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An Experimental Investigation on Strength Behaviour of Concrete by Partial Replacement of Fine Aggregate with Copper Slag and Cement with Silica Fume

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***Abstract*—** Concrete is the most widely used building material in civil engineering industry throughout the globe because of its high structural strength and constancy, where the fine aggregate is generally natural sand. The usage of sand in construction activity results in the excessive mining, causing depletion of natural resources resulting increase in scour depth and sometimes flood possibility. Copper Slag waste is most usually made from the copper industry, whereas Silica Fume is a by-product from many manufactures. Chuck out of both copper slag waste and Silica Fume is one of the major environmental problems worldwide today. Hence the reuse of waste material has been emphasized to sustainable growth. This research paper presents a study of the Strength properties of concrete by partial replacement of fine aggregate with copper slag and cement with silica fume. In the present Experimental Investigation, for M40 grade of concrete, fine aggregate (River Sand) was partially replaced with Copper Slag (40%) and cement was partially replaced with Silica Fume from 5% to 15% at an interval of 5%. This research gives a detailed observational study on Compressive strength, split tensile strength, flexural strength at age of 28 days. Test results indicate that the strength properties of concrete were improved having copper slag as a partial replacement of Sand (up to 40%) and Silica fume as a partial replacement of cement (up to 10%).

***Keywords*—** Copper Slag, Compressive strength, Flexural Strength, Silica Fume, Split tensile strength.

I. INTRODUCTION

Concrete is a mixture of cement, fine aggregate, coarse aggregate and water. River Sand is a common kind of fine aggregate used in the fabrication of concrete. Alternative to river sand, which is a usual pattern of fine aggregate in preparation of concrete have been in demand due to large scale depletion of river bottom and increasing price of river sand. Many non-established resources such as Stone Dust, Carbonate Sand, Fly Ash, Copper Slag etc. with a larger percentage of Silica (SiO_2) have been strained out as an alternative to river sand as fine aggregate in preparation of concrete. Copper Slag is an industrial by-product abundantly available near copper producing industries having similar physical &chemical properties of Sand can be regarded as an alternative to the river sand. This will help in resolving a major concern of industrial waste disposal along with decreased cost of construction.

A. ADVANATAGE OF USE OF COPPER SLAG IN CONCRETE

- Cost of Concrete production reduces when Copper Slag is used as a fine aggregate in concrete.
- High toughness of Copper Slag attributes to Increased Compressive strength.
- Due to low water absorption, coarser (in nature than sand) and glassy surface of Copper slag the workability of Concrete increased substantially with the increase of Copper Slag content in the concrete mix.
- The use of copper slag helps in waste management and dumping industrial wastes.
- Copper Slag behaves similar to River Sand as it contains Silica (SiO_2) similar to sand.
- Addition of Copper Slag increases the density of the concrete, thereby increasing the Self-weight.

Cement is one of the primary ingredients used for the production of concrete and has no alternative in the civil construction industry. Unfortunately, production of cement involves emission of great quantities of carbon-dioxide gas into the air, a major contributor to the greenhouse effect and the global warming, so it is inevitable either to hunt for some other material or partly replace it by some other material [1]. On that point are some materials, which can be utilized as an alternative or as a supplement for cement should lead to

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global sustainable growth and lowest possible environmental impact. Significant energy and price savings can result when industrial byproducts are used as a partial replacement of cement. Fly ash, Ground Granulated Blast Furnace Slag, Rice husk ash, High Reactive Metakaolin, silica fume is some of the pozzolanic materials which can be utilized in concrete as partial replacement of cement. Silica fume is a byproduct obtained during the production of elemental silicon or an alloy containing silicon and it is a very fine non-crystalline silica produced in electric arc furnaces. Silica fume is also recognized as micro silica, Condensed silica fume, volatized silica or silica dust. It is normally a gray colored powder, slightly similar to Portland cement or some fly ashes. It exhibits both Pozzolanic and cementations properties. The incorporation of silica fume in concrete improves the different mechanical properties like concrete strength, modulus of elasticity, durability, corrosion protection, chemical and abrasion resistance.

B. Chemical Composition of Silica Fume

- Contains more than 90 percent silicon dioxide
- Other constituents are carbon, sulphur and oxides of aluminum, iron, calcium, magnesium, sodium and potassium

C. Physical Composition of Silica Fume

- Diameter is about 0.1 micron to 0.2 micron
- Surface area about 30,000 m^2/kg
- Density varies from 150 to 700 kg/m^3

D. Significance of Silica Fume in Concrete

- High early compressive strength
- High tensile flexural strength and modulus of elasticity
- Very low permeability to chloride and water intrusion
- Enhanced durability
- Increased toughness
- Increased abrasion resistance on decks, floors, overlays and marine structures
- Superior resistance to chemical attack from chlorides, acids, nitrates and sulfates and life-cycle cost efficiencies
- Higher bond strength
- High electrical resistivity and low permeability

II. LITERATURE REVIEW

A. Leema Rose & Suganya

Examined the Performance of Copper Slag on Strength and Durability Properties as Partial Replacement of Fine Aggregate in Concrete. The primary purpose of this work is to determine the strength and durability properties of concrete in which fine aggregate replaced with Copper slag partially by 10%, 20%, 30%, 40%. They reasoned out that the addition of copper slag in concrete increases the density of the concrete. The results of compressive tests show that the strength of the concrete increases with respect to the percentage of copper slag added by weight of fine aggregate up to 30% of replacement of copper slag strength was found to be 45.42 N/mm2 for a design mix 1: 1.4: 2.6 keeping w/c ratio as 0.4[2]

B. Srinivasu, Kranti, Nagasaki & Saikumar

Studied for compressive strength properties and effects of copper slag as partial replacement of fine aggregate in concrete. The Two different types of concrete grades M30 & M40 were used with different percentage of copper slag replacement from 0 to 100 percentage. The percentage replacement of sand was 0%, 10%, 20%, 30%, 40%, 50%, 60%, 80% & 100%. The concrete was tested for 7 days & 28days compressive strength after casting the mounds. Increased compressive strengths for the above grade of concretes were observed. For M30 grade concrete, the highest compressive strength was achieved at 7days by 50% replacement of copper slag is39.105Mpa and the maximum compressive strength was achieved at 28days by 10% replacement of copper slag and which was found about 44.66MPa, compared with nominal mix (29.87N/mm^2 and 41.65N/mm^2) and for M40 grade concrete, the maximum compressive strength was achieved at 7days by 20% replacement of copper slag is 44.44MPa and the highest compressive strength was achieved at 28days by 50% replacement of copper slag and which was found about 53.105MPa, compared with nominal mix (32.33N/mm^2 and 47.11N/mm^2).[3]

C. Zerdi

Conducted an Experimental Investigation on Properties of Concrete by Replacement Copper Slag for Fine Aggregate. The fine aggregates were replaced with percentages 0% (for the control mix), 20%, 40%, and 60% of Copper Slag by weight. Tests were performed for properties of fresh concrete and Hardened Concrete. Compressive strength was determined at 3, 7,14 and 28 days. Properties like workability and density were increased with the use of copper slag in concrete. Improvement in the strength properties of plain concrete by the inclusion of up to 40% Copper slag as replacement of fine aggregate was observed as 25.58 N/mm2at 28 days for M20 concrete. [4]

D. Patil, Patil & Veshmawala

Observed the Performance of Copper Slag as Sand Replacement in Concrete.M30 concrete was used and several tests like compressive, flexural, split tensile strength were taken for different portions of copper slag and sand from 0 to 100%. The outcome showed that workability increases with growth 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 force than

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normal concrete strength. The flexural strength of concrete found to be increased by 14% with 30% substitution of copper slag. [5]

E. Arivalagan

An Experimental Study on the Flexural Behavior of Reinforced Concrete Beams as Replacement of Copper Slag as Fine Aggregate. The test results of concrete were obtained by adding copper slag to sand in various percentages ranging from 0%, 20%. 40%, 60%, 80% and 100%. All specimens were cured for 28 days before the compression strength test, splitting tensile test and flexural strength. The high compressive strength obtained was 35.11MPa (for 40% replacement) and the corresponding strength to control mix was 30MPa [6].

F. Velumani & 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, then it can be utilized as a replacement for 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 upper limit of 15% to 20%. [7]

G. Madhavi, Pavan Kumar &Jothilingam

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 determined that the optimum capacity of copper slag is 40% beyond which the strength starts decreasing. [8]

H. Nataraja, Chandan & Rajeeth

Studied on concrete mix design using copper slag as fine aggregate. This paper presents the experimental results of an on-going project to produce concrete with copper slag as a fine aggregate. The issue of replacing fine aggregate with copper slag on the compressive, flexural and split tensile strength of concrete is studied in this oeuvre. It was determined that in the design mix (1:1.66:3.76) with w/c = 0.45 and 0 to 60% replacement 7- days compressive strength (MPa) was found to be 36.00 (equivalent volume) 37.26 (equivalent weight) for 100% substitution of copper slag [9]

I. Amudhavalli & Mathew

Studied the Effect of silica fume on the effectiveness and durability parameters of concrete. The main parameter investigated in this study is M35 grade concrete with partial replacement of cement by silica fume by 0, 5, 10,15and by 20%. A detailed experimental study in Compressive strength, split tensile strength, flexural strength at age of 7 and 28 day was carried out. Results indicate that the use of Silica fume in concrete has improved the performance of concrete in strength as well as in durability aspect. [10]

J. Perumal & Sundararajan

Observe the Effect of partial replacement of cement with silica fume on the effectiveness and strength features of high performance concrete**.** Strength and durability properties for M60, M70 and M 110 grades of HPC trial mixes and to arrive at the maximum levels of replacement of cement with Silica Fume (SF), investigations were taken. The strength and durability characteristics of these mixes are compared with the mixes without SF. Compressive strengths of 60 MPa, 70 MPa and 110 MPa at 28days were obtained by using the 10 percent replacement of cement with SF. The results also indicate that the SF concretes possess superior strength properties. [11]

K. Ghutke & Bhandari

Examine the Influence of silica fume in concrete. Results indicated that the silica fume is a better replacement of cement. The rate of strength gain in silica fume concrete is high. Workability of concrete decreases as increase with % of silica fume. The optimum value of compressive strength can be achieved in 10% replacement of silica fume. As strength of 15% replacement of cement by silica fume is more than normal concrete. The optimum silica fume replacement percentage is varying from 10 % to 15 % replacement level. [12]

L. Hanumesh, Varun & Harish

Observes the Mechanical Properties of Concrete Incorporating Silica Fume as Partial Replacement of Cement. The primary purpose of this study is to examine the mechanical properties of M20 grade control concrete and silica fume concrete with different percentages (5, 10, 15 and 20%) of silica fume as a partial replacement of cement. The outcome showed that the compressive strength of concrete is increased by the use of silica fume up to 10% replacement of cement. From 10% there is a reduction in compressive strength and the split tensile strength of concrete is increased by the use of silica fume up to 10% replacement of cement. From 10% there is a decrease in split tensile strength. The optimal percentage of replacement of cement by silica fume is 10% for M20 grade of concrete. [13]

M. Sasikumar & Tamilvanan

Performed an Experimental Investigation on Properties of Silica Fumes as a Partial Replacement of Cement. The main parameters investigated in this study is M30 grade concrete with partial replacement of cement by silica fume0%, 25%, 30%, 40% and 50%. The normal consistency increases about 40% when the silica fume percentage increases from 0% to 25%. The optimum 7 and 28-day compressive strength has been obtained in the 25 % silica fume replacement level. As well the split tensile strength is high when using 25% silica fume replacement for cement. [14]

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*N. **Sharma & Seema***

Examined the issue of partial replacement of cement with silica fume on compressive strength of concrete. M20 grade of concrete with a W/C ratio as 0.5 and percentage replacement was 0%, 10%, 20%. The optimum compressive strength is obtained at 20% cement replacement by a Silica Fume at all age strata (i.e. 24 hours, 7& 28 days). The 28 days' compressive strength at 20% replacement was found to be 32.29 MPa with a slump value of 21 mm. [15]

III. EXPERIMENT DETAILS

A. Material used and their Properties

i. Cement

Ordinary Portland cement of 43 grades manufactured by Shree Ultratech Cement was used throughout the Experimental investigation. The quality of the cement was confirming to IS 8112:1989 was used in the field [16] (Specification, Bureau of Indian Standards, New Delhi). The Physical Properties of OPC Cement are shown in Table 1.

Table 1: Physical Properties of Ordinary Portland cement

Properties	Observed Value
Normal Consistency	30%
Initial Setting Time	45 minutes
Final Setting Time	615 minutes
Specific Gravity	3.15
Compressive Strength at 28 days	43.5 MPa

ii. Fine Aggregate

Fractions from 4.75 mm to 150 microns are termed as fine aggregate. Locally available river sand passed through 4.75mm IS sieve is applied as fine aggregate conforming to the requirements of IS 383:1970 [17]. The specific gravity of sand is 2.60 and fineness modulus is 3.30. The free and compacted bulk density values obtained are 1645 Kg/m^3 and 1780 Kg/m^3 and water absorption is 1.10%. The effects of the various test are tabulated in table 2.

Table 2: Physical Properties of Fine Aggregate

Properties	Observed Value
Grade Zone	III
Fineness Modulus	2.26
Specific Gravity	2.60
Silt Content	1.67%

iii. Coarse Aggregate

Fractions from 20 mm to 4.75 mm are used as coarse aggregate. The Coarse aggregate are obtained from a local quarry, conforming to IS 383:1970 is used. The coarse aggregate with a maximum size 20 mm. The free and compacted bulk density values obtained are 1600 Kg/m^3 and 1790 Kg/m^3 respectively, water absorption of 1.50%. The effects of the various test are tabulated in table 3.

Table 3: Physical Properties of Coarse Aggregate

Properties	Observed Value
Fineness modulus	6.50
Specific Gravity	2.70
Water Absorption	1.50%

iv. Copper Slag

Copper slag used in this work was brought from Taj Abrasive Industries. Physical and Chemical Properties of copper slag Used in the Study are tabulated in table 4 and 5. **Copper Slag used in the Experiment** is shown in Figure 1.

Figure 1: Copper slag

Table 4: Physical Properties of Copper Slag

Properties	Description
Particle shape	Multifac
Appearance	Black &
Type Air	Cooled
Specific gravity	3.51
Bulk density at 25^0 C (Ton/m^3)	1.8 - 2.2
Hardness	5 – 7 Mohs
pH	6.5
Conductivity at 25^{0}C	Nil
Moisture Content	< 0.1%

(Source: Taj Abrasive Industries, Rajasthan)

Table 5: Chemical Properties of Copper Slag

Properties	% of Chemical component
SiO_2	33-35 %
Fe_2O_3	40-44%
Al_2O_3	4-6%
CaO	0.8-1.5%
MgO	1-2%

(Source: Taj Abrasive Industries, Rajasthan)

v. Silica Fume

Silica Fume used in this work was brought from Taj Abrasive Industries, Rajasthan. Physical and Chemical Properties of Silica Fume used in the experiment are tabulated in Table 6 and 7. Silica Fume used in the experiment is shown in figure 2

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Figure 2: Silica Fume

Table 6: Physical Properties of Silica Fume

Properties	Description
Diameter	0.1-0.2 micron
Appearance	Grey
Type Air	Cooled
Bulk density (Kg/m^3)	650

Table 7: Chemical Properties of Silica Fume

Properties	% of Chemical component
SiO_2	91.50 %
Fe_2O_3	0.94%
Al_2O_3	0.9%
CaO	0.28%
MgO	1.19%
K_2O	0.85%
Na_2O	0.17%
TiO_2	0.10%

(Source: Taj Abrasive Industries, Rajasthan)

vi. Chemical Admixture

Chemical Admixtures (CICO PLAST SUPER-HS @1. 5%) are materials in the form of fluids that are summed to the concrete to make it certain characteristics not obtainable with plain concrete mixes. Properties of CICO PLAST SUPER-HS are shown 8.

Table 8: Properties of Admixture

racteristi	Description
Specific	1.14
Role in Concrete	Improves workability & flow properties, Produces concrete of very high strength.

(Source: Local Market, Lucknow, Uttar Pradesh, India)

vii. Mix Design

As per the Code IS: 10262 -2009 [18], the mix design was done for M40 grade mix and the amount of materials was estimated. Table 7 gives the quantities required for M40 grade of concrete Mix.

Table 9: Mix design and proportion of M40 grade concrete.

Grade	M40
Cement (kg/m^3)	431.17
F. A (kg/m^3)	625.2
C. A (kg/m^3)	1121.05
Water (kg/m^3)	172.46
W/C Ratio	0.4
Admixture (kg/m^3)	6.46
Mix Proportion	1:1.45:2.6

(Source: Reading from Design Mix Calculation as per IS 10262 (2009) by trail mix for 1 m^3 of concrete)

IV. EXPERIMENTAL METHODOLOGY

The evaluation of Copper Slag as a replacement of fine aggregate and Silica Fume as a replacement of Cement begins with the concrete testing. The study is conducted to analyze the compressive strength, split tensile Strength and Flexural Strength of concrete when the base materials, i.e. Fine Aggregate is replaced with Copper Slag and Cement is replaced with Silica Fume respectively. Firstly, the copper slag replacement was made at proportions 0%, 10%, 20%, 30%, 40%, and 50% by weight of M-40 grade concrete. Nine samples per batch were tested with the average strength values reported in this paper. The maximum mean value of the strength of a certain definite replacement proportion of fine aggregate with copper slag was noted. Now, the copper slag replacement is kept at the constant proportion (proportion attaining maximum average value of strength) and silica fume replacement was made at proportions 5%, 10% and 15%, by weight of M-40 grade concrete. Again, nine samples per batch were tested with the average strength values reported in this paper. In all total 27 cubes of OPC (150mm × 150mm × 150mm), 27 cylinders of OPC (150 mm x 300 mm) and 27 beams of OPC (100 mm x 100 mm x 500 mm) were examined and results were analyzed after curing 28 days. The result obtained from the partial replacement of fine aggregate with copper slag and partial replacement of cement with Silica fume is compared to conventional concrete.

Table 10: Partial Replacement of Fine Aggregate with Copper Slag

Water (w/c = 0.4 kg) = 9.5
Admixture (gm) = 356

S.No	%age replacement of copper slag	Cement (kg)	Fine aggregate (kg)	Copper slag (kg)	Coarse aggregate (kg)
1	0	23.76	34.45	0	61.78
2	10	23.76	31	3.45	61.78
3	20	23.76	27.56	6.89	61.78

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4	30	23.76	24.12	10.33	61.78
5	40	23.76	20.67	13.78	61.78
6	50	23.76	17.225	17.225	61.78

Table 11: Partial Replacement of Cement by Silica Fume with copper slag fixed as 40%

Water (w/c = 0.4 kg) = 9.5
Admixture (gm) = 356

S.No	% replacement of silica fume	Cement (kg)	Silica Fume (kg)	Fine aggregate (kg)	Copper slag (kg)	Coarse aggregate (kg)
1	5	22.57	1.18	20.67	13.78	61.78
2	10	21.38	2.37	20.67	13.78	61.78
3	15	20.19	3.56	20.67	13.78	61.78

V. DISCUSSION OF RESULT

i. Compressive Strength Test Results

The results in Table-12 show the compressive strength of M40 grade concrete with Copper slag at 28 days. Table 13 show the compressive strength of concrete with copper slag fixed as 40 % and varying proportions of silica fume. The percentage change in strength with respect to normal concrete at 28 days is graphically plotted.

Table 12 Compressive Strength of concrete at 28 days

% Replacement of Copper Slag	Compressive Strength (N/mm^2)
0	48.90
10	49.20
20	49.65
30	49.95
40	50.45
50	49.30

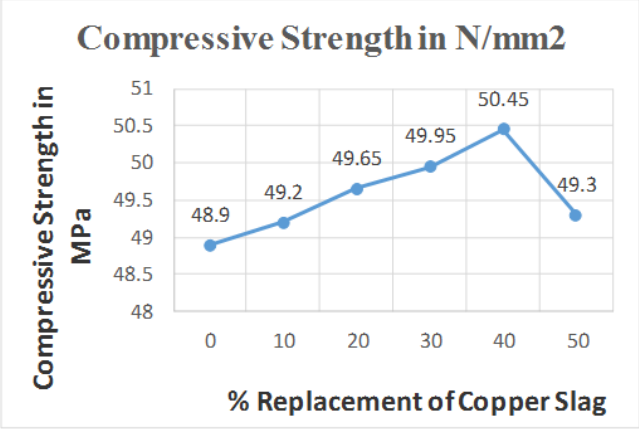

Figure 3: Compressive Strength of Concrete with Partial Replacement of fine aggregate by copper slag

Table 13: Compressive Strength of concrete at 28 days

(Partial Replacement of Cement, with Copper Slag Proportion, i.e. 40%)

% Replacement of Silica Fume	Compressive Strength (N/mm^2)
5	51.25
10	**53.76**
15	50.20

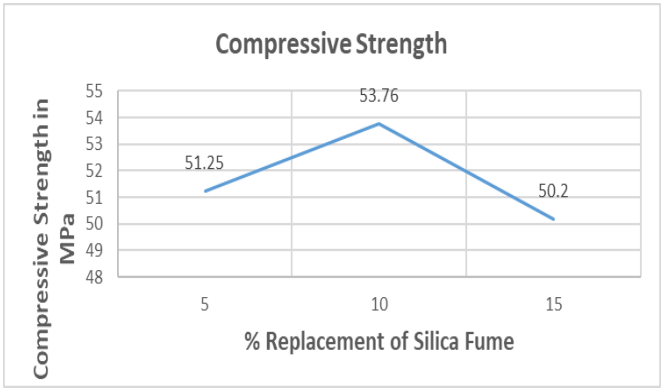

Figure 4: Compressive Strength of Concrete with Partial Replacement of Cement by Silica Fume

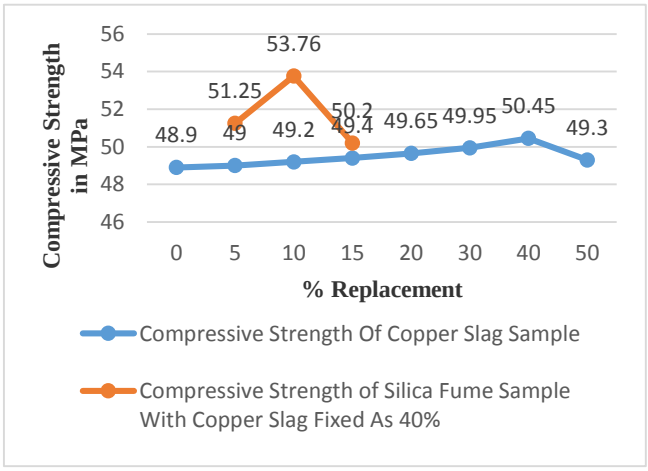

Figure 5: Comparison of Compressive Strength

ii. Split Tensile Strength Test Results

The results in table-12 shows the Split Tensile strength of M40 grade concrete with Copper slag and table-13 shows Split Tensile strength with copper slag fixed as 40% and varying silica fume at 28 days. The percentage change in strength with respect to normal concrete at 28 days is graphically plotted.

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Table 14: Split Tensile Strength of concrete at 28 days

% Replacement of Copper Slag	Split Tensile Strength (N/mm^2)
0	5.92
10	5.94
20	5.97
30	6.15
40	**6.50**
50	6.01

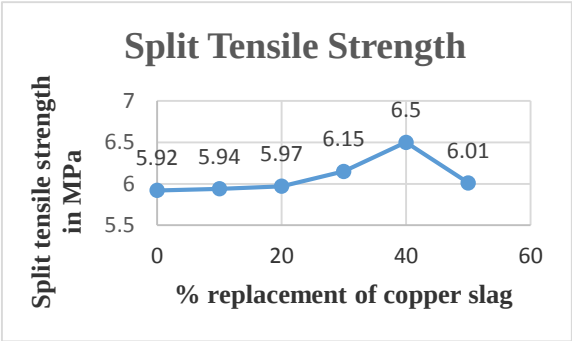

Figure 6: Split Tensile Strength of Concrete with Partial Replacement of fine aggregate by copper slag

Table 15: Split Tensile Strength of concrete at 28 days (Partial Replacement of Cement, with Copper Slag Proportion, i.e. 40%)

% Replacement of Silica Fume	Split Tensile Strength (N/mm^2)
5	6.70
10	**6.85**
15	6.15

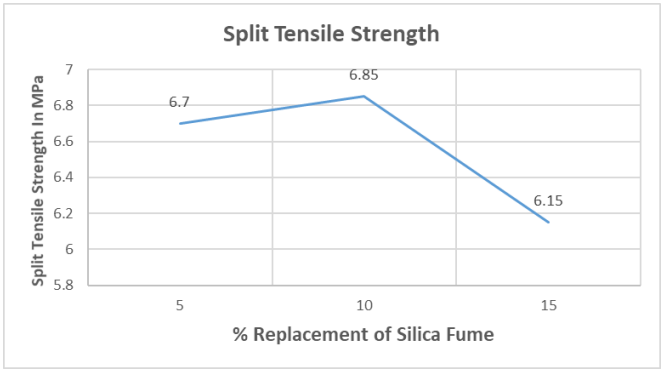

Figure 7: Split Tensile Strength of Concrete with Partial Replacement of Cement by Silica Fume

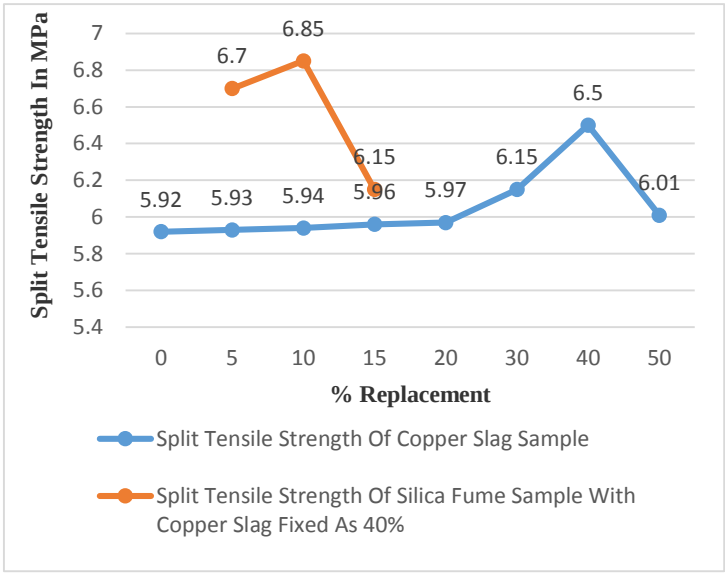

Figure 8: Comparison of Split Tensile Strength

iii. **Flexural Strength Test Results**

The results in table-14 show the flexural strength of M40 grade concrete with copper slag fixed and table-15 shows the flexural strength with Copper slag fixed as 40% and varying silica fume (at 28 days Along with Flexural strength, the percentage change in Flexural strength with respect to normal concrete is plotted. Figure 12 shows the testing of flexural strength.

Table 16: Flexural Strength of concrete at 28 days

% Replacement of Copper Slag	Flexural Strength (N/mm^2)
0	6.85
10	7.03
20	7.14
30	7.29
40	**7.41**
50	7.09

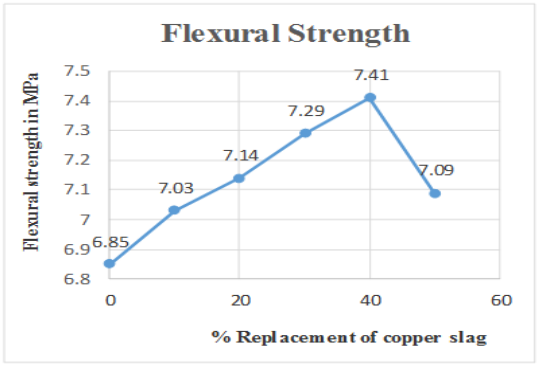

Figure 9: Flexural Strength of Concrete with Partial Replacement of Fine aggregate by Copper Slag

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Table 15: Flexural Strength of Concrete at 28 days (Partial Replacement of Cement, with Copper Slag Proportion, i.e. 40%)

% Replacement of Silica Fume	Flexural Strength (N/mm^2)
5	7.52
10	**7.63**
15	7.03

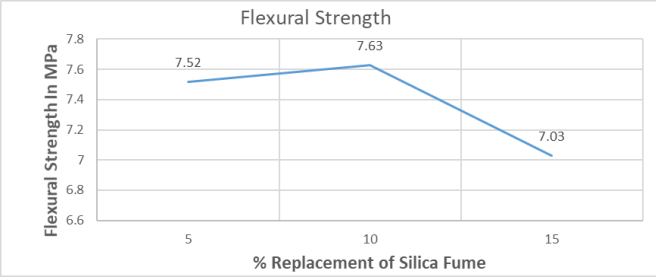

Figure 10: Flexural Strength of Concrete with Partial Replacement of cement by silica fume

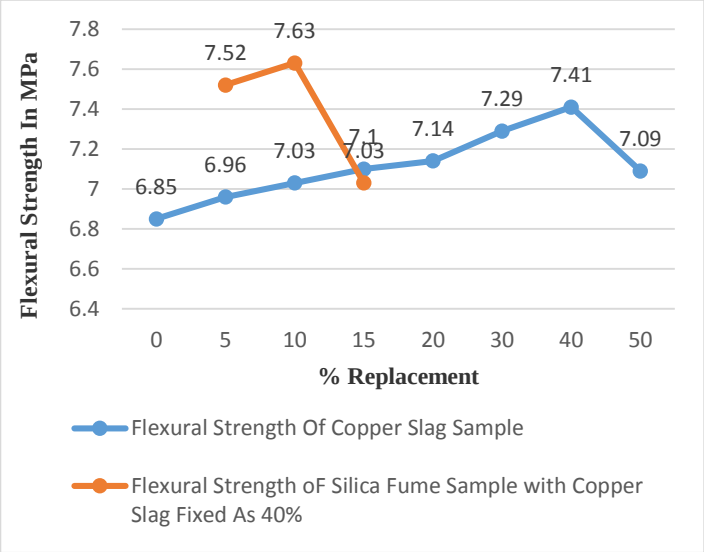

Figure 11: Comparison of Flexural Strength

Figure 12: Testing for Flexural Strength at Integral University, Advanced Material Testing Lab, Lucknow

VI. CONCLUSION

From the experimental investigations conducted, the following are the conclusions drawn.

- Copper slag is a desirable material for replacement of fine aggregate in concrete.
- Copper slag concrete showed a considerable gain in effectiveness when used within permissible quantities.
- The utmost intensity was achieved for 40 % replacement of fine aggregate with copper slag. Further increase of copper slag reduces the effectiveness.
- Silica Fume concrete showed a considerable gain in effectiveness when used within permissible quantities
- The utmost intensity was achieved for 10 % replacement of Cement with Silica Fume. Further addition of Silica Fume reduces the effectiveness.
- Compressive Strength was increased by 3.16% when compared to the Nominal mix for 40% replacement of fine aggregate with Copper Slag
- Split tensile Strength was increased by 9.79% when Compared to Nominal mix for 40% replacement of Copper Slag
- Flexural Strength was increased by 8.75% when Compared to Nominal mix for 40% Replacement of Copper Slag
- Copper Slag have a potential to provide alternative to fine aggregate Up to 40% and helps in maintaining the environment as well as economical balance.

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