AN EXPERIMENTAL INVESTIGATION ON STRENGTH PROPERTIES OF COPPER SLAG CONCRETE

Mr. Nishchay R. More [1], Prof. Prashant M. Kulkarni[2]

[1]PG Student, Department of Civil Engineering, KJEI's Trinity College of Engineering and Research-Pune, Maharashtra, India

[2]Asst. Professor, Department of Civil Engineering, KJEI's Trinity College of Engineering and Research-Pune, Maharashtra, India

ABSTRACT

This paper presents the experimental investigation of properties of concrete using copper slag as replacement material of fine aggregates to increase the hardened concrete properties such as compressive strength, split tensile strength, flexural strength and ultrasonic pulse velocity of concrete. The present study encouraged the use of industrial by-product or waste copper slag as replacement material of fine aggregates in concrete. Mix proportion has to be done for M25 grade of concrete with water cement ratio 0.50. The fine aggregate is replaced with copper slag in proportions of 0%, 20%, 30%, 40%, 50%, 60%, 80%, and 100%. Tests were performed for properties of fresh concrete and hardened concrete. All concrete specimens were cured for 28 days before compression strength test, split tensile strength test, flexural strength test and ultrasonic pulse velocity test. The results indicate that workability and density of concrete increases significantly with the increase of copper slag content in concrete mixes. The results also demonstrated that the highest compressive strength, split tensile strength and flexural strength obtained were 41.53 N/mm^2, 3.86 N/mm^2 and 5.42 N/mm^2 for 40% replacement of fine aggregate by copper slag as compared to control mixture. The ultrasonic pulse velocity test indicated the excellent quality of concrete at all percentage replacement level. Therefore, it is recommended that 40% of copper slag can be use as replacement of fine aggregates. Also on the basis of obtained results the empirical relationships between the mechanical properties of concrete were established.

Keyword: - *Cement, Copper slag, Fine aggregate, concrete, ultrasonic pulse velocity, compressive strength, split tensile strength, flexural strength, workability, density.*

---

1. INTRODUCTION

Huge quantities of industrial waste or by-products accumulated every year by various industries in the developing countries. The main objective of environmental protection agencies and governments are to look for ways to minimize the dual problems of disposal and health hazards of these by-products. For many years, by-products such as silica fume, fly ash and copper slag were considered as waste materials. They have been successfully used in the construction industry as a fine aggregate substitute [1]. For every ton of copper production, about 2.2 tons of copper slag is generated. Therefore, in india 8 lakhs tons of copper slag is generated every year and in world-wide generation of annually about 24.6 million tonnes of slag. Copper slag is widely used in the sand blasting industry and it has been used in the manufacture of abrasive tools, cutting tools, roofing granules, glass, tiles, road based construction and rail road ballast [2]. As per Chavan and Kulkarni, It has been reported that the copper slag does not cause leaching [3]. Application of copper slag in concrete as a replacement material investigates the possibility of reducing the environmental impact. Copper slag is granular and has similar properties to that of sand [4].

Velumani and Maheswari studied on Mechanical and Durability Properties of RC Beams Using Copper Slag as Fine Aggregate in Concrete. Copper slag has physical properties similar to the fine aggregate, so it can be used as a replacement of fine aggregate in concrete. Copper slag has lower absorption and higher strength properties than fine aggregate. Replacement of copper slag increases the self-weight of concrete specimens to the maximum of 15% to 20% [5]. Caijun Shi et al (2008) investigated the effect of copper slag on the Engineering properties of cement mortars and concrete. They reported that the utilization of copper slag in cement mortar and concrete is very effective and beneficial for all related industries, particularly in areas where a considerable amount of copper slag is produced. It proved both environmental as well as technical benefits. They observed that there was more than 70% improvement in the compressive strength of mortars with 50% copper slag substitution [6]. Madhavi et al studied on Effect of Copper Slag on the Mechanical Strengths of Concrete. Experimental investigations are carried out by replacing the sand with copper slag in proportions of 10%, 20%, 30%, 40%, 50%, 60% and 100% keeping all other ingredients constant. It was seen that the optimum content of copper slag is 40% beyond which the strength starts decreasing [7]. Patil et al observe the Performance of Copper Slag as Sand Replacement in Concrete. M30 concrete was used and various tests like compressive, flexural, split tensile strength were conducted for different percentages of copper slag and sand from 0 to 100%. The result showed that workability increases with increase in percentage of copper slag. Maximum Compressive strength of concrete increased by 34 % at 20% replacement of fine aggregate with copper slag, and up to 80% replacement of copper slag, concrete gain more strength than normal concrete strength. The flexural strength of concrete found to be increased by 14% with 30% replacement of copper slag [8].

2. RESEARCH OBJECTIVES

1. To find the optimum proportion of copper slag that can be used as a replacement/ substitute material for fine aggregate.
2. To evaluate the effect of copper slag replacement on the workability and density of concrete.
3. To find the compressive strength, split tensile strength, flexural strength and ultrasonic pulse velocity of copper slag replaced concrete specimens.
4. To propse an empirical relationship between mechanical properties of concrete.

3. MATERIALS AND PROPERTIES

3.1 Cement

The cement used in this project is Ordinary Portland Cement (OPC) of 53 Grade (Birla Super Cement Company) conforming to IS 12269 [9]. This cement is most widely used in the construction industry in India.Some physical properties of Ordinary Portland Cement (OPC) are mentioned in Table 1 below.

Table 1: Physical properties of cement

Sr. No.	Cement	Initial Setting Time	Final Setting Time	Specific Gravity
1	OPC 53 Grade	30 min	620 min	3.15

3.2 Coarse And Fine Aggregate

The fine aggregate used in this study is river sand conforming to grading zone II Table 1 of IS 383 were procured from local river in Maharashtra [10]. The coarse aggregate used in this study is of angular in shape and the maximum nominal size of coarse aggregate is 20 mm and it is Conforming to Table 2 of IS 383 and which is taken from pune area [10]. Some physical properties of fine aggregate and coarse aggregate are mentioned in Table 2 below.

Table 2: Physical properties of fine aggregate and coarse aggregate

Sr. No.	Test	Fine Aggregate	Coarse Aggregate
1	Specific gravity	2.50	2.68
2	Fineness modulus	2.91	7.17
3	Water absorption (%)	1.21	1.297

3.3 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 final product is a solid, hard material that goes to the crusher for next processing. Copper slag is an irregular, black, glassy and granular in nature and its properties are similar to the river sand. Copper slag used in this work was brought from Sundara Enterprises (zone-II), a dealer in Bhosari MIDC area, Pune. The nature of copper slag used in experimental work shown in fig. 1. The physical and chemical properties of Copper slag are shown in table 3 and table 4.

Figure 1: Copper slag

Table 3: Physical properties of copper slag.

Sr. No.	Physical Properties	Copper Slag
1	Particle shape	Irregular
2	Appearance	Black and glassy
3	Type	Air cooled
4	Specific gravity	3.74
5	Fineness modulus	2.89
6	Water absorption	0.40

Table 4: Chemical properties of copper slag.

Sr. No.	Component	% of chemical component
1	Sio_2	25.84
2	Fe_2O_3	68.29
3	Al_2O_3	0.22
4	CaO	0.15
5	Na_2O	0.58
6	K_2O	0.23
7	Mn_2O_3	0.22
8	TiO_2	0.41
9	SO_3	0.11
10	CuO	1.20
11	Sulphide sulphur	0.25
12	Insoluble Residue	14.88

3.4 Water

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. This bonds the other components together, creating a robust stone like material. The tap water is used in this study.

4. METHODOLOGY

The study aims to investigate the strength properties of concrete using copper slag as replacement material of fine aggregates of M25 grade concrete. The proportions of ingredients of the control concrete of grade M25 had to be determined by mix design as per IS 10262: 2009 code [11]. The specimens were casted by replacements of fine aggregate with copper slag by 0%, 20%, 30%, 40%, 50%, 60%, 80% and 100%. For each concrete mixture, three cubes, three beams and three cylinders were casted. Then the specimens were cured for 28 days. In fresh state; the workability parameters such as slump value was studied. In hardened state; the strength tests such as density, compressive strength, split tensile strength, flexural strength and ultrasonic pulse velocity were studied. The obtained results are tabulated. Also on the basis of obtained results the empirical relationships between the mechanical properties of concrete were established. The conclusions were made from the results and discussions.

5. EXPERIMENTAL WORK

In this research work, the concrete strength and replaced concrete strength for M25 grade of concrete was found out. The properties of concrete materials and concrete strength were determined. Mix design carried for M25 grade of concrete by IS 10262-2009 yielded mix proportions of 1:1.70:2.97 with water cement ratio of 0.50. Keeping w/c ratio as constant for control mix and by 0%, 20%, 30%, 40%, 50%, 60%, 80% and 100 % replacements. Specimens were prepared according to the mix proportion and by replacing sand with copper slag in different proportions.

5.1 Mix Proportion of Concrete Grade

As per IS 10262: 2009, mix design for M25 grade concrete is given in table 5**.**

Table 5: Mix proportion by weight

Water K/m^3	Cement Kg/m^3	Sand Kg/m^3	Coarse Aggregate Kg/m^3
191.58	383.16	652.37	1141.03
0.50	1	1.70	2.97

5.2 Various Replacements of Copper Slag In Concrete

The concrete mixtures with various proportion of copper slag with fine aggregate are given in table 6.

Table 6: Concrete mixtures with various proportion of copper slag with fine aggregate

Mix Identity	Cement (Kg/m^3)	Fine Aggregate (Kg/m^3)	Copper Slag (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Water (Kg/m^3)
CC	383.16	652.37	0	1141.03	191.58
CS20	383.16	521.90	130.47	1141.03	191.58
CS30	383.16	456.66	195.71	1141.03	191.58
CS40	383.16	391.42	260.95	1141.03	191.58
CS50	383.16	326.18	326.18	1141.03	191.58
CS60	383.16	260.95	391.42	1141.03	191.58
CS80	383.16	130.47	521.90	1141.03	191.58
CS100	383.16	0	652.37	1141.03	191.58

6. RESULT AND DISCUSSIONS

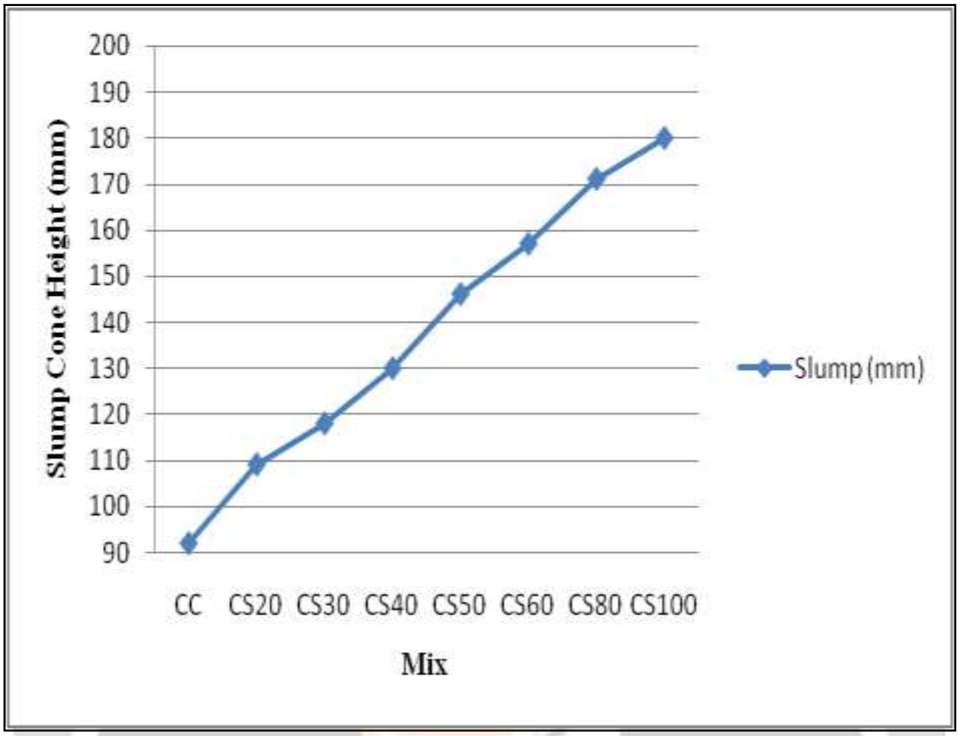
6.1 Fresh Concrete

6.1.1 Workability Test

Workability of fresh concrete is checked immediately after mixing of water in dry concrete with the help of slump cone instrument. Slump test as per IS: 1199-1959 is followed [12]. Table 7 shows results of workability of various sets of concrete. The effect of copper slag replacement on workability of concrete is presented in graph 1.

Table 7: Workability of concrete mixture

Sr. No.	Mix Identity	Slump (mm)
1	CC	92
2	CS20	109
3	CS30	118
4	CS40	130
5	CS50	146
6	CS60	157
7	CS80	171
8	CS100	180



Graph1: Effect of copper slag replacement on workability of concrete

From Graph 1, it was observed that there is a substantial increase in the workability of concrete as copper slag content increases.This significant increase in the workability was due to the low water absorption and glassy surface of copper slag compared with sand in concrete.

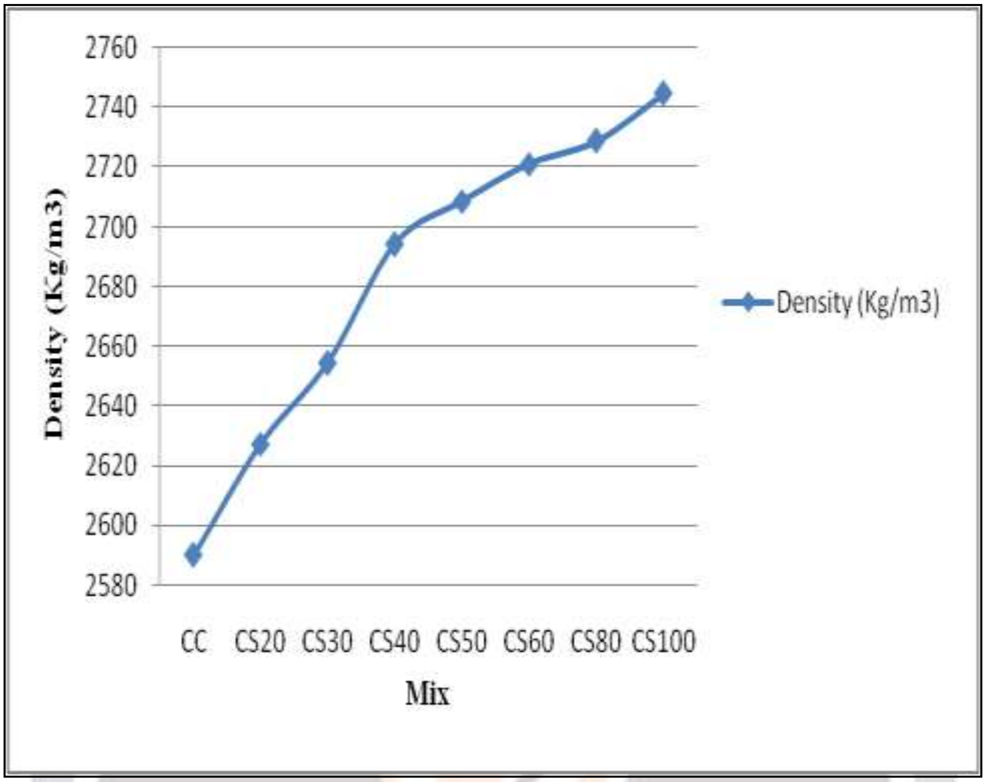
6.2 Hardened Concrete

6.2.1 Density Test

The density of hardened concrete at saturated surface dried condition was measured at the age of 28 days of curing as presented in table 8. The effect of copper slag replacement on density of concrete is presented in graph 2.

Table 8: Density of concrete at 28 days

Sr. No.	Mix Identity	Density (Kg/m^3)	(%) Increase In Density Compare with CC
1	CC	2590.20	-
2	CS20	2627.31	1.43
3	CS30	2654.48	2.48
4	CS40	2694.28	4.02
5	CS50	2708.67	4.57
6	CS60	2721.12	5.05
7	CS80	2728.95	5.36
8	CS100	2744.73	5.97



Graph 2: Effect of copper slag replacement on density of concrete

From graph 2, the test results indicate that there is a substantial increase in the density of concrete as copper slag content increases. Density of concrete was increased by 5.97% (for 100 % replacement) as compare to the control concrete, which is attributed to the high specific gravity of copper slag.

6.2.2 Compressive Strength Test

In order to determine the compressive strength cube mould of size 150×150×150 mm were casted. The cubes were casted for different percentage of copper slag ranging from 0% to 100%. Then the cubes are kept curing for 28 days. Three samples were tested at each concrete mixtures. The compression test is done according to the specification IS 516:1959 [13]. The compressive strength is calculated using the formula,

Compressive strength (N/mm^2) = $\frac{P}{A}$ (1)

Where,

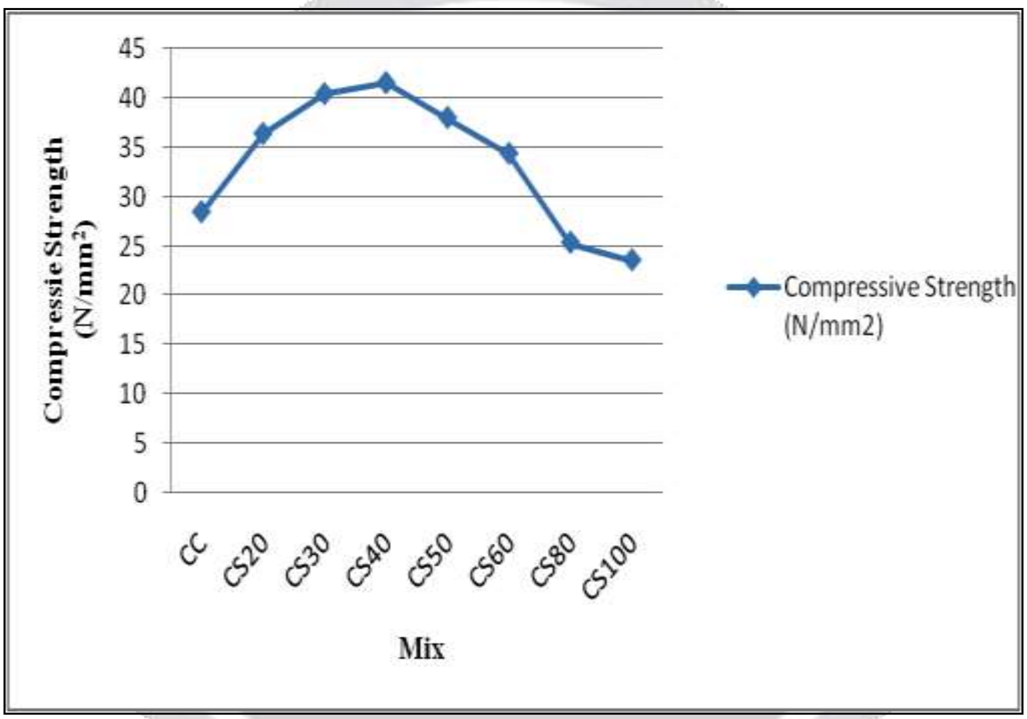
P – Ultimate Load (N)

A – Loaded area of the cube (mm^2)

Tables 9 show the compressive strength for various replacement of copper slag in concrete. Graph 3 display effect of copper slag substitution as a fine aggregate on the compressive strength of concrete.

Table 9: Compressive strength results in N/mm^2

Sr. No.	Mix Identity	Compressive Strength (N/mm^2)	(%) Increase In Strength At 28 Days Compare with CC
1	CC	28.46	-
2	CS20	36.38	27.83
3	CS30	40.42	42.02
4	CS40	41.53	45.92
5	CS50	38.01	33.56
6	CS60	34.37	20.77
7	CS80	25.36	-10.89
8	CS100	23.58	-17.15



Graph 3: Effect of copper slag substitution as a fine aggregate on the compressive strength of concrete

From test result, it can be seen that the optimum percentage of replacement was obtained at 40 % replacement of sand by copper slag. The maximum percentage of increase in strength is found to be 45.92 % at 40 % replacement of sand by copper slag, which was about 41.53 N/mm^2 compared with 28.46 N/mm^2 for the control mixture. Afterwards there was gradually a decrease up to 17.15 % for 100 % replacement of sand in concrete as shown in graph 3 is due to the excessive free water content in the mixes with high copper slag content causes the particles of the constituents to separate leaving pores in the hardened concrete which consequently causes reduction in the concrete strength.

6.2.3 Split Tensile Strength Test

For testing split tensile strength, concrete cylinder of size 150 mm diameter and 300 mm height were casted with different percentage of copper slag ranging from 0% to 100%. It is cured for 28 days. The split tensile strength test for cylinders was carried out as per IS 516: 1964 [13]. The split tensile strength is calculated using the formula,

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

Where,

P – Ultimate Load (N)

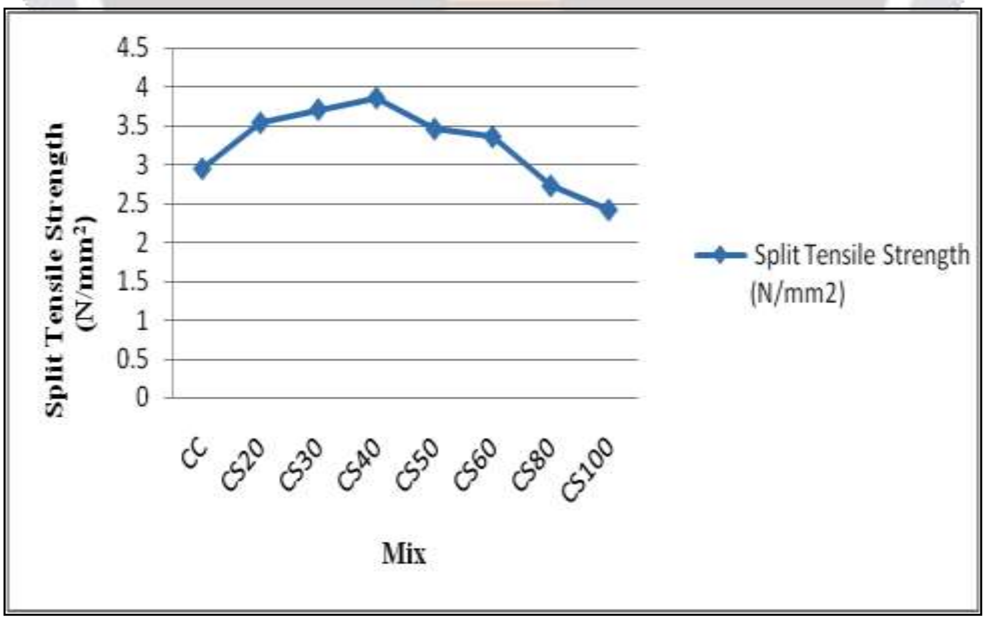
L - Length of cylinder (mm)

D = Diameter of cylinder (mm)

Tables 10 show the split tensile strength for various replacement of copper slag in concrete. Graph 4 display effect of copper slag substitution as a fine aggregate on the split tensile strength of concrete.

Table 10: Split tensile strength results in N/mm^2

Sr. No.	Mix Identity	Split Tensile Strength (N/mm^2)	(%) Increase In Strength At 28 Days Compare with CC
1	CC	2.95	-
2	CS20	3.54	19.75
3	CS30	3.71	25.56
4	CS40	3.86	30.50
5	CS50	3.46	17.00
6	CS60	3.36	13.73
7	CS80	2.73	-7.48
8	CS100	2.42	-18.06



Graph 4: Effect of copper slag substitution as a fine aggregate on the split tensile strength of concrete

From the test results, it was observed that the split tensile strength of cylinder showed a similar behaviour to the compressive strength of the cube for all mixtures. Graph 4 showed that the split tensile strength of cylinder was found to be 2.95 N/mm^2 at 0% fine aggregate replacement and of 2.42 N/mm^2 at 100% fine aggregate replacement by copper slag. The maximum split tensile strength was found to be at 40% fine aggregate replacement of about 3.86 N/mm^2. This means that there is an increase in the strength of almost 30.50% compared to the control mix.The split tensile strength of copper slag added concrete was gradually increased up to 40% replacement and then decreased with further fine aggregate replacement.

6.2.4 Flexural Strength Test

For flexural strength, concrete beam of size 700 × 150 × 150 mm, were casted with different percentage of copper slag ranging from 0% to 100%. Then the beams are kept curing for 28 days. Three samples were tested at each curing age. The flexural strength test for beams was carried out as per IS 516: 1964 [13]. The flexural strength is calculated using the formula,

$$F = \frac{PL}{bd^2} \qquad (3)$$

Where,

F = Flexural Strength (N/mm2)

P = Ultimate load (N)

L = span length (mm)

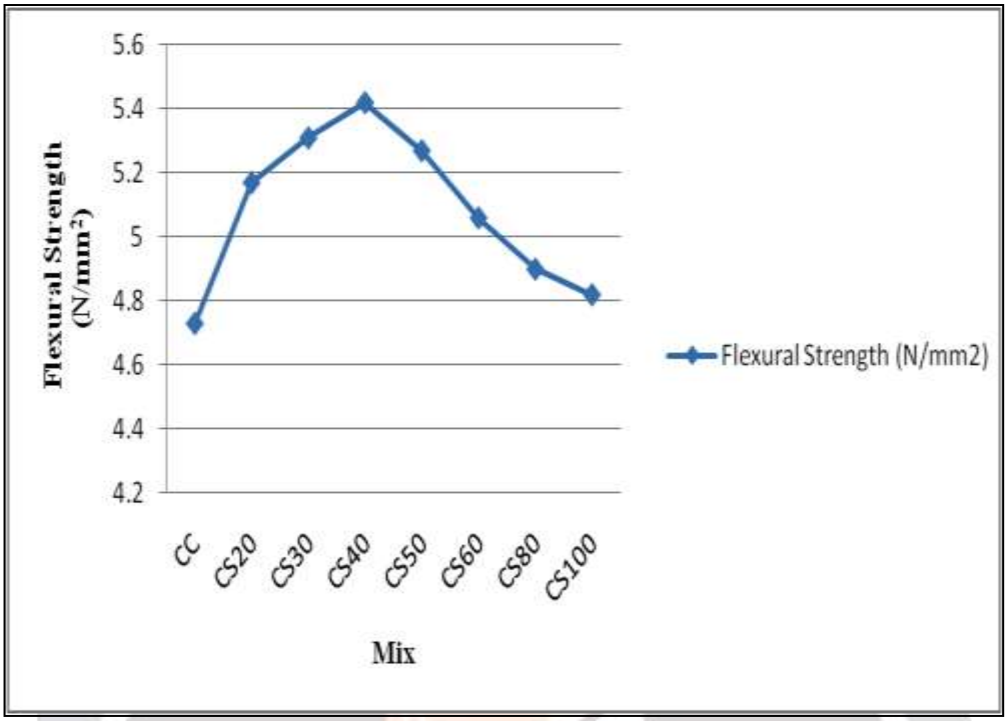
b = average width (mm)

d = average depth (mm)

Tables 11 show the flexural strength for various replacement of copper slag in concrete. Graph 5 display effect of copper slag substitution as a fine aggregate on the flexural strength of concrete.

Table 11: Flexural strength strength results in N/mm^2

Sr. No.	Mix Identity	Flexural Strength (N/mm^2)	(%) Increase In Strength At 28 Days Compare with CC
1	CC	4.73	-
2	CS20	5.17	9.30
3	CS30	5.31	12.31
4	CS40	5.42	14.71
5	CS50	5.27	11.49
6	CS60	5.06	7.01
7	CS80	4.90	3.74
8	CS100	4.82	1.94



Graph 5: Effect of copper slag substitution as a fine aggregate on the flexural strength of concrete

Graph 5 showed that the flexural strength of beam was found to be 4.73 N/mm^2 at 0% fine aggregate replacement and of 4.82 N/mm^2 at 100% fine aggregate replacement. This test results indicate that for mixtures prepared using up to 100% copper slag replacement, the flexural strength of concrete is higher than that of the strength of the control mix with 100% sand. Mixture CS40 with 40% copper slag content yielded the highest 28 day flexural strength of 5.42 N/mm^2 compared with 4.73 N/mm^2 for the control mixture. This means that there is an increase in strength of almost 14.71% compared to the control mix at 28 days.

6.2.5 Ultrasonic Pulse Velocity Test

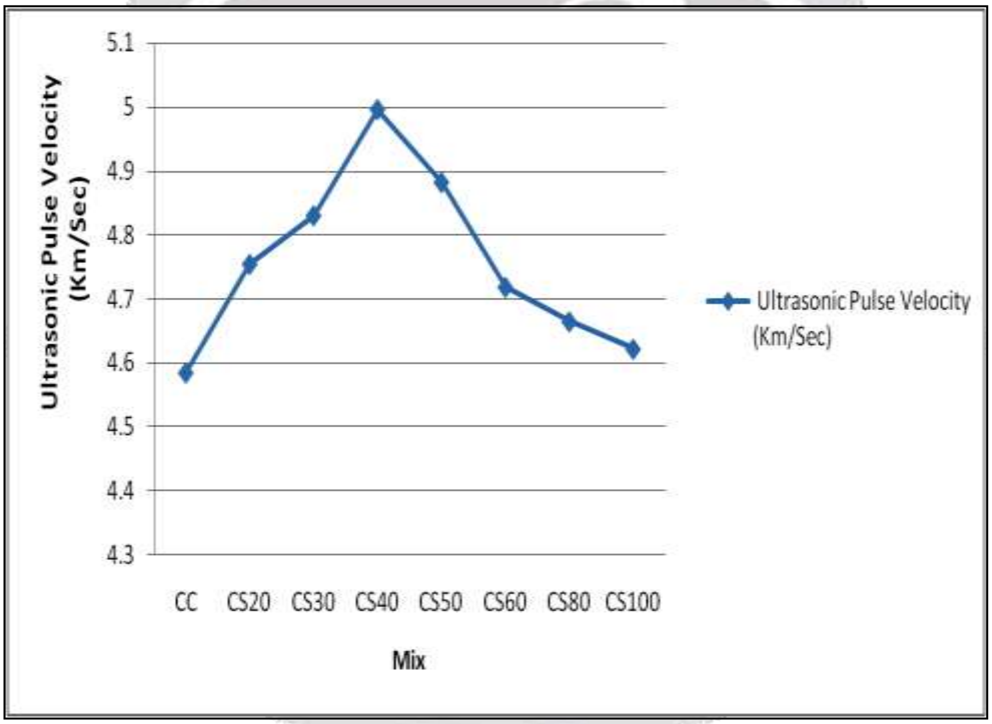
An ultrasonic pulse velocity test is an nondestructive test to check the quality of concrete. In this test, the strength and quality of concrete is assessed by measuring the velocity of an ultrasonic pulse passing through a concrete structure. This test is conducted by passing a pulse of ultrasonic wave through concrete to be tested and measuring the time taken by pulse to get through the structure. Higher velocities indicate good quality and continuity of the material, while slower velocities may indicate concrete with many cracks or voids. The quality of concrete was assessed using the guidelines given in table 2 of IS 13311 (PART 1)-1992 [14]. The Basic formula for estimating the pulse velocity is given by,

Pulse velocity = (Path length/Travel time)

Tables 12 show the ultrasonic pulse velocity for various replacement of copper slag in concrete. Graph 6 display effect of copper slag substitution as a fine aggregate on the ultrasonic pulse velocity of concrete.

Table 12: Ultrasonic pulse velocity in Km/Sec

Sr. No.	Mix Identity	Distance (mm)	Ultrasonic Pulse Velocity 'V' (Km/Sec)	Concrete Quality
1	CC	150	4.58	Excellent
2	CS20	150	4.75	Excellent
3	CS30	150	4.83	Excellent
4	CS40	150	4.99	Excellent
5	CS50	150	4.88	Excellent
6	CS60	150	4.71	Excellent
7	CS80	150	4.66	Excellent
8	CS100	150	4.62	Excellent



Graph 6: Effect of copper slag substitution as a fine aggregate on the ultrasonic pulse velocity of concrete

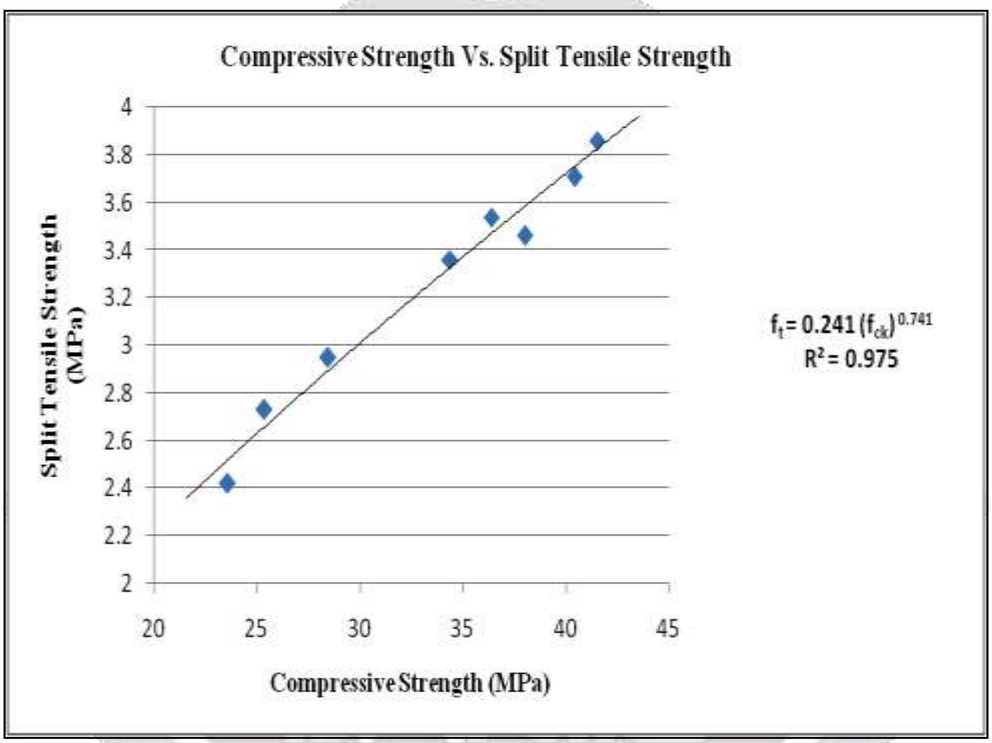
The ultrasonic pulse velocity measurement is the measure of quality of concrete. It is mainly related to its density and modulus of elasticity which in turn, depends upon the materials and mix proportions used in making concrete as well as the method of placing, compaction and curing of concrete. From graph 6 it was observed that the pulse wave velocity showed 4.996 Km/sec at 28^{th} day measurement for 40 % copper slag content. This is due to the density of the mix is high and free from pores. It is also observed that the concrete at all percentage replacement level showed excellent quality as per table 2 of IS 13311 (I)-1992 [14]. The important observation was that the addition of copper slag definitely reduced the pores of concrete and made the concrete impermeable.

6.3 Empirical Relationship Between The Mechanical Properties of Conrete

Empirical relationships were established between the mechanical properties of concrete i.e, compression strength, split tensile strength, flexural strength and ultrasonic pulse velocity respectively.

6.3.1 Relationship Between Compressive Strength And Split Tensile Strength

Empirical relation was obtained for expressing compressive strength and split tensile strength for concrete with and without different percentage of copper slags. The non linear relationship between the compressive strength and splitting tensile strength concrete is shown in graph 7.



Graph 7: Relationship between compressive strength and split tensile strength

Above relation was corresponds to concrete prepared by 0%, 20%, 30%, 40%, 50%, 60%, 80% and 100% copper slag by weight of fine aggregate. Based on this experimental investigation, the empirical relationship between the compressive strength and splitting tensile strength of concrete for 28 days was found to be as follows,

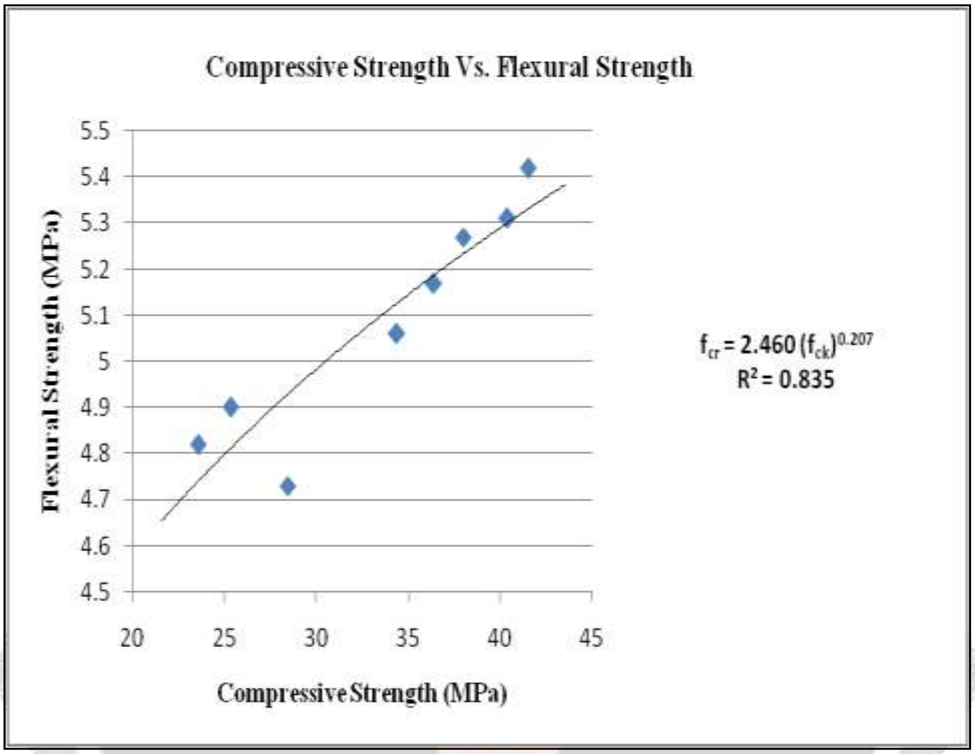
$$f_t = 0.241 (f_{ck})^{0.741}$$
$$R^2 = 0.975$$

Where, f_{ck} = Compressive strength and,

f_t = Split tensile strength

6.3.2 Relationship Between Compressive Strength And Flexural Strength

Empirical relation was obtained for expressing compressive strength and flexural strength for concrete with and without different percentage of copper slags. The non linear relationship between the compressive strength and flexural strength concrete is shown in graph 8.



Graph 8: Relationship between compressive strength and flexural strength

Above relation was corresponds to concrete prepared by 0%, 20%, 30%, 40%, 50%, 60%, 80% and 100% copper slag by weight of fine aggregate. Based on this experimental investigation, the empirical relationship between the compressive strength and flexural strength of concrete for 28 days was found to be as follows,

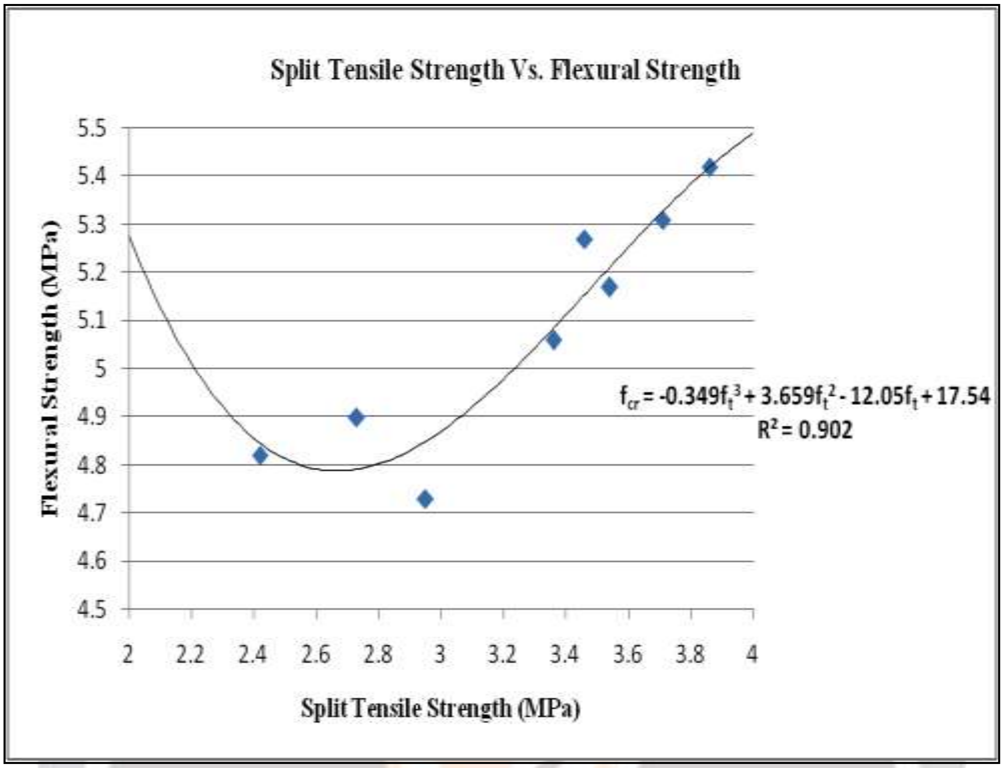
$$f_{cr} = 2.460\ (f_{ck})^{0.207}$$
$$R^2 = 0.835$$

Where, f_{ck} = Compressive strength and,

f_{cr} = Flexural strength

6.3.3 Relationship Between Split Tensile Strength And Flexural Strength

Empirical relation was obtained for expressing split tensile strength and flexural strength for concrete with and without different percentage of copper slags. The empirical relationship between the split tensile strength and flexural strength of concrete is shown in graph 9.



Graph 9: Relationship between split tensile strength and flexural strength

Above relation was corresponds to concrete prepared by 0%, 20%, 30%, 40%, 50%, 60%, 80% and 100% copper slag by weight of fine aggregate. Based on this experimental investigation, the empirical relationship between the split tensile strength and flexural strength of concrete for 28 days was found to be as follows,

$$f_{cr} = -0.349\, f_t^{3} + 3.659\, f_t^{\,2} - 12.05\, f_t + 17.54$$

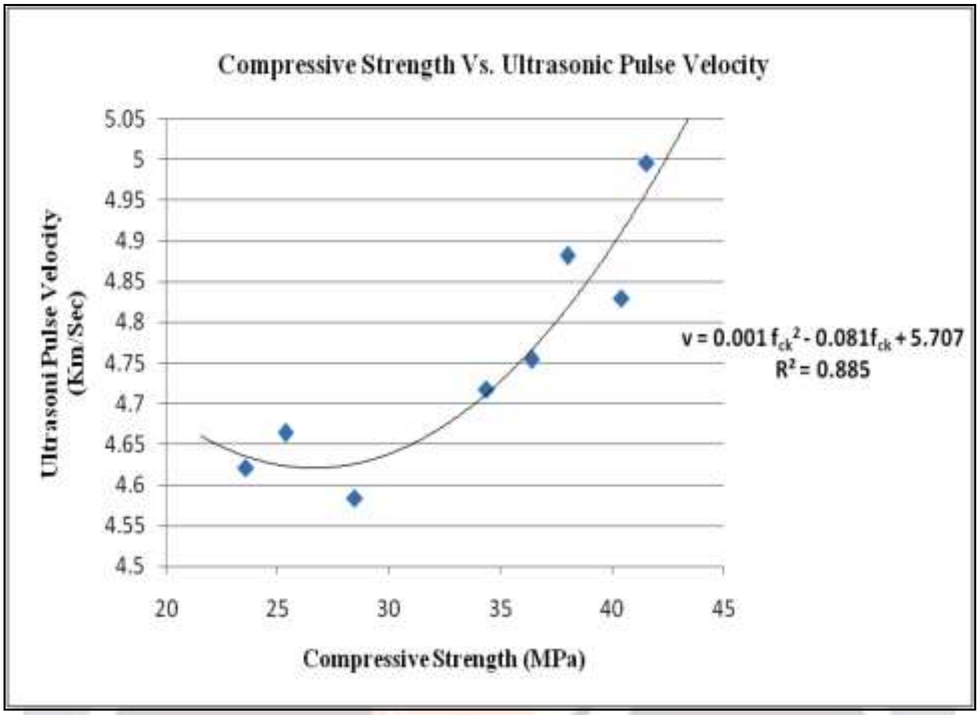
$$R^2 = 0.902$$

Where, f_t = Split tensile strength and,

f_{cr} = Flexural strength

6.3.4 Relationship Between Compressive Strength And Ultrasonic Pulse Velocity

Empirical relation was obtained for expressing compressive strength and ultrasonic pulse velocity for concrete with and without different percentage of copper slags. The empirical relationship between the compressive strength and ultrasonic pulse velocity of concrete is shown in graph 10.



Graph 10: Relationship between compressive strength and ultrasonic pulse velocity

Above relation was corresponds to concrete prepared by 0%, 20%, 30%, 40%, 50%, 60%, 80% and 100% copper slag by weight of fine aggregate. Based on this experimental investigation, the empirical relationship between the compressive strength and ultrasonic pulse velocity of concrete for 28 days was found to be as follows,

$$v = 0.001\ f_{ck}^{\ 2} - 0.081\ f_{ck} + 5.707$$

$$R^2 = 0.885$$

Where, f_{ck} = Compressive strength and ,

v = Ultrasonic pulse velocity

7. CONCLUSION

Based on this experimental study, the following conclusions are drawn

1. The workability of concrete increases significantly with the increase of copper slag content in concrete mixes. This was attributed to the low water absorption and glassy surface of copper slag.

2. 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 5.97% when replacement of fine aggregate by 100% copper slag. This is because weight of concrete increases with copper slag.
3. Maximum Compressive strength and Split Tensile strength of concrete increased by 46% and 30.5% at 40% replacement of fine aggregate by copper slag, and up to 60% replacement, concrete gain more strength than normal concrete strength. Beyond 60% replacement the strength started to reduce due to an increase of free water content in the mix.

4. It is observed that, the flexural strength of concrete at 28 days is higher than control mix concrete (Without replacement) for 40% replacement of fine aggregate by Copper slag, the flexural strength of concrete is increased by 14.71%. This also indicates for all other mixes the flexure strength is more than the control concrete.
5. Based upon the results obtained it was concluded that 40% of copper slag can be used as replacement of fine aggregates.
6. Replacement of copper slag in fine aggregate reduces the cost of making concrete.
7. The relation between compressive strength and split tensile strength of copper slag concrete for 28 days was found to be $f_t = 0.241 (f_{ck})^{0.741}$ with $R^2 = 0.975$.
8. The relation between compressive strength and flexural strength of copper slag concrete for 28 days was found to be $f_{cr} = 2.460 (f_{ck})^{0.207}$ with $R^2 = 0.835$.
9. The relation between split tensile strength and flexural strength of copper slag concrete for 28 days was found to be $f_{cr} = -0.349 f_t^3 + 3.659 f_t^2 - 12.05 f_t + 17.54$ with $R^2 = 0.902$.
10. The relation between compressive strength and ultrasonic pulse velocity of copper slag concrete for 28 was found to be $v = 0.001 f_{ck}^2 - 0.081 f_{ck} + 5.707$ with $R^2 = 0.885$.

8. ACKNOWLEDGMENT

The authors would like to express their thanks to the Principal and Department of Civil Engineering, Trinity College of Engineering and Research, Pune, Maharashtra for supporting this research study.

9. REFERENCES

1. Al-Jabri K.S., Taha R.A., Al-Hashmi A. and Al-Harthy A.S. "Effect of copper slag and cement by-pass dust addition on mechanical properties of concrete", Construction and building materials, Vol. 20, pp. 322-331, 2006.
2. BipraGorai, Jana R. K. and Premchand, "Characteristics and utilisation of copper slag-a review", Resources, Conservation and Recycling, Vol. 39, No. 4, pp. 299-313, 2002.
3. Chavan R.R. and Kulkarni, D.B. "Performance of copper slag on strength properties as partial replacement of fine aggregate in concrete mix design", International Journal of Advanced Research and Studies, Vol.2, No.4, pp.95-98, 2013.
4. ThongamPrantic Singh, Dr.Rajashekhara.M.R. andSuhas R., "Utilization of Copper Slag as Fine Aggregates in Cement Concrete Pavements", International Journal for Research in Applied Science and Engineering Technology, Vol. 2 Issue VII, pp. 358-365, 2014.
5. Velumani and Maheswari, "Mechanical and Durability Properties of RC Beams Using Copper Slag as Fine Aggregate in Concrete". International Research Journal of Engineering and Technology, 3(3), 2016.
6. Caijun Shi, Christian Meyer, and Ali Behnood, "Utilization of copper slag in cement and concrete", Resources Conservation and Recycling, Vol. 52, pp. 1115-1120, 2008.
7. Madhavi,T.C. Effect of Copper Slag on the Mechanical Strengths of Concrete. International Journal of ChemTech Research, 8(12), 442 449, 2015.
8. Patil, M. V. Performance of Copper Slag as Sand Replacement in Concrete. International Journal of Applied Engineering Research, 11(6), 4349-4353, 2016
9. IS 12269 (1987) Indian Standard Ordinary Portland cement, 53 gradespecification. CED 2: Cement and Concrete.
10. IS 383 (1970) Indian Standard Specifications for Coarse and Fine aggregates from Natural Sources for Concrete. CED 2: Cement and Concrete.
11. IS 10262 (2009) Guidelines for Indian Standard Concrete Mix Design Proportioning. CED 2: Cement and Concrete.
12. IS 1199 (1959) Indian Standard Methods of sampling and analysis of concrete. CED 2: Cement and Concrete.
13. IS 516 (1959) Indian Standard Methods of tests for strength of concrete. CED 2: Cement and Concrete.
14. IS 13311-1 (1992) Indian Standard Methods Non-destructive testing of concrete: Part 1 Ultrasonic pulse velocity.