Strength and Durability Assessment of Concrete with Fine Aggregate Replaced by Copper Slag

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Abstract— **The present work focuses on assessing the viability of applying blasted copper slag, an industrial by-product obtained during the manufacture of copper, as a replacement material for fine aggregate in concrete mixes. The chemical composition of copper slag including iron, silica and aluminum oxide, which makes it work efficiently as fine aggregate in concrete and also imparts pozzolanic activity in concrete. Mix design of concrete was done on weight basis by adding various percentages of copper slag. The replacement percentages focused on this study are 20%, 30%, 40%, 50% and 60%. Different tests were carried out on these mixes to investigate its strength, workability and durability properties, hence established the optimum percentage of copper slag that can be used as a replacement to fine aggregate in concrete. The change in trend of all these properties, with different replacement percentages was examined and the reason for the change is also investigated. The increase in concrete characteristics after 28 days, due to the pozzolanic property of copper slag has also been studied.**

Keywords— Concrete, Copper slag, Fine aggregates, Replacement, Strength, Durability, Workability

I. INTRODUCTION

The construction industry exhibits a rapid growth and is in constant need of natural resources for the development of the infrastructure. Simultaneously, the wastes generated from the industries are increasing rapidly. This research was performed to evaluate the potential use of copper slag, an industrial waste, as sand replacement in the production of concrete. Copper slag is a by-product of the manufacture of copper. It has various applications like blasting medium replacement in industrial cleaning, as a filler material and additive to Portland cement in construction industry etc. Copper slag is characterized by lower water absorption and comparable gradation of fine aggregate, at the same time producing a pozzolanic effect in concrete matrix when incorporated due to its chemical composition. These characteristics make copper slag to be a promising replacement material for fine aggregate without compromising the workability, strength and durability of conventional concrete.

II. MATERIAL PROPERTIES

A. Cement
The Cement used for preparing specimens is Ultratech OPC 53 grade cement. *Table I* shows the physical properties of cement

B. Fine aggregate
Fine aggregate used for the preparation of control concrete and replaced concrete is Manufactured sand of zone II confirming to IS 383: 1970. It is observed to have a specific gravity of 2.69 and water absorption of 1.42 when tested according to the standard procedure mentioned in IS 2386 Part 2 (1963).

Sand grains are angular, shape of the grains approximating to spherical form, elongated and flattened grains being present only in very small or negligible quantities. *Fig.1* shows the gradation curve for fine aggregates observed by sieve analysis.

C. Coarse Aggregates
The coarse aggregate having a nominal size of 20mm is used for the experimentation. The coarse aggregates used are tested for their gradation, specific gravity and water absorption as recommended in IS 2386 Part 1 (1963), IS 2386 Part 3 (1963), IS 2386 Part 3 (1963) respectively. It is observed from the testing that the coarse aggregates used have a specific gravity of 2.73 and water absorption 0.34. *Fig.2* shows the gradation curve for coarse aggregates observed by sieve analysis.

Sl no.	Properties	Results
1	Grade	53
2	Specific Gravity	3.13
3	Initial Setting Time	150 minutes
4	Final Setting Time	225 minutes

TABLE I: PROPERTIES OF CEMENT
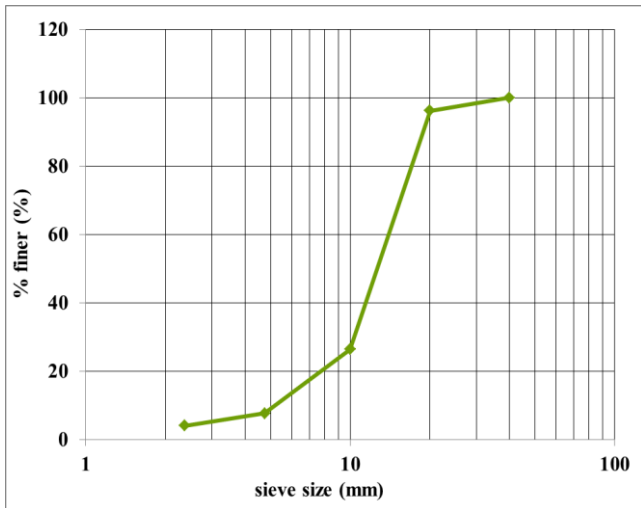

Fig 1: Gradation curve of fine aggregates
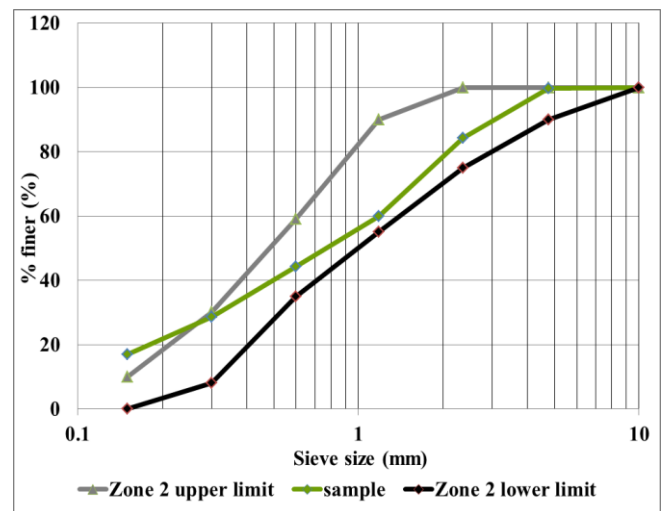
Fig 2: Gradation curve of coarse aggregates

D. Copper Slag

The properties and chemical composition of copper slag are listed in *Table II* indicates the physical properties of copper slag and *Table III* shows the chemical composition of copper slag. *Fig.3* emphasizes the gradation curve of copper slag obtained by conducting sieve analysis.

TABLE II: PHYSICAL PROPERTIES OF COPPER SLAG

Sl. No.	Property	Results
1	Grain Shape	Angular, Multifaceted
2	Appearance	Black Glassy
3	Specific Gravity	3.50
4	Particle Size	0.075 to 4.75mm
5	Water absorption	0.16

TABLE III: CHEMICAL COMPOSITION OF COPPER SLAG

Constituents	Weight
Silica (SiO_2) (Combined as Silicate)	26 – 30%
Free Silica	Less than 0.5%
Alumina (Al_2O_3)	2%
Iron Oxide as FeO	42 – 47%
Calcium Oxide CaO	1 – 2%
Magnesium Oxide MgO	1.04%
Copper Oxide CuO	6.1% max
Sulphates	0.13%

Fig 3: Gradation curve of copper slag

III. METHODOLOGY

Mix proportions are worked out after attaining the material properties. According to the requirement, various specimens are cast to test for their characteristics. Fresh as well as hardened concrete are tested to attain properties like workability, durability and strength on various apparatus according to standard procedure given by specified IS codes or ASTM codes. Results are then analyzed and property variation with replacement is found.

A. Mix proportioning

Mix proportioning is done conforming to IS 10262: 2009 for M25 grade concrete. Percentage of copper slag replacement is taken as 20%, 30%, 40%, 50% and 60%. *Table IV* shows the mix proportioning worked out for the same for 1 m^3 volume.

TABLE IV: MIX PROPORTION FOR 1 m^3

Mix	Cement (kg)	FA (kg)	Copper slag(kg)	CA (kg)	Water (kg)
Control Concrete (CC)	383.16	701.23	0	1161.24	205.50
20 % FA replaced with copper slag (CS20)	383.16	560.98	140.25	1161.24	205.50
30 % FA replaced with copper slag (CS30)	383.16	490.86	210.37	1161.24	205.50
40 % FA replaced with copper slag (CS40)	383.16	420.74	280.49	1161.24	205.50
50 % FA replaced with copper slag (CS50)	383.16	350.62	350.62	1161.24	205.50
60 % FA replaced with copper slag (CS60)	383.16	280.49	420.74	1161.24	205.50

B. Specimen requirements

3 Cubes of size 150mm x 150mm x 150mm were cast for Compressive strength and Surface resistivity test for all the mixes. 3 Cylinders of height 300mm and diameter 150mm were cast for Split tensile strength test for all the mixes. For the Rapid Chloride Penetration test, 3 RCPT disc of diameter 100mm and height 50mm were cast for all the mixes.

IV. TEST PROCEDURE

A. Slump Test

The test specimen is prepared by mixing the components of concrete in suitable proportions with a water-cement ratio of 0.5. The test is administered employing a metal mould within the sort of a conical frustum mentioned as Abram's cone with a height of 30cm, bottom diameter 20cm and top diameter 10cm. A tamping rod 16mm diameter and 60cm long was used.

B. Compressive Strength Test

Three cubes of size 15 cm x 15 cm x 15 cm are used for experimentation. Mixing of concrete was done in a laboratory batch mixer for preparation of cubes and are cured for 28 days. The specimens, after curing, are surface dried and placed centrally on the base plate of the machine with load applied continuously at the rate of $140kg/cm^2$/minute till the specimen fails. The maximum load at which the specimen failed is recorded.

C. Split tensile Strength Test

Three cylindrical specimens of 150 mm diameter and 300 mm height are tested in surface dry condition after curing for at least 28 days for each mix using a compression testing machine. The cylindrical specimen was placed such that the longitudinal axis is perpendicular to the load. Load was applied uniformly and continuously without shock at a nominal rate within the range 1.2 N/mm^2/min to 2.4 N/mm^2/min, until failure. The maximum applied load at failure was recorded.

D. Surface Resistivity Test

Three cubes of size 150 x 150 x 150 mm are used for the test. The Resipod proceq meter was made to come in contact with the levelled surface of the specimen which has undergone a curing of at least 28 days. The probes of the proceq meter were dipped into water in a tray immediately before taking measurement since it is completely dry and no measurement is possible since the current is carried by the ions in the pore liquid. Then the instrument is placed on the specimen and the screen will directly show the reading which was the measure of resistivity offered by the particular specimen against the flow of ions in kΩcm. Once a stable reading has been achieved, the reading was noted.

E. Rapid Chloride Penetration Test

Three cylindrical discs of diameter 100 mm and height 50 mm are used for testing. Cylindrical specimen, side coated with epoxy, was put in a vacuum chamber for 3 hours. Then the specimen was made to vacuum saturated for about 1 hour and then for about 18 hours allowed to soak in water. It is further placed in the test device where the left-hand side (–)

of the test cell is filled with a 3% NaCl solution and the right-hand side (+) is filled with 0.3N NaOH solution. The system is connected and a 60-volt DC potential that is applied for 6 hours where readings are taken every 30 minutes.

V. RESULTS

A. Workability- Slump test

Slump test is conducted on all mixes for a desired slump of 75 mm corresponding to medium workability. *Table V* shows the slump obtained for various mixes. A graph is plotted with percentage of copper slag replaced v/s slump observed as shown in *Fig.4*. An equation is formed with the results obtained as $y = 0.00667x^2 + 0.01667x + 65$

where, x = percentage of copper slag replaced

y = slump in mm,

so that the corresponding slump can be predicted for any percentage replacement of fine aggregate with copper slag. From CC to CS 60, the slump observed shifts from 65 mm to 90 mm. Hence, a gradual increase can be seen in the slump value with an increase in the percentage replacement of fine aggregate with copper slag.

TABLE V: SLUMP OBSERVED

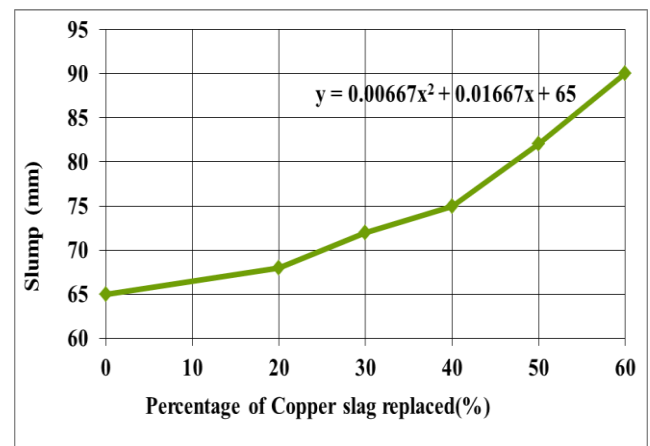| Mix	Slump observed	Workability result
CC	65 mm	Medium
CS20	68 mm	Medium
CS30	72 mm	Medium
CS40	75 mm	Medium
CS50	82 mm	Medium
CS60	90 mm	Medium

Fig 4: Graphical representation of slump observed

Fineness modulus of fine aggregates is 2.6 while that of copper slag is 2.7. This can result in a smaller specific surface area. Also, the surface texture of copper slag is glassy and smooth, which reduces its water absorption. Furthermore, the water absorption of fine aggregate is 1.42 % while that of copper slag is 0.46 %. These all result in increased free water content in the concrete matrix, that in turn may have increased the workability with increase in copper slag content in mixes.

B. Compressive strength

Compressive strength of CC and CS40 is found out after 28 days curing and is obtained as 40.57 MPa and 39.87 MPa respectively. All the remaining mixes were tested at 60 days due to inconveniences related to pandemic outbreaks.

A graph is drawn with the results obtained as in *Fig.5* An equation is formed with the 60-day compressive strength curve in order to project the 28 days strength to 60 days strength for an efficient and accurate analysis, given by,

$$y = -0.0089x^2 + 0.3913x + 40.63$$

where, x = percentage replacement by copper slag in %

y = 60-day compressive strength in MPa

Hence, the approximate values for CC and CS 40 at 60 days as well as the results obtained for other mixes are tabulated in *Table VI.*

All observed values were above the target strength of 31.6 MPa of M25 concrete. Strength gain with age is also observed comparing the 28 day and predicted 60-day compressive strength.

Maximum increase in compressive strength is observed at 30% replacement. Hence, optimum replacement of fine aggregate with copper slag can be attained at 30 % replacement, with an increase in strength than normal control concrete.
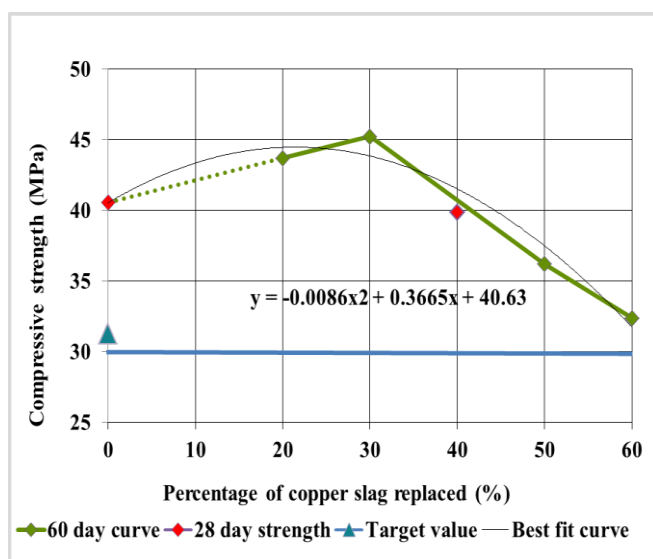
TABLE VI: 60-DAY COMPRESSIVE STRENGTH OBSERVED

Mix	Approximate 60-day compressive strength (MPa)	% Increase in compressive strength
CC	40.63	-
CS20	43.72	+ 7.61
CS30	45.23	+ 11.32
CS40	42.04	+ 3.47
CS50	36.20	- 10.9
CS60	32.40	- 20.26

C. Split tensile strength

Split tensile strength of various concrete mixes including the control concrete (CC) as well as mixes with fine aggregate replaced by copper slag in various percentages is found out conforming to IS code recommendations and is expected to be near a target split tensile strength of 2.8 MPa as per ACI 318.

Split tensile strength of CC and CS 40 is observed at 28 days which is 3.37 and 3.35 respectively. All other mixes were tested at 60 days. A graph is plotted with percentage of copper slag replaced and observed split tensile values as shown in *Fig.6.*

An equation is formulated with the 60-day split tensile strength to find the approximate 60-day strength of specimens tested at 28 days for an impartial analysis given by,

$$y = -0.0002x^2 + 0.004x + 3.35$$

where, x = percentage replacement of copper slag in %

y = 60 day split tensile strength in MPa

The approximate values of the mixes hence found as well as the observed 60-day values of split tensile strength are tabulated in *Table VII.*

The values are above the target strength desired and a slight strength gain for 28-day samples is observed. Split tensile strength increased from CC to CS 30 and decreased further. Hence, an optimum replacement with copper slag can be achieved at 30 %, with a strength gain than CC.
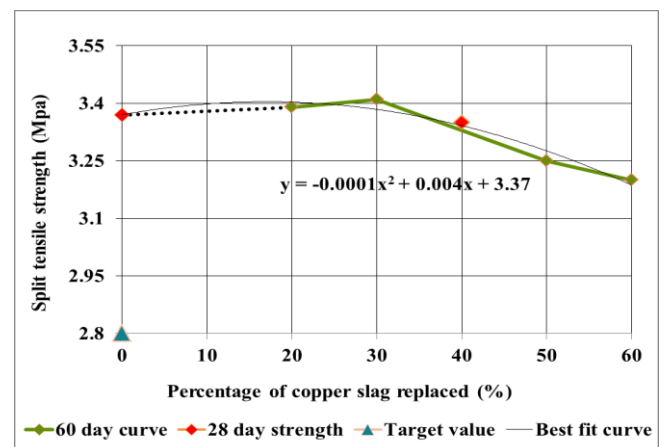

Fig 5: Graphical representation of compressive strength

Fig 6: Graphical representation of split tensile strength

TABLE VII: 60-DAY SPLIT TENSILE STRENGTH OBSERVED

Mix	Approximate 60 day split tensile strength (MPa)	% Increase in split tensile strength
CC	3.37	-
CS20	3.39	+ 0.59
CS30	3.41	+ 1.19
CS40	3.36	+ 0.29
CS50	3.25	- 3.56
CS60	3.20	- 5.04

TABLE VIII: 60-DAY RESISTIVITY OBSERVED

Mix	Approximate resistivity observed (60 days) (kΩcm)	% Increase in resistivity
CC	32.22	-
CS20	34.47	+ 6.99
CS30	36.70	+ 13.91
CS40	33.13	+ 2.83
CS50	28.20	- 12.47
CS60	26.63	-17.34

D. Surface resistivity test

Surface resistivity of CC and CS 40 are found using non destructive testing methods at a curing period of 28 days for which value of 32.20 kΩcm and 31.16 kΩcm is obtained respectively.

Other mixes are tested at 60 days and a graph is plotted with these observations as y axis and percentage replacement of copper slag as X axis as given in *Fig 7*. The 28-day resistivity values are projected to 60-day values for approximate analysis with the help of equation formulated from the 60-day resistivity curve, given by,

$$y = -0.0066x^2 + 0.287x + 32.218$$

where, x = percentage replacement of copper slag in %

y = 60-day surface resistivity in kΩcm

The 60-day resistivity values are tabulated in *table VIII*.

The resistivity values when compared to standard values given in AASHTO TP 95 shows a low permeability, indicating high resistivity. *Table IX* indicates the standard values of surface resistivity as per AASHTO TP 95. Resistivity is observed to at a peak at 30% replacement indicating the optimum replacement percentage along with improved conditions of durability.
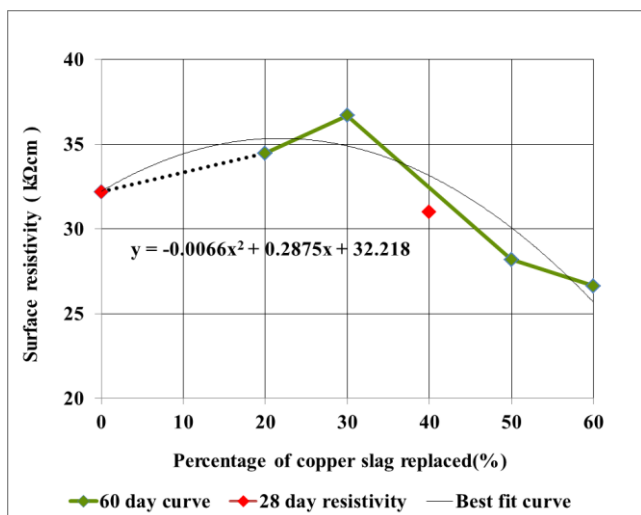
TABLE IX: STANDARD VALUES OF SURFACE RESISTIVITY

Range	Penetrability
<12	High
12 TO 21	Moderate
21 TO 37	Low
37 TO 254	Very low
>254	Negligible

E. Rapid chloride penetration test

The permeability of chloride ions is measured using RCPT test where CC and CS 40 has amount of charge passed as 1570.28 coulombs and 1560.17 coulombs respectively after 28-day curing. All other mixes were tested at a period of 60 days curing for which values obtained are graphically represented in *Fig. 8*. An analytical equation is formulated using the 60-day values obtained to find approximate 60-day permeability of specimens tested at 28 days. The equation is given as,

$$y = 0.0449x^2 - 2.1287x + 1573.5$$

where, x = percentage replacement of copper slag in %

y = 60-day RCPT value in coulombs.

The values observed as well as approximated values for 28 days permeability are given in *Table X*.
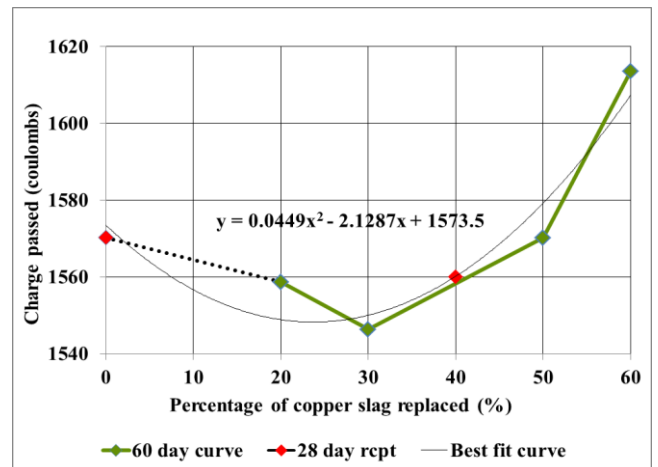

Fig 7: Graphical representation of surface resistivity

Fig 8: Graphical representation of permeability

TABLE X: 60-DAY PERMEABILITY OBSERVED

Mix	Approximate charge passed -60days(coulomb)	% Decrease in permeability
CC	1573.50	-
CS20	1558.69	+ 0.94
CS30	1546.32	+ 1.73
CS40	1560.19	+ 0.85
CS50	1570.17	+ 0.21
CS60	1613.49	- 2.54

Maximum decrease in permeability of chloride ions is observed at 30 % replacement. All the values are under the range of low permeability as per standard provisions in - ASTM C 1202, as given in *Table XI*.

Hence, optimum replacement of fine aggregates with copper slag can be done at 30 % with an increased durability than CC.

TABLE XI: STANDARD VALUES OF SURFACE RESISTIVITY

Current passing (Coulombs)	Chloride ion permeability
>4000	High
2000 to 4000	Moderate
1000 to 2000	Low
100 to 1000	Very low
<100	Negligible

VI. CONCLUSIONS

- The slump value of concrete was found to increase from 65mm to 90mm from CC to CS60. However, slump for all the mixes were in the range of medium workability as per IS 456:2000.
- Compressive strength of concrete increased from 40.57 MPa to 45.23 MPa from CC to CS30, which is 11.3% increase.
- For all the mixes from CC to CS60, compressive strength and split tensile strength are greater than target strength.
- Split tensile strength of concrete increased from 3.37 MPa to 3.41 MPa from CC to CS30, which is 1.19% increase.
- Surface resistivity of concrete increased from 32.2 to 36.7 kΩcm from CC to CS30, which is 13.91% increase.
- Chloride ion penetration of concrete decreased from 1570.28 to 1546.32 Coulomb from CC to CS30 depicting better durability. However, all the mixes from CC to CS60 lies in the range of low permeability.

- Hence, the optimum percentage of copper slag replacement in concrete, with respect to its strength and durability characteristics was found to be 30%.
- From the analytical relationship between concrete properties Vs. percentage of copper slag replaced, there is an increase in strength and durability aspects from 28 to 60 days. This is due to the pozzolanic property of copper slag

A. Scope for future research

Constant W/C ratio kept for all mixes was found to be a prime reason for decrease in strength and durability as the percentage replacement by copper slag increases. This is due to low water absorption of copper slag. Therefore, moisture correction factor can be worked out to reduce the extra water in the matrix and thereby the properties of replaced concrete such as workability, strength and durability can be effectively improved.

The strength of concrete is found to improve post 28 days, however the same needs to be studied in detail.

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