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Durability Aspects of Copper Slag Admixed Concrete

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Abstract
This research work reports the results of a study undertaken in enhancing properties of concrete with partial replacement of fine aggregate with copper slag. In this context an experimental investigation to study the durability effects of replacement fine aggregate (by weight) with zero, optimum (40%) and full (100%) percentages of copper slag were taken up. Durability properties like permeability, elevated temperature effect, sorptivity, water absorption were conducted along with these test Young's Modulus and size effect ratio is also conducted. A control mixture of proportions 1:2.10:3.18 with w/c of 0.45 was designed for the M30 concrete. Fine aggregate (Sand) was replaced with 40% and 100% of copper slag as optimum and full replacement. Test results showed that the replacement of fine aggregate with copper slag reduced permeability, sorptivity and water absorption up to 100%. In addition to this Young's Modulus and elevated temperature test gives good result at 40% replacement. These findings suggest that copper slag in the range 40% could potentially replace sand in concrete without compromising the strength and durability aspects.

Keywords: copper slag, permeability, sorptivity, water absorption, elevated temperature effect, Young's modulus

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INTRODUCTION
Sustainable development is mandatory to protect the environment. Aggregate, besides cement and water, forms one of the main constituent materials of concrete since it occupies nearly 55%–80% of concrete volume, Aggregates which are used in concrete are obtained either from natural sources or by crushing large size rocks. The rapid increase in the natural aggregates consumption every year due to the increase in the construction industry worldwide means that the aggregate reserves are being depleted, the concrete industry globally will consume 8–12 billion tons annually of natural aggregates. This large consumption of natural aggregates will cause destruction of the environment. Therefore there is an urgent need to find and supply alternative substitutes for natural aggregates by exploring the possibility of utilization of industrial by-products and waste materials like copper slag in making concrete. This will lead to sustainable concrete design and greener environment. [1–3]

MATERIALS USED
1) Cement
Ordinary Portland Cement (OPC) of grade 53 conforming to IS 12269:1987 was used. The specific gravity of the cement is found to be 3.11

2) Fine Aggregate
Good quality river sand was used as fine aggregate conforming to grading zone I of IS 383:1970 was used. Its specific gravity is 2.68

3) Coarse Aggregate

Coarse aggregate obtained from local quarry units have been used for this experimental investigation. Maximum size of aggregate used is 20mm with specific gravity of 2.77

4) Copper Slag

Copper slag (CS) is a waste material widely obtained from the industrial sector in the manufacturing of copper during the matte smelting process. Copper slag is black in color with glassy appearance. Copper Slag has comparable particle size distribution compared to sand, with sand having more fines. Specific Gravity of Copper slag is bit high 3.4 when compared with sand 2.68. The water absorption is nearly 0.1% compared to 1.27% of sand.[4–6]

Copper slag has a number of favorable mechanical properties for aggregate use such as excellent soundness characteristics, good abrasion resistance and good stability. Copper slag exhibits pozzolanic properties since it contains a low CaO content and other oxides, such as Al2O3, SiO2, and Fe2O3. Free and combined limes contribute to nearly 63% of the chemical composition of OPC whereas copper slag has a very low lime content of approximately 6%. It indicates that copper slag is not chemically a very reactive material to be used as a cementitious material since sufficient quantity of lime must be available in order to reach the required rate of hydration.

In this investigation Copper Slag is collected from Sterlite Copper India limited Tuticorin Tamil Nadu. The specific gravity found to be 3.4

5) Water

The locally available potable water, as per IS: 456-2000 which is free from concentration of acid and organic substances is used for the preparation of concrete.

EXPERIMENTAL INVESTIGATIONS

In present study M30 grade concrete were designed as per IS 10262:2009

Finalized Mix Design is given in Table 1.

Table 1. *Finalized Mix Proportions.*

Finalized mix	**Cement (kg/m³)**	**Fine aggregate (kg/m³)**	**Coarse Aggregate (kg/m³)**	**Water (l/m³)**
Proportion	1	2.11	3.19	0.45
M30 IS 10262:2009	380	796	1212	164

Water Absorption

The test is done to study the porosity property of the concrete. After ambient curing the specimens for 28 days, the specimen kept in oven at at 65°C and weight should be checked dry weight for every 8 hours.

Usually it will take 24 hours to attain constant weight. After obtaining the constant weight the specimens will be placed in buckets filled with water. It will be kept for one day and weighed. The surface water should be removed using absorbent like sponge or paper. [6,7]

Permeability

Permeability property indicates the pore connectivity in the matrix of the specimen. This test is conducted as per IS 3085 (1965) Standards. The pressure exerted is 14 kg/cm^2 = 140 m pressure head.

Sorptivity

Sorptivity can be found according to ASTM C1585. The sorptivity is a material property that characterizes the tendency of a material to absorb and transmit water by capillarity. Lower the value of sorptivity, the higher the resistance of concrete towards water absorption. The volume of water absorbed per unit cross sectional area at each time interval was evaluated and the sorptivity determined from the slope of the graph of the water absorbed against the square root of time. It was conducted at the age of 28 days after initial curing of 28 days.

Elevated Temperature Effect

Temperature can cause spalling in the concrete and also under high temperature it may not allow moisture to escape resulting in build-up of pore pressure and rapid development of micro cracks leading to a faster deterioration of strength. This test was conducted to identify the strength loss in elevated temperature and spalling resistance.

The cubes were tested in muffle furnace for 200, 400 and 600°C for 3 hours each. Initial and final weights have been noted before and after the test. Strengths of each cube is calculated using compression testing machine.

Modulus of Elasticity

The modulus of elasticity of concrete is a function of the modulus of elasticity of the aggregates and the cement matrix and their relative proportions. The modulus of elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develops.

RESULTS AND DISCUSSIONS

Water Absorption

Water absorption test was carried on control mix, Optimum mix and full replaced mix with copper slag. The variation of water absorption is given in Table 2. The results are graphically shown in Figure 1.

Table 2. *Water Absorption.*

Mix designation	Percentage water absorption
CS0	4.1
CS40	2.81
CS100	2.42

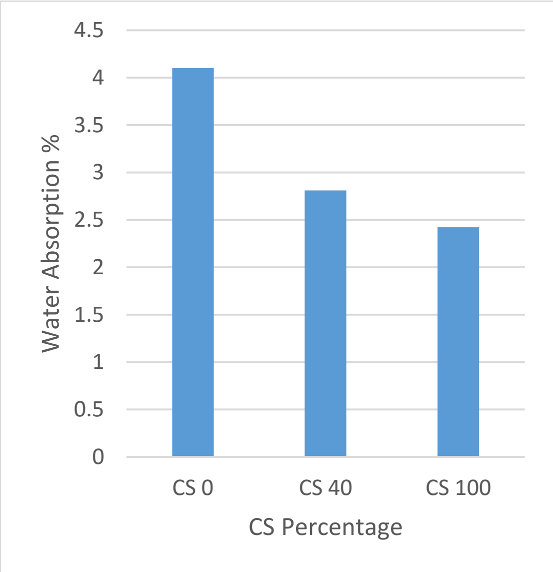

Fig. 1. *Water Absorption.*

It shows that with increase in copper slag content the concrete mix get dense and the free pores in the concrete get filled by the copper slag resulting in reducing the water absorption

Sorptivity

The test to find the co efficient of sorptivity was carried on control mix, Optimum mix and full replacement mix. The 150 × 150 × 150 mm cubes were prepared and used for the test after 28 days period of normal water curing. The variation of sorptivity for different mixes is given in Table 3. The results are graphically shown in Figure 2

Table 2. *Sorptivity.*

Mix designation	Sorptivity mm/min$^{1/2}$
CS0	0.14
CS40	0.09
CS100	0.04

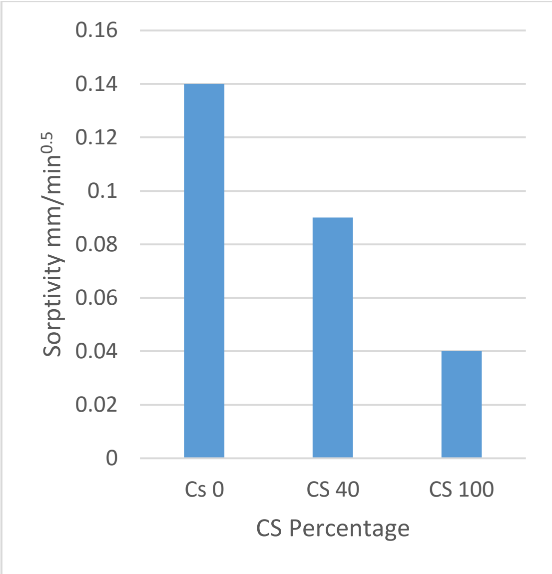

Fig. 2. *Coefficient of Sorptivity.*

The sorptivity values are getting reduced from control mix to full replacement mix. The addition of copper slag making the concrete dense and impermeable thus closing the free pores of concrete and thus hindering the capillary action.

Permeability

Permeability property indicates the pore connectivity in the matrix of the specimen. The test is conducted for control mix, Optimum mix and full replacement mix. 100 × 100 mm cubes are prepared to conduct the test after 28 days of curing.

The permeability values are given in Table 4. The results are graphically shown in Figure 3. [8–10]

Table 4. *Permeability.*

Mix designation	Permeability (m/s)
CS0	4.62×10^{-11}
CS40	4.36×10^{-11}
CS100	3.76×10^{-11}

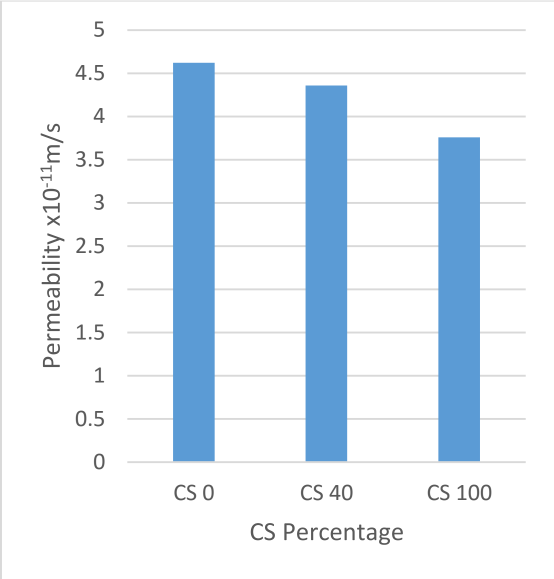

Fig. 3. *Coefficient of Permeability*

Elevated Temperature Effect

The test was conducted to identify the strength loss in elevated temperature and spalling resistance. The cubes were tested in muffle furnace for 200^{0}C, 400^{0}C and 600^{0}C for 3 hours each. Initial and final weights have been noted before and after the test. Strengths of each cube is calculated using compression testing machine. The percentage change in weight and strength are shown Table 5

Table 5*. Elevated Temperature Effects.*

Mix designation	Temperature (°C)	Percentage change in weight	Percentage change in compressive strength
	200	1.65	+12.57
CS0	400	3.15	–8.3
	600	4.25	–22.15
	200	1.51	+8.28
CS40	400	3.43	–10.49
	600	4.08	–27.5
	200	1.69	7.87
CS100	400	3.26	–9.31
	600	4.74	–28.64

The temperature effect result shows that the CS makes the concrete highly impermeable and under high temperature it does not allow moisture to escape resulting in build-up of pore pressure and rapid development of micro cracks leading to a faster deterioration of strength.

Modulus of Elasticity

The modulus of elasticity of concrete is a function of the modulus of elasticity of the aggregates and the cement matrix and their relative proportions.

The modulus of elasticity obtained is shown in Table 6 and Figure 4

Table 6. *Modulus of Elasticity.*

Mix designation	Modulus of elasticity (GPa)
CS0	35.23
CS40	37.63
CS100	34.17

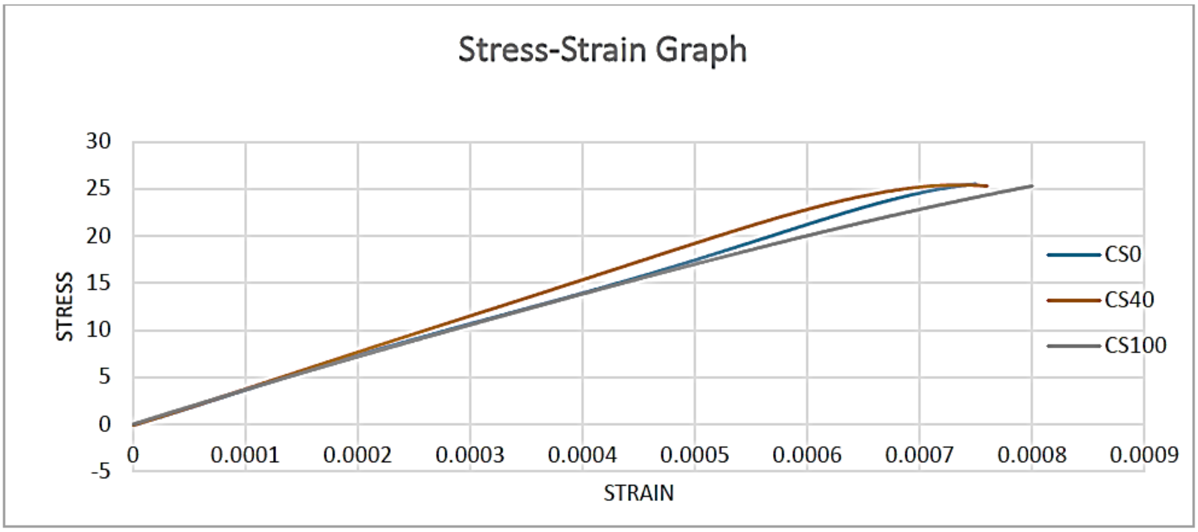

Fig. 4. *Stress Strain Curve.*

CONCLUSION

1) Water Absorption value reduced from 4.1% (CS0) to 2.8 % (CS40) and 2.4% (CS100).
2) Water absorption value has cut down below 3% for both CS40 and CS100.
3) Sorptivity value is reduced from 0.13mm/min$^{1/2}$ for CS0 to 0.04 mm/min$^{1/2}$ for CS100.
4) Sorptivity value for CS40 and CS100 is less than 0.1 mm/min$^{1/2}$ which classify the concrete in the category good.
5) Permeability of the mix reduced from 4.76 x 10^{-11} m/s to 3.61 x 10^{-11} m/s showing the CS makes the concrete impermeable.
6) Water absorption, Permeability and sorptivity results conclude the copper slag used makes the concrete dense and highly impermeable.
7) At an elevated temperature of 200°C the compressive value increased by 8% for CS40 and by 7% for CS100.
8) The Increase in strength may be due to hydration of excess free water present in the pores.
9) At 400°C the compressive strength is reduced by 10% for CS40 and 9% for CS100.
10) At 600°C the compressive strength is reduced by 27% and 28% for CS40 and CS100.
11) The decrease in strength may be due to the evaporation of water from the calcium silicate hydrate structure reducing the strength.
12) CS makes the concrete highly impermeable and under high temperature it does not allow moisture to escape resulting in build-up of pore pressure and rapid development of micro cracks leading to a faster deterioration of strength.
13) Copper Slag may be also acting as an insulating material since at 400°C as reduction is in the range of 10%.
14) Young's Modulus of the obtained in the range of 34 GPa to 37 GPa.

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