fire. The optimal performance of fire resistant structure is related to restrict the spread of fire from original point or to sustain the design load even after being subjected to intensity of fire exposure. The structural integrity during the entire duration of fully developed fire as well as its decaying period is much important in assessing the fire safety conditions.

5. Discussion of Test Results

5.1 Workability

The workability of concrete is determined by slump cone and compaction factor tests, as these tests are suitable for low workable mixes also. While casting the specimens only the workability is measured, if any mix does not have required slump of 25-50mm then the mix would be made again with plasticizer. The tests were conducted on M30 grade concrete. It can be observed that as the percentage of the replacement of fine aggregate with Copper slag increases the slump is decreasing, as the water absorption capacity of Copper slag is more as compared to river sand. Hence the workability decreases.

5.1.1 Workability in terms of Slump

The values of slum obtained in the present investigation for various percentages of replacement of fine aggregate with Copper slag are shown in Table 7. It can be observed that as the percentage of the replacement of fine aggregate with Copper slag increases the slump decreases. Hence it can be concluded that as the percentage of Copper slag increases the workability decreases.

5.1.2 Workability in terms of Compaction Factor

The values of compaction factor obtained in the present investigation for various percentages of replacement of fine aggregate with Copper slag are shown in Table 8. It can be observed that as the percentage of the replacement of fine aggregate with Copper slag increases the compaction factor decreases. Hence it can be concluded that as the percentage of Copper slag increases the workability decreases.

Table 7 Workability in terms of slump cone test

Grade of Concrete	M30			
Percentage Replacement of Copper slag concrete	0%	30%	40%	50%
Slump in (mm)	14	13	12	8

Table 8 Workability in terms of compaction factor

Grade of Concrete	M30			
Percentage Replacement of Copper slag concrete	0%	30%	40%	50%
Compaction Factor	0.891	0.882	0.874	0.847

5.2 Compressive Strength

Compressive strength test has been conducted on cubes of size 150mmx150mmx150mm for all mixes and resulting compressive strength obtained at the age of 1, 3, 7, 28, 56 and 91 days for M30 grade concrete were tabulated in the Table 9, 10 and fig 5. It can be seen that the compressive strength of concrete with fine aggregate replaced by Copper slag is more than the conventional concrete mix at all ages except for 56 and 91 days. The compressive strength is increasing from 0%, 30%, 40%, 50% replacement of fine aggregate with Copper slag.

Table 9 Preliminary investigation for optimum dosage

Compressive strength at the age (days)	M30+0% CS (MPa)	M30+30% CS (MPa)	M30+40% CS (MPa)	M30+50% CS (MPa)
7	28.29	27.81	42.51	24.88
28	42.03	30.57	53.48	32.79

Table 10 Compressive strength values

Compressive strength at the age (days)	M30+0%CS (MPa)	M30+40%CS (MPa)
1	19.91	27.84
3	26	35.7
7	28.29	42.51
28	42.03	53.48
56	45.7	53.72
91	46.6	53.86

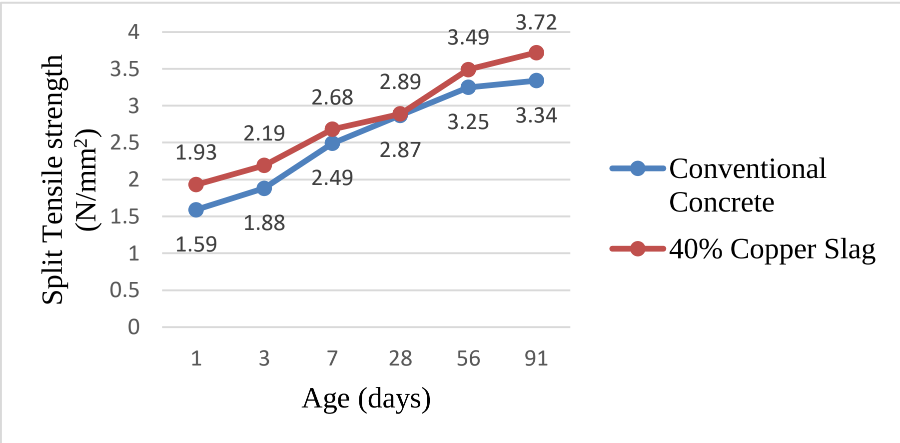

Fig 5. Variation of compressive strength for M30 grade concrete

5.3 Split Tensile strength test

Split tensile strength test has been conducted on cylinders of size 150mm x 300mm for all mixes and resulting split tensile strength obtained at the age of 1, 3, 7, 28, 56 and 91 days for M30 grade concrete were tabulated in the Table 11 and fig.6. It can be seen that the split tensile strength of concrete with fine aggregate replaced by Copper slag is more than the conventional concrete mix at later ages.

Table: 11 Split tensile strength values

Split Tensile strength at the age (days)	M30+0%CS (MPa)	M30+40%CS (MPa)
1	1.59	1.93
3	1.88	2.19
7	2.49	2.68
28	2.87	2.89
56	3.25	3.49
91	3.34	3.72

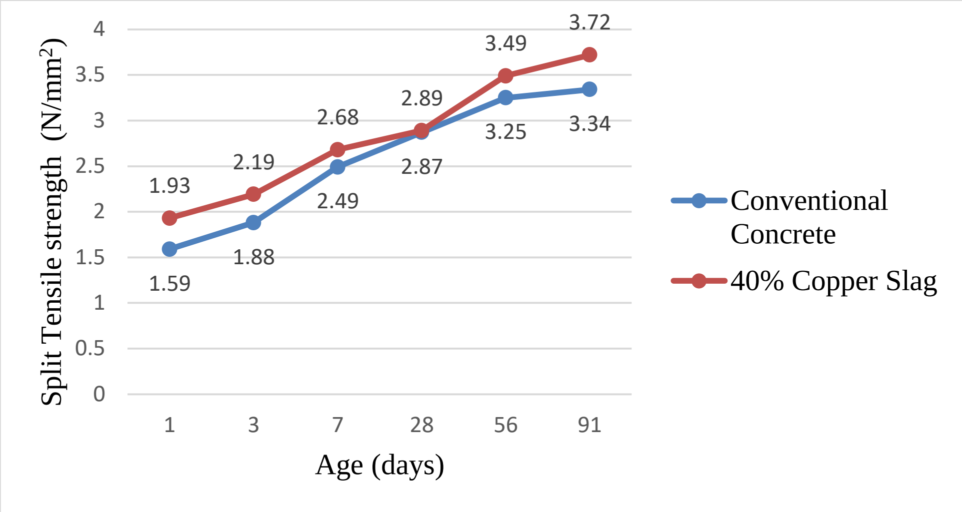

Fig 6. Variation of split tensile strength for M30 grade concrete

5.4 Flexural Strength test

Flexural strength test has been conducted on beams of size 500mm x 100mm x 100mm for all mixes and resulting flexural strength obtained at the age of 1, 3, 7, 28, 56 and 91 days for M30 grade of concrete were tabulated in the Table 12 and fig 7. It can be seen that the flexural strength of concrete with fine aggregate replaced by Copper slag is more than the conventional concrete mix at later ages.

Table 12 Flexural Strength values

Flexural strength at the age (days)	M30+0%CS (MPa)	M30+40%CS (MPa)
1	3.71	3.21
3	4.57	4.49
7	5.69	4.86
28	5.85	5.96
56	6.19	6.32
91	6.28	7.34

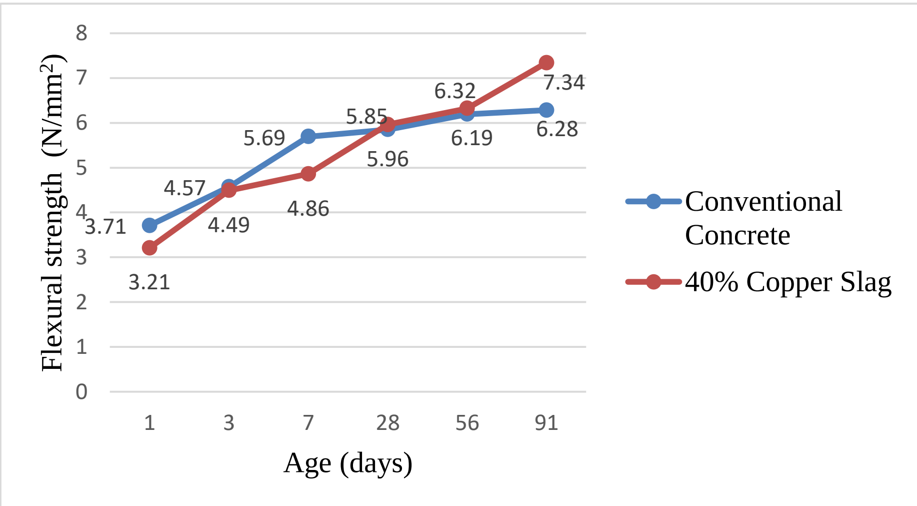

Fig 7. Variation of flexural strength values for M30 grade concrete

5.5 Results of Compressive Strength when subjected to different temperatures

The comparison of cubes with 40% copper slag concrete at 27°C and cubes with 40% copper slag concrete subjected to temperatures of 100, 200, 300, 400, 500°C for durations of 1, 2 and 3 hours respectively for M30 grade concrete after 28 days curing were tabulated in the table 13, 14, 15 and is shown in fig.9.

5.5.1 Effect of Temperature on Copper slag concrete

From the graphs we can see that the 40% replacement of natural sand by Copper slag gave more resistance when subjected to temperature of 200°C for a duration of 1 hour and 2 hours, 100°C for a duration of 3 hours

Table 13 Compressive Strength for M30 grade of copper slag concrete after 28 days curing for 1 hour duration

Temperatures in °C	Residual compressive Strength for 40% CS (MPa)	Compressive Strength for 40% CS (MPa)
27	100	53.48
100	100.54	53.77
200	102.8	54.98
300	96.49	51.55
400	89.2	47.7
500	83.2	44.44

Table 14 Compressive Strength for M30 grade of copper slag concrete after 28 days curing for 2 hours duration

Temperatures in °C	Residual compressive Strength for 40% CS (MPa)	Compressive strength for 40% CS (MPa)
27	100	53.48
100	100.51	53.71
200	101.92	54.50
300	90.56	48.43
400	84.95	45.43
500	79.3	42.38

Table 15 Compressive Strength for M30 grade of copper slag concrete after 28 days curing for 3 hours duration

Temperatures in °C	Residual compressive Strength for 40% CS (MPa)	Compressive strength for 40% CS (MPa)
27	100	53.48
100	99.76	53.35
200	97.22	51.99
300	86.39	46.20
400	80.8	43.21
500	76.44	40.88

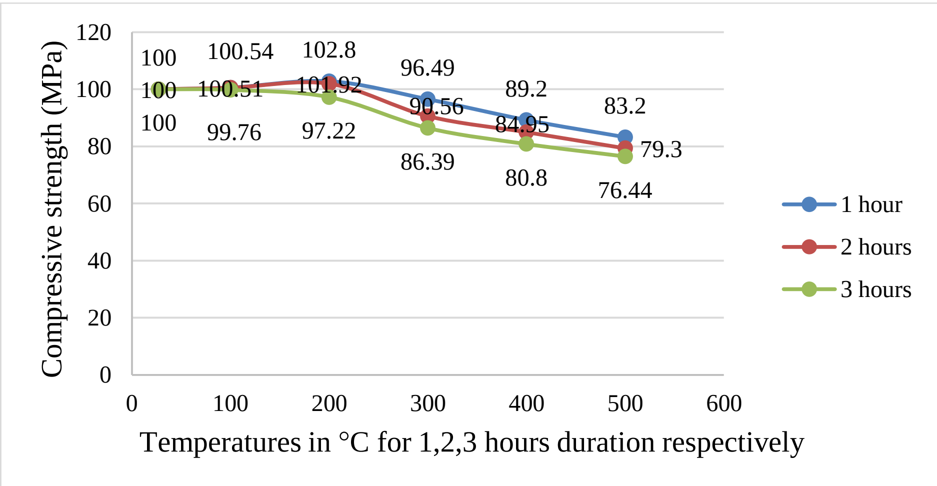

Fig 8. Variation of compressive strength when subjected to various temperatures

Table 16 Loss of weights for M30 grade concrete with 40% copper slag concrete after 28 days curing when subjected to various temperatures for 1, 2, 3 hours duration

Temperature in °C	Weights (grams) for 40% CS (1 hour)	Weights (grams) for 40% CS (2 hours)	Weights (grams) for 40% CS (3 hours)
27	0	0	0
100	14	19	22
200	56	76	84
300	284	342	344
400	380	426	526
500	458	488	512

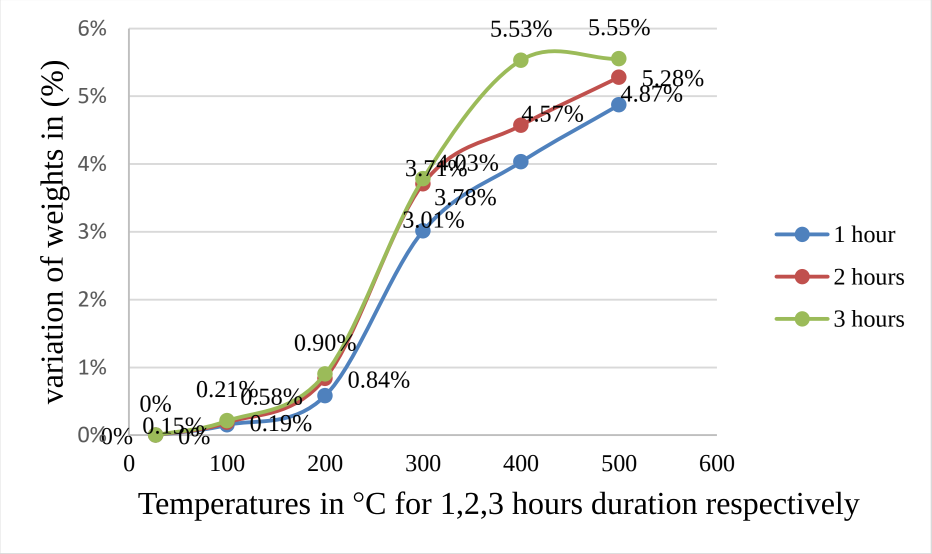

Fig 9 Variation of loss of weights in percentage

6. Conclusions

1. The Copper slag can be used as a best alternative material for partial replacement of natural sand and gives more compressive strength in order of 15.5% to 50.26% for M30 grade concrete than conventional concrete.

2. The slump values of concrete with Copper slag are observed to be relatively less when compared to conventional concrete, as Copper slag has more water absorption capacity compared to the river sand. Therefore, workability of concrete decreases significantly with the increase of Copper slag percentage in concrete.

3. The Compaction factor values of concrete with Copper slag were observed to be relatively less when compared to conventional concrete, as Copper slag has more water absorption capacity compared to the river sand. Therefore, workability of concrete decreases significantly with the increase of Copper slag percentage in concrete.

4. It is observed that 40% replacement of natural sand by Copper slag is giving better compressive strength when compared to other proportions (0%, 30% and 50%) of mixes for 7 and 28 days from optimum dosage graphs.

5. It is observed that 40% replacement of natural sand by Copper slag is giving better split tensile strength when compared to other proportions of mixes for later ages (28,56,91 days).

6. It is observed that 40% replacement of natural sand by Copper slag is giving better flexural strength when compared to other proportions of mixes for later ages (28,56,91 days).

7. The variation in compressive strength is of order 39.83%, 37.30%, 50.26%, 27.24%, 17.5%, 15.5% for 1, 3, 7, 28, 56 and 91 days respectively for 40% copper slag concrete when compared with conventional concrete.

8. The variation in split tensile strength is of order 21.38%, 16.48%, 7.6%, 0.69%, 7.38%, 11.37% for 1, 3, 7, 28, 56 and 91days respectively for 40% copper slag concrete when compared with conventional concrete.

9. The variation in flexural strength is of order 13.4%, 1.75%, 14.58%, 1.88%, 2.10%, 16.87% for 1, 3, 7, 28, 56, 91 days respectively for 40% copper slag concrete when compared with conventional concrete.

10. The variation in compressive strength is of order 0%, 0.54%, 2.80%, 3.51%, 10.8%, 16.88% subjected to temperatures of 27, 100, 200, 300, 400, 500^{o}C after 28 days curing for 1 hour duration respectively with 40% replacement of fine aggregate with Copper slag.

11. The variation in compressive strength is of order 0%, 0.51%, 1.92%, 9.44%, 15.05%, 20.75% subjected to temperatures of 27, 100, 200, 300, 400, 500^{o}C after 28 days curing for 2 hours duration respectively with 40% replacement of fine aggregate with Copper slag.

12. The variation in compressive strength is of order 0%, 0.24%, 2.78%, 13.61%, 19.22%, 23.56% subjected to temperatures of 27, 100, 200, 300, 400, 500^{o}C after 28 days curing for 3 hours duration respectively with 40% replacement of fine aggregate with Copper slag.

13. The variation of weights is of order 0%, 0.15%, 0.58%, 3.01%, 4.03%, 4.87% subjected to temperatures of 27, 100, 200, 300, 400, 500^{o}C after 28 days curing for 1 hour duration respectively with 40% replacement of fine aggregate with Copper slag.

14. The variation of weights is of order 0%, 0.19%, 0.84%, 3.71%, 4.57%, 5.28% subjected to temperatures of 27, 100, 200, 300, 400, 500^{o}C after 28 days curing for 2 hours duration respectively with 40% replacement of fine aggregate with Copper slag.

15. The variation of weights for is of order 0%, 0.21%, 0.90%, 3.78%, 5.53%, 5.55% subjected to temperatures of 27, 100, 200, 300, 400, 500^{o}C after 28 days curing for 3 hours duration respectively with 40% replacement of fine aggregate with Copper slag.

References

1. Alnuaimi AS, (2012), “ Effects of Copper slag concrete as a replacement for Fine Aggregate in the behavior and ultimate strength of reinforced concrete slender columns”, ITJER,Vol.9,No.2, pp 90-102

2. Antonio M. Arino and Barzin Mobasher, “Effect of ground copper slag concrete on strength and toughness of cementitious mixes”, ACI material Journal, Vol.96, No.1, pp 68-74

3. Arivalagan.S, "Experimental Study on the Flexural Behaviour of Reinforced Concrete Beams as Replacement of Copper slag concrete as Fine Aggregate", Journal of Civil Engineering

4. Binod kumar, (2012), “Properties of pavement quality concrete and dry lean concrete with copper slag concrete as fine aggregate” International Journal of Pavement engineering, vol. 1, pp1-6.

5. Brindha.D and Nagan.S, "Durability studies on copper slag concrete admixed concrete", Asian journal of civil engineering (Building and Housing) VOL. 12, NO. S, pages 563-578(2011)

6. Chavan R and Kulkarni D B international "Performance of copper slag concrete on strength properties as partial replace of fine aggregate in concrete Mix Design", Journal of Civil and Structural Engineering Volume 1 No.4 (2011)

7. Lavanya C et al "Review On Utilization or Copper slag concrete in geo-technical Applications", PaperNo.H-212(2011).

8. Meenakshi, et al "Performance of Copper slag concrete and ferrous slag as partial replacement of sand in concrete international journal of Advanced Engineering Research and Studies.(2013)

9. Mobasher.B , and Devaguptapu .R, "Effect of copper slag concrete on the hydration of blended cementitious mixtures", Design", Journal of Civil and Structural Engineering

10. Nagan.S, et al “Assessment of Corrosion and Durability Characteristics of Copper slag concrete Admixed Concrete", International Journal of civil and structural engineering volume1, no.2 (2010).

11. Pundhir NKS et al. "Use of copper slag concrete as construction material in bituminous pavements, Journal of Scientific &industrial research vol 64 (2005)

12. IS:383:1970 Indian standard institution, Specifications of coarse and fine aggregate from natural sources of concrete, New Delhi.

13. IS: 456:2000 Plain and reinforced concrete code of practice , Bureau of Indian Standards, New Delhi

14. IS: 455-1989 Specification for Portland Slag Cement. Bureau of Indian Standards, New-Delhi.

15. IS: 516-1959 Specification for Method of Tests of Strength of Concrete, Reaffirmed 1999, edition 1.2, Bureau of Indian Standards, New Delhi

16. IS: 1199:1959 Specification for methods of sampling and analysis of concrete, Bureau of Indian Standards, New Delhi

17. IS: 2386 (Part I) - 1963 Specification for methods of test for aggregates for concrete. Part-I particle size and shape. Reaffirmed 1997. Bureau of Indian Standards, New Delhi

18. IS: 4031-1968 Specification for fineness test of cement Bureau of Indian Standards, NewDelhi

19. IS 4031 (Part 1):1996 Specification for Methods of physical tests for hydraulic cement Part 1 Determination of fineness by dry sieving. Bureau of Indian Standards, New-Delhi.

20. IS: 4031 (Part-V) - 1988 Specification for initial and final setting time of cement.

21. IS: 5816: 1999 Specification for Splitting Tensile Strength of Concrete - Method of Tests first revision. Bureau of Indian Standards, New Delhi.