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"Effect of copper slag as partial replacement of fine aggregate in concrete of M35 & M40 grade"

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Abstract: "Green concrete" is concrete that is produced using environmentally friendly industrial/concrete waste. The term "green concrete" refers to concrete that has undergone additional measures throughout the mix design and laying process to provide a long-life cycle and minimal maintenance surface. In current study, fine aggregates were replaced with copper slag at varying proportion of 10%, 20%, 30%, 35%, 40% and 50% in M35 and M40 grade of concrete. Laboratory testing was done to determine slump value, compressive strength value, split tensile value and flexural strength value. Along with laboratory tests, cost analysis was also carried out. After obtaining all the results, it has been concluded that the copper slag (35%) replacing fine aggregates gives the optimum results for both M35 and M40 grade of concrete.

IndexTerms **– Green Concrete, Copper Slag.**

I. INTRODUCTION

A common and adaptable building material, concrete is crucial to the construction of buildings and infrastructure. It is a composite material made of cement, water, aggregate (such crushed stone or sand and gravel), and occasionally further admixtures or additives. One of the most popular and traditional building materials still in use today, concrete is prized for its affordability, strength, durability, and easy availability. Concerns about the environment are brought up by the concrete industry's reliance on natural resources, particularly aggregates. The manufacturing of concrete, which is projected to be 11 billion metric tons annually and is composed of 10-15% cementitious binder, 15% water, and 70–75% aggregate (mostly natural rock), has increased demand for aggregates as a result of globalization, privatization, and liberalization.

To produce concrete, water, cement, and aggregates are taken as per the design mix and then mixed properly until the mixture resembles paste. The mixture of cement and water binds the aggregates which creates a solid mass. After that, the concrete mixture is poured into the molds, where it is allowed to solidify, after hardening of the concrete, it is removed from the moulds and cure it for 7 to 28 days for strength gaining. Concrete properties and performance can be influenced by a number of variables, including as mix design, curing conditions, material quality, and construction methods. Ensuring the desired strength, longevity, and durability of concrete requires appropriate mix proportioning, placing techniques, and quality control systems.

"Green concrete" is concrete that is produced using environmentally friendly industrial/concrete waste. The term "green concrete" refers to concrete that has undergone additional measures throughout the mix design and laying process to provide a long-life cycle and minimal maintenance surface. e.g. Energy saving, CO2 emissions, wastewater. The concept of "green concrete" is ground breaking in the annals of the concrete industry. This was first invented in Denmark in the year 1998 by Dr.WG. Wastes like slag, power plant wastes, recycled concrete, mining and quarrying wastes, waste glass, incinerator residue, red mud, burnt clay, sawdust, combustor ash and foundry sand can be utilized in the production of concrete in some way or the other. Reducing concrete's negative environmental effects is the centre for Green Concrete's main objective.

There are numerous advantages of using green concrete instead of conventional concrete. They are as follows:

- Reduction in CO2 emission by at least 20%.
- Utilization of concrete industrial waste such as debris etc.
- Utilization of industrial waste products which caused landfill and environmental problems.
- Green Concrete needs less maintenance as it has better workability, strength and durability.
- Good thermal and fire resistance.
- Less utilization of natural resources which reduces the environmental burden.

One industrial by-product that is created during the copper manufacturing process is copper slag. Similar to fine and coarse sand, copper slag is a granular, glassy, blackish substance. It is created by:

(i) Roasting, in which Sulphur in the ore is eliminated as Sulphur Dioxide (SO2);
(ii) Smelting, in which the roasted product is melted in a siliceous flux and the metal is reduced; and
(iii) Converting, where the melt is de-sulphurized with lime flux, iron ore, or a basic slag and then oxygen lanced to remove other impurities.

As per IRC: SP:121-2018, the entire amount of copper slag accumulated was around 10 million tons, and approximately 2 million tons are generated annually at present. As per Sterlite Industries India Ltd, Tuticorin, every ton of copper will yield 2.5 to 3 tons amount of copper slag.

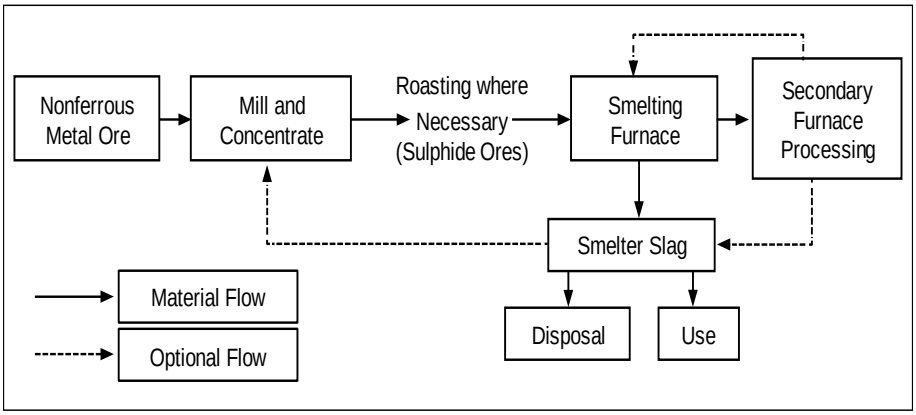

Figure 1. General Process Diagram of Copper Slag Production

Copper slag can be utilized in the process of manufacturing concrete by replacing river sand. This is an intriguing concept, especially in light of the growing worry over the depletion of river sand resources. Utilizing leftover resources, such as copper slag, not only addresses the issue of resource depletion but also advances sustainable building techniques.

II. MATERIALS

Cement: Portland Pozzolana Cement (PPC) was obtained and used in the current experimental investigation which confirms to Indian Code IS: 1489 (part-2):2015. Parameters of cement such as setting time and fineness of cement were determined in laboratory.

Table 1. Physical Properties of Cement.

Property	Cement
Unit weight, Kg/m^3	3150
Specific gravity	3.15
Initial Setting Time (min.)	85
Final Setting Time (min.)	232

Fine Aggregates: Sand was obtained for concrete preparation as fine aggregates. The zone of sand was determined with sieve analysis (gradation method) as per the specifications of Indian Code i.e. IS: 383-1970. The physical properties of fine aggregates are as follows:

Table 2. Physical Properties of Sand (Fine Aggregates).

Test	Value Obtained
Specific Gravity	2.53
Fineness Modulus	2.32
Silt Content	4.28 %

Coarse Aggregates: Angular shaped crushed aggregates of nominal size (20mm along with 10mm) were mixed together in proportion of 2:1 and then sieve analysis of carried out for gradation of the obtained aggregates.

Table 3. Physical Properties of Graded Coarse Aggregates

Test	Results
Specific Gravity	2.74
Water Absorption	0.58 %

Water: Readily available potable water which was used for the manufacturing the concrete in the laboratory confirming to Indian specifications of IS: 456-2000.

Copper Slag: Copper Slag, used as a replacement material for fine aggregates, was obtained from Ghatshila, Jharkhand. The specific gravity of Copper Slag is 2.80 g/cc. The chemical composition of this material is shown below:

Table: 4. Chemical Composition of Copper Slag.

S. No.	Composition	Proportion (%)
1.	Silica (SiO_2)	33-35
2	Alumina (Al_2O_3)	4-6
3	Ferrous Oxide (FeO)	50-55
4	Calcium oxide (CaO)	0.8-1.5
5	Magnesium oxide (MgO)	1-2
6	Copper (Cu)	0.6-0.9
7	Nickel (Ni)	0.01-0.03
8	Lead (Pb)	0.01-0.04
9	Zinc (Zn)	0.2-0.3

Figure 2. Copper Slag.

III. Results and Discussions

Results of Slump Flow Test

The ease of mixing, placing, compacting, and finishing fresh concrete without segregation or excessive bleeding is referred to as workability. It is essential to ensure proper construction and getting the concrete's required strength and durability. The concrete's workability was evaluated in the laboratory using a slump flow test. The following are the outcomes:

Table: 5. Slump Flow Test Results.

Mix Designation	Slump Value (mm) M35	Slump Value (mm) M40
CM	87	83
SC10	90	80
SC20	86	79
SC30	79	74
SC35	75	70
SC40	70	67
SC50	63	62

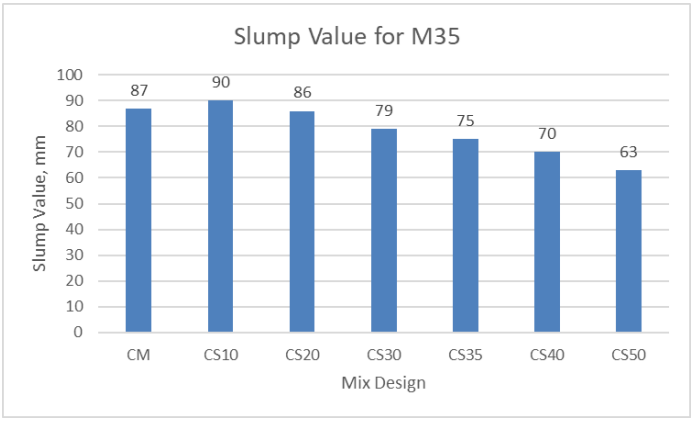

Figure 3. Slump Flow Test results for M35.

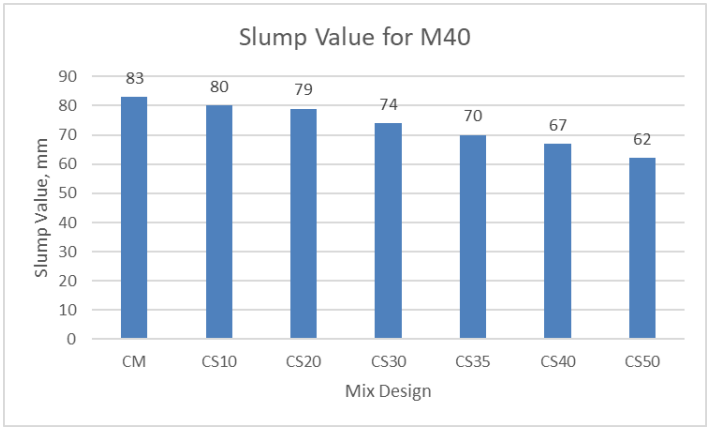

Figure 4. Slump Flow Test results for M40.

Results of Compressive Strength

In order to evaluate concrete's ability to withstand the crushing loads, the compressive strength test was performed. In laboratory compressive strength test was conducted to ascertain the concrete's compressive strength at every replacement level. Three cube specimens of each combination were evaluated for this at 7 and 28 days after the curing time. The test findings were recorded and are shown below:

Table: 6. Compressive Strength Test Results.

Mix	Compressive Strength for M35		Compressive Strength for M40	
	at 7 Days	at 28 Days	at 7 Days	at 28 Days
CM	28.00	43.62	32.11	48.53
SC10	28.67	43.95	32.60	49.03
SC20	29.62	44.26	32.96	49.21
SC30	29.82	44.65	33.38	49.68
SC35	30.60	45.06	34.51	50.62
SC40	30.49	44.92	33.24	49.65
SC50	29.22	43.53	33.00	49.24

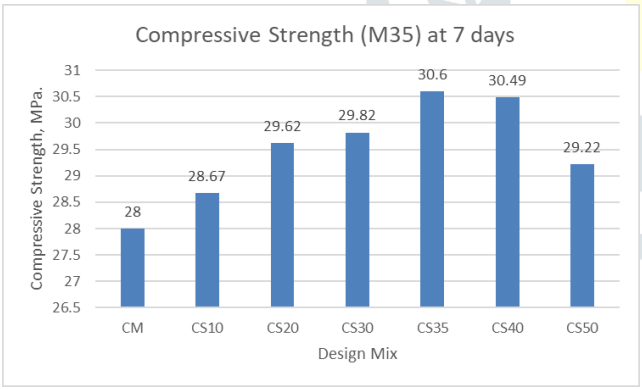

Figure 5. Compressive Strength Test Results at 7 days for M35.

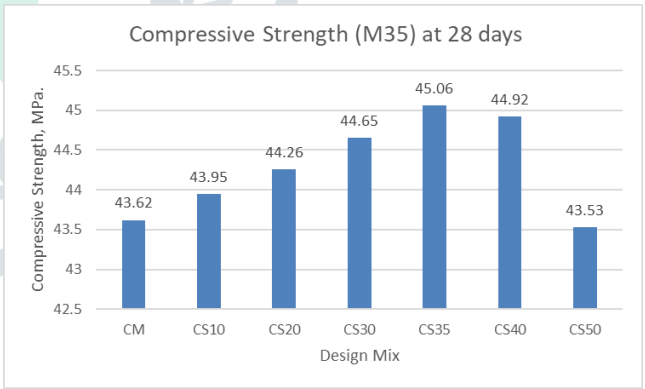

Figure 6. Compressive Strength Test Results at 28 days for M35.

For M35 Grade of concrete, the compressive strength value for control mix comes out to be 28 MPa and 43.62 MPa at 7 days and 28 days respectively. The maximum value of compressive strength for M35 comes out to be 30.60 MPa and 45.06 MPa at 7 days and 28 days respectively, which is 9.30% (at 7 days) and 3.30% (at 28 days) more than the value of control mix.

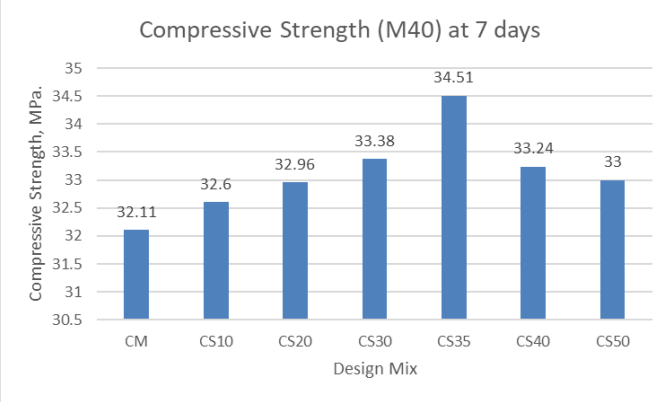

Figure 7. Compressive Strength Test Results 7 days for M40.

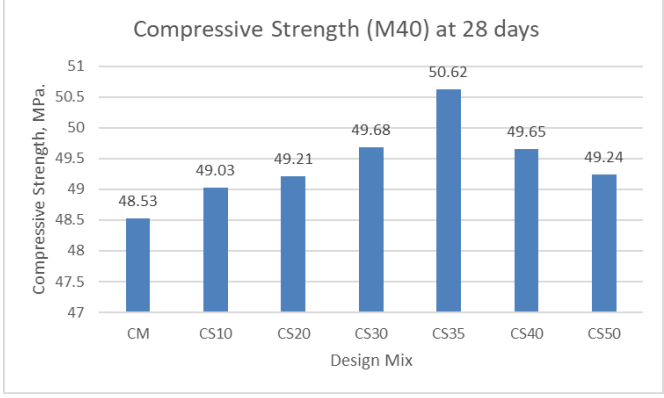

Figure 8. Compressive Strength Test Results at 28 days for M40

For M40 grade, the compressive strength value for control mix was 32.11 MPa and 48.53 MPa at 7 days and 28 days respectively. The maximum value of strength for M40 comes out to be 34.51 MPa and 50.62 MPa at 7 days and 28 days respectively, which is 7.5% (at 7 days) and 4.31% (at 28 days) more than the value of control mix.

Results of Split Tensile Strength

In laboratory split tensile strength test was conducted at every replacement level. Three cylindrical specimens of each combination were evaluated for this at 7 and 28 days after the curing time. The test findings were recorded and are shown below:

Table: 7. Split Tensile Strength Test Results.

Mix	Split Tensile Strength for M35		Split Tensile Strength for M40	
	at 7 Days	at 28 Days	at 7 Days	at 28 Days
CM	2.76	4.23	2.98	4.51
SC10	2.91	4.3	3.21	4.58
SC20	2.98	4.43	3.29	5.63
SC30	3.21	4.65	3.42	5.72
SC35	3.33	4.78	3.58	5.82
SC40	3.28	4.55	3.51	5.75
SC50	3.03	4.31	3.38	5.45

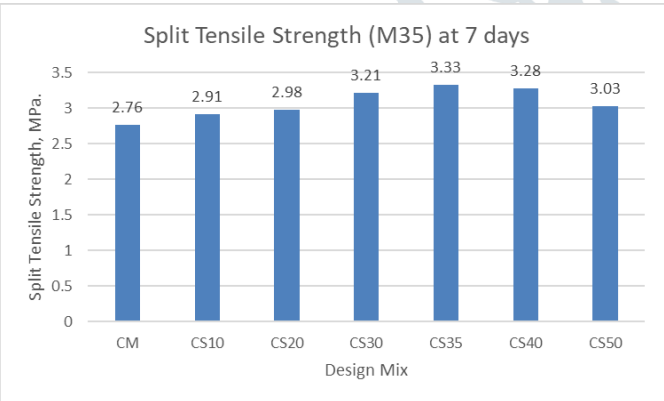

Figure 9. Split Tensile Strength Test Results at 7 days for M35.

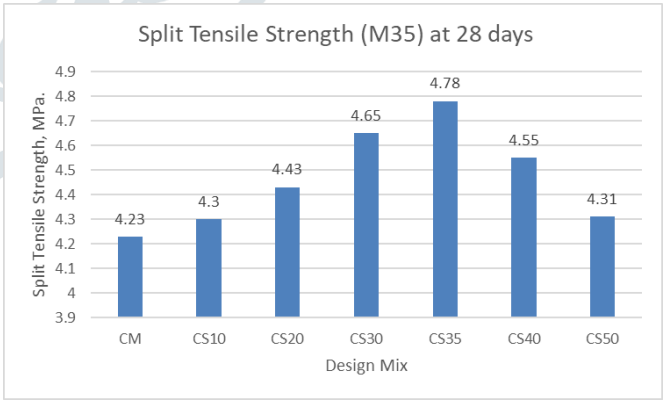

Figure 10. Split Tensile Strength Test Results at 28 days for M35.

For M35 grade, the Split Tensile strength value for control mix was 2.76 MPa and 4.23 MPa at 7 days and 28 days respectively. However, the maximum value of strength for M35 comes out to be 3.33 MPa and 4.78 MPa at 7 days and 28 days respectively, which is 20.65% (at 7 days) and 13.00% (at 28 days) more than the value of control mix.

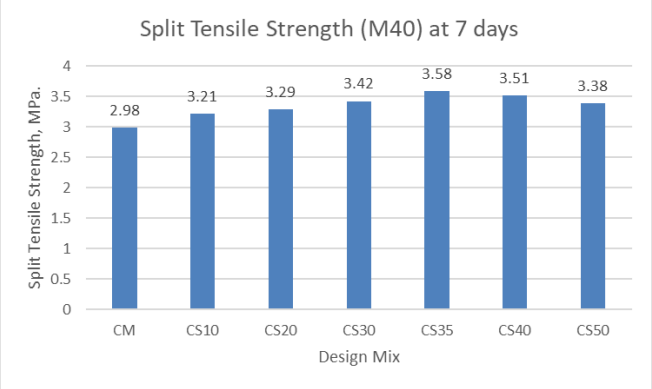

Figure 11. Split Tensile Strength Test Results 7 days for M40.

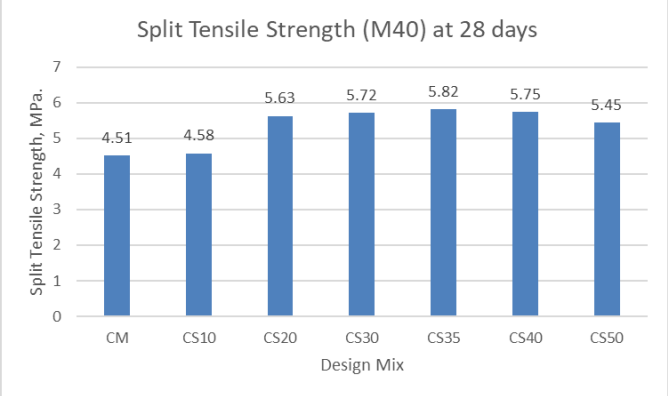

Figure 12. Split Tensile Strength Test Results at 28 days for M40.

For M40 grade, the Split Tensile strength value for control mix was 2.98 MPa and 4.51 MPa at 7 days and 28 days respectively. However, the maximum value of strength for M40 comes out to be 3.58 MPa and 5.82 MPa at 7 days and 28 days respectively, which is 20.13% (at 7 days) and 29.05% (at 28 days) more than the value of control mix.

Results of Flexural Strength

This test is performed in laboratory on beam samples which measures the concrete's ability to withstand bending or flexural loads. Three beam specimens of each combination were evaluated for this at 7 and 28 days after the curing time. The test findings were recorded and are shown below:

Table: 8. Flexural Strength Test Results.

Mix	Flexural Strength for M35		Flexural Strength for M40	
	at 7 Days	at 28 Days	at 7 Days	at 28 Days
CM	3.65	5.38	3.85	5.61
SC10	3.73	5.55	3.93	5.68
SC20	3.8	5.61	3.97	5.74
SC30	4.01	5.69	4.09	5.85
SC35	4.16	5.82	4.21	6.02
SC40	4.06	5.74	4.1	5.92
SC50	3.89	5.58	3.88	5.71

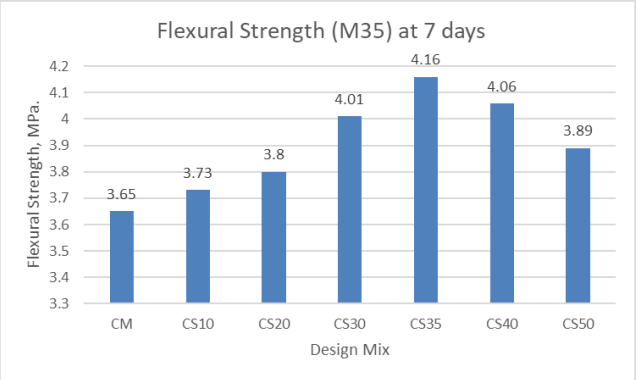

Figure 13. Flexural Strength Test Results at 7 days for M35.

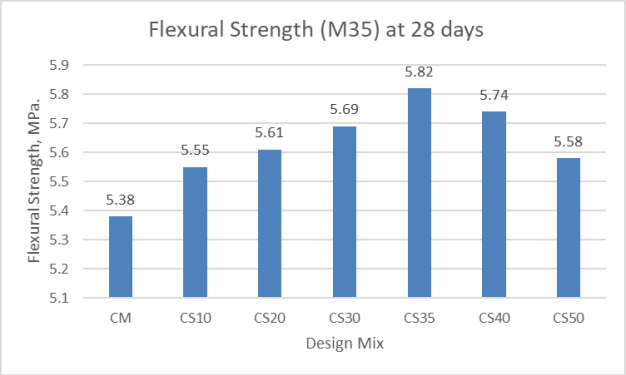

Figure 14. Flexural Strength Test Results at 28 days for M35.

For M35 grade, the flexural strength value for control mix was 3.65 MPa and 5.38 MPa at 7 days and 28 days respectively. However, the maximum value of strength for M35 comes out to be 4.16 MPa and 5.82 MPa at 7 days and 28 days respectively, which is 14.00% (at 7 days) and 8.18% (at 28 days) more than the value of control mix.

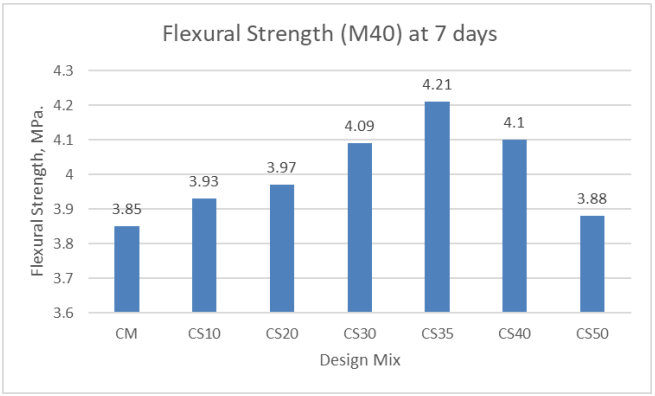

Figure 15. Flexural Strength Test Results 7 days for M40.

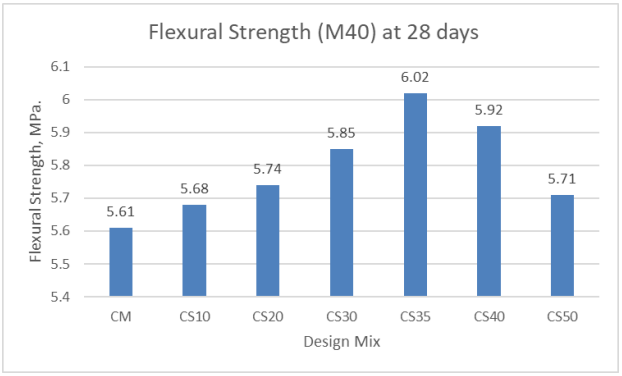

Figure 16. Flexural Strength Test Results at 28 days for M40.

For M40 grade, the flexural strength value for control mix was 3.85 MPa and 5.61 MPa at 7 days and 28 days respectively. However, the maximum value of strength for M40 comes out to be 4.21 MPa and 6.02 MPa at 7 days and 28 days respectively, which is 9.65% (at 7 days) and 7.31% (at 28 days) more than the value of control mix.

Cost Analysis

The cost analysis plays a critical role in determining the economic factor for green concrete. Therefore, in current study, cost analysis was performed for the most optimum percentage of the copper slag (35%) replacing fine aggregates. The analysis is as follows:

Cost of Fine Aggregates (Sand) = Rs. 1.0 per Kg

Cost of Copper Slag (Replacement Material) per m3 = Rs. 2.5 per Kg

Table: 9. Cost analysis for M35 grade.

Concrete Type	Material	Rate per Kg	Quantity (kg/m^3)	Total Price
Conventional	Sand (100%)	Rs. 1/-	766.52	Rs. 766.52/-
Replacement	Sand (65%)	Rs. 1/-	498.24	Rs. 498.24/-
	Copper Slag (35%)	Rs. 2.5/-	268.28	Rs. 670.71/-

Therefore,

Total cost of fine aggregates in conventional concrete is Rs. 766.52/-

Total cost of fine Aggregates with 35% copper slag is Rs. 1168.95/-

The cost of fine aggregates with copper slag per m3 is 52.5% higher than the cost of fine aggregates in conventional concrete.

Table: 10. Cost analysis for M40 grade.

Concrete Type	Material	Rate per Kg	Quantity (kg/m^3)	Total Price
Conventional	Sand (100%)	Rs. 1/-	753.42	Rs. 753.42/-
Replacement	Sand (65%)	Rs. 1/-	489.72	Rs. 489.75/-
	Copper Slag (35%)	Rs. 2.5 /-	263.70	Rs. 659.25/-

Therefore,

Total cost of fine aggregates in conventional concrete is Rs. 753.42/-

Total cost of fine Aggregates with 35% copper slag is Rs. 1149/-

The cost of fine aggregates with copper slag per m3 is 52.5% higher than the cost of fine aggregates in conventional concrete.

IV. CONCLUSIONS

The experimental study was conducted by replacing fine aggregates with varying proportion of copper slag to reduce the use of raw material such as sand. The laboratory tests were carried out and the final outcomes were recorded. Based on these outcomes, the following conclusion was drawn:

1. The slump value decreases as the proportion of copper slag in concrete increases. The slump value for control mix for grade M35 is 87 mm and for M40 is 83 mm. While the lowest slump values come out to be 63 mm (M35) and 62 mm (M40) for SC50 concrete mix.
2. For M35 grade, the compressive strength value for control mix comes out to be 28 MPa and 43.62 MPa at 7 days and 28 days respectively. The maximum value of strength for M35 comes out to be 30.60 MPa and 45.06 MPa at 7 days and 28 days respectively, which is 9.30% (at 7 days) and 3.30% (at 28 days) more than the value of control mix. And for M40 grade, the strength value for control mix was 32.11 MPa and 48.53 MPa at 7 days and 28 days respectively. The maximum value of compressive strength for M40 comes out to be 34.51 MPa and 50.62 MPa at 7 days and 28 days respectively, which is 7.5% (at 7 days) and 4.31% (at 28 days) more than the value of control mix.
3. For M35 grade, the Split Tensile strength value for control mix was 2.76 MPa and 4.23 MPa at 7 days and 28 days respectively. However, the maximum value of strength for M35 comes out to be 3.33 MPa and 4.78 MPa at 7 days and 28 days respectively, which is 20.65% (at 7 days) and 13.00% (at 28 days) more than the value of control mix. And for M40 grade, the Split Tensile strength value for control mix was 2.98 MPa and 4.51 MPa at 7 days and 28 days respectively. However, the maximum value of strength for M40 comes out to be 3.58 MPa and 5.82 MPa at 7 days and 28 days respectively, which is 20.13% (at 7 days) and 29.05% (at 28 days) more than the value of control mix.
4. For M35 grade, the flexural strength value for control mix was 3.65 MPa and 5.38 MPa at 7 days and 28 days respectively. However, the maximum value of strength for M35 comes out to be 4.16 MPa and 5.82 MPa at 7 days and 28 days respectively, which is 14.00% (at 7 days) and 8.18% (at 28 days) more than the value of control mix. And for M40 grade, the flexural strength value for control mix was 3.85 MPa and 5.61 MPa at 7 days and 28 days respectively. However, the maximum value of strength for M40 comes out to be 4.21 MPa and 6.02 MPa at 7 days and 28 days respectively, which is 9.65% (at 7 days) and 7.31% (at 28 days) more than the value of control mix.
5. The cost of fine aggregates with copper slag (35%) per m3 is 52.5% higher than the cost of fine aggregates in conventional concrete for both grades i.e. M35 and M40.

V. RECOMMENDATION

From the results of the current experimental study, it is recommended to use 35 % of copper slag by replacing fine aggregates to obtain optimum strength of concrete of grade M35 and M40. Future research should focus on determining the long-term performance of concrete entailing copper slag.

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