EFFECTIVE UTILIZATION OF COPPER SLAG FOR THE PRODUCTION OF GREEN AND SUSTAINABLE CONCRETE

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Abstract: Scarcity and increasing cost of river sand due to large scale depletion of river bed has created a huge demand for alternative form of fine aggregate in preparation of concrete by the construction industry and builders. Several non-conventional resources such as stone dust, fly ash, carbonated sand, copper slag etc. with higher percentage of silica (SiO_2) have been tried out as a substitute to river sand as fine aggregate in concrete preparation. Out of these non-conventional materials, copper slag is one such industrial waste, which is produced during the metal smelting process of copper production. Few studies have indicated that it can be suitably used as one of the major component of green concrete contributing towards reducing CO_2 emission from concrete. As part of this research, experimental studies have been conducted to study various strength and durability aspects of copper slag admixed concrete and outcome on strength properties of concrete by partially replacing river sand with copper slag has been promising, also the optimum percentage of copper slag has been established as 40% for partial replacement of sand. However to prove copper slag as a building material it is imperative to study the durability aspects of copper slag concrete as well. This paper presents the mechanical properties and durability properties of copper slag concrete. An attempt has been made to find the optimum percentage of copper slag for partial replacement of sand in preparation of concrete from strength perspective. From durability perspective, effect of elevated temperature and acid attack on copper slag concrete have been presented. The results show that copper slag concrete has an excellent strength and durability properties compared to normal concrete and can be effectively utilized as a partial replacement of fine aggregate in preparation of green and sustainable concrete.

Index Terms **- Copper Slag. High Temperature. Acid Attack. Compressive Strength. Durability.**

1. INTRODUCTION

Copper slag is a waste material produced through the metal smelting phase of copper production. According to ICSG (International Copper Study Group), the global copper production in 2017 was about 19.1 million tonnes. During metal smelting phase, approximately 2.5 kgs of copper slag is produced for extracting 1 kg of copper from the ore. The amount of waste produced is too huge which creates a big disposal problem for the copper manufacturing plants. Huge piles of copper slag can be seen around the copper manufacturing plants which is a big concern from the perspective of environmental pollution. Copper slag have been tried as a landfilling material, also few strength studies have proved that copper slag can be used as a partial replacement of sand in concrete. However, durability aspects of concrete is a major issue these days owing to several deteriorations caused by environmental and manmade disorders. Major attention was generally given to strength criteria of concrete, however lately durability criteria of concrete also drew consideration of the researchers and engineers. Generally, durability of concrete is the ability to resist the chemical attack, unforeseen events, abrasion and weathering action without compromising the essential strength properties. Durable concrete performs in a satisfactory manner in the working condition during its anticipated service life. This paper presents the initial experimental investigation results for identifying the optimum percentage of copper slag in concrete to be used as a partial replacement of sand. Further, as part of durability study the impact of high temperature and acids attack on copper slag concrete (with optimum percentage of copper slag) and have been examined and compared with normal concrete.

2. MATERIAL PROPERTIES

2.1 Coarse Aggregate

Angular crushed granite metal of size 20mm, having specific gravity 2.6 and fineness modulus 7.1 was used. Loose state bulk density and compacted state bulk density were found to be 1414 kg/m^3 and 1550 kg/m^3 respectively. The water absorption was found to be 1.1%.

2.2 Fine Aggregate

Locally available river sand having specific gravity 2.6 and fineness modulus 2.4 was used for this experimental investigation. Loose state bulk density and compacted state bulk density were found to be 1597 kg/m^3 and 1700kg/m^3 respectively. The water absorption was found to be 1.20%.

2.3 Cement

53 grade ordinary portland cement having specific gravity 3.094, fineness modulus 4.62% and normal consistency 32% was used. The quality of the cement was verified by conducting various tests as per IS 4031-1988, and confirming to specifications of IS 12269-1987.

2.4 Copper Slag

Copper slag having specific gravity 3.47 and fineness modulus 3.3 was used for this experimental investigation. Loose state bulk density and compacted state bulk density were found to be 1898 kg/m^3 and 2024 kg/m^3 respectively. The water absorption was found to be 0.24%. According to the chemical analysis 33.52% of silica was found in the copper slag used in the current investigation.

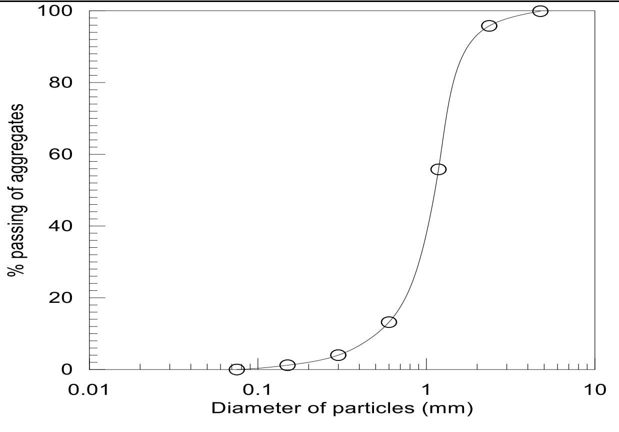

Figure 1: Grading of Copper Slag

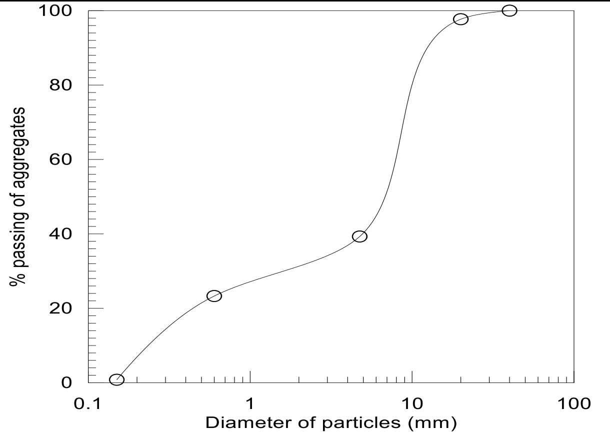

Figure 2: Combined grading of Aggregates

Table 1: Chemical Composition of Cement

S. No.	Composition	Percentage (in %)
1	Sulphuric Anhydride	1.93
2	Loss of Ignition	1.39
3	Magnesia	1.12
4	Insoluble Residue	1.14
5	Alumina Iron Ratio	1.18
6	Alkali Oxides	0.6
7	LimeSaturation Factor	0.82

Table 2: Chemical Composition of Copper Slag

S. No.	Composition	Percentage (in %)
1	Iron - Fe_2O_3	55.8
2	Silica - SiO2	33.52
3	Aluminium - Al_2O_3	3.8
4	Calcium –CaO	3.14
5	Potassium - K_2O	0.76
6	Magnesium –MgO	0.72
7	Sodium - Na_2O	0.4
8	Titanium - TiO_2	0.5
9	Copper – Cu	0.99

3. Mix Design and Mixes

According to IS: 10262 – 2009, the concrete mix design was done and the materials quantities were calculated. Six type of concrete mixes were prepared by replacing copper slag by river sand from 0% to 50% (CS0, CS10, CS20, CS30, CS40 and CS50). From the compressive strength test results the optimum percentage of copper slag was fixed and further the concrete test specimens with optimum percentage of copper slag were used to study the effect of high temperature and compared with normal concrete. The mix proportions is presented in the Table 3.

Table 3: Proportions of M20 grade Concrete

Grade	Cement (Kg/m3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate Kg/m^3)	W/C Ratio	Water (Kg/m3)	Mix Proportion
M-20	**320**	**712**	**1178**	**176**	**0.55**	**1:2.225:3.68**

4. Testing Procedure

During the concrete preparation process, the vital factors like appropriate mixing, compaction and sufficient curing were adopted. For mixing the concrete, pan mixture was preferred over hand mixing and the mixing was kept for about 3-4 minutes. The samples were taken out of the moulds after 24 hours of casting and adequately cured using clean water. The specimens were tested for their compressive strength at different age i.e 28 days, 90 days and 180 days. To study the effect of high temperature, test specimens were taken out of curing after 28 days and surface dried by a dry cloth after which they were put in an electric oven for 4 hours at three different temperatures i.e. 200°C, 400°C and 600°C. After the concrete specimens were exposed to high temperature for 4 hours, those were taken out of the electric oven and the weight and strength changes were calculated. To measure the effect of acids attack on copper slag concrete, the 28 days cured concrete cube specimens were completely immersed in three different solutions i.e. H_2SO_4, HCl and Na_2SO_4 and tested at 28, 56 and 90 days to check the effect on compressive strength. For each test result an average of three test samples were used.

5. Results and Discussion

5.1 Effect of Copper Slag as a Fine Aggregate in Concrete

The effect of using copper slag as a partial replacement of sand (0% to 50%) on compressive strength of concrete at different ages is shown in Table 4. The strength variations have also been shown graphically in Figure 3. The compressive strength test set up is shown in the Figure 4.

Table 4: Effect of copper slag as a fine aggregate in concrete

Mix	% Copper Slag replacement	Density (Kg/m^3)	Percentage increase in Compressive Strength with respect to CS0			Percentage increase in Compressive Strength with respect to Age		
			28 days	90 days	180 days	28 days	90 days	180 days
M20	0%	2571	-	-	-	-	20.49	25.54
	10%	2578	2.23	5.68	5.41	-	24.56	29.45
	20%	2588	6.3	15.52	16.17	-	30.93	37.19
	30%	2679	10.41	18.11	17.71	-	28.89	33.84
	40%	2696	11.55	24.42	27.92	-	34.4	43.97
	50%	2724	6.66	14.46	19.78	-	29.3	40.99

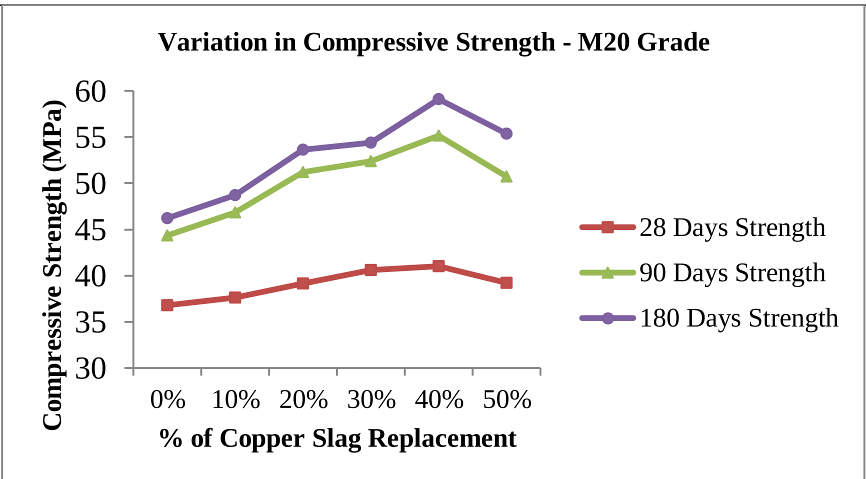

Figure 3: Strength variation in concrete with use of copper slag

It can be clearly observed from the Table 4 that with increase in the copper slag percentage from 0% to 40%, the compressive strength of concrete is improving. By rising the copper slag content beyond 40%, the compressive strength of concrete is reducing. Similar tendency of strength variation is observed at 28 days, 90 days and 180 days. It has been observed that the workability of concrete increases by increasing the copper slag content due to the low water absorption, glassy surface and coarser particles of the copper slag, which helps in increasing the compressive strength. But beyond 40% of copper slag replacement, the free water content significantly increases there by reducing the compressive strength. As per the above test results, the optimum percentage of copper slag as partial replacement of sand in concrete is fixed to be 40%.

5.2 Effect of Higher Temperature on Copper Slag Concrete

The effect of high temperature on weight, ultrasonic pulse velocity and compressive strength of M20 grade normal and copper slag concrete after exposed to 200°C, 400°C and 600°C for 4 hours has been presented in Table 5. Test samples subjected to high temperature in an electric oven is shown in the Figure 5. A copper slag concrete sample after exposed to 600°C for 4 hours is shown in the Figure 6. It can be clearly observed from the Table 5 that, the weight loss for both normal and copper slag concrete are increasing when subjected to 200°C, 400°C and 600°C for 4 hours. It can also be observed that the weight loss for copper slag concrete is relatively low compared to normal concrete.

The percentage loss in ultrasonic pulse velocity and compressive strength is increasing with the increase in temperature. At 200°C and 400°C, the percentage of loss for copper slag concrete is comparatively low than normal concrete however the percentage of loss of for copper slag concrete is little higher than normal concrete at 600°C.

The high amount of loss in ultrasonic pulse velocity and compressive strength in copper slag concrete at 600° C is attributed to the thermal expansion of copper slag causing development of thermal cracks on the surface of copper slag concrete. At 600°C, due to the high pore pressure produced by the internal moisture in the highly dense and impermeable copper slag concrete sever deformation and spalling are found.

Table 5: Variation in Wt., UPV and Compressive Strength Copper Slag Concrete at Elevated Temperature

Mix	Temp (°C).	Initial wt. (kg)	Final wt. (kg)	% of loss in weight	Initial UPV (Km/S)	Final UPV (Km/S)	% of loss in UPV	Initial Comp. Strength	Final Comp. Strength	% of loss in Comp. Strength
M20-CS-SFRC-0-0	200	2.431	2.36	2.92	4.358	3.372	22.63	36.8	34.78	5.49
	400	2.393	2.314	3.3	4.366	2.799	35.89	36.8	32.05	12.91
	600	2.513	2.399	4.54	4.358	1.725	60.42	36.8	28.96	21.3
M20-CS-SFRC-40-0	200	2.583	2.524	2.28	4.462	3.57	19.99	41.05	39.04	4.9
	400	2.58	2.498	3.18	4.46	2.914	34.66	41.05	36.64	10.74
	600	2.645	2.541	3.93	4.558	1.725	62.15	41.05	31.54	23.17

Figure 4: Compressive Strength Test Setup in CTM

Figure 5: Concrete Specimens Subjected to Elevated Temperature

Figure 6 : Copper slag Concrete after exposed to 600° C

5.3 Effect of Acids Attack on Copper Slag Concrete

<u>Impact on Compressive Strength Due to HCl Acid Attack:</u>

The impact on compressive strength of M20 grade copper slag concrete after immersing in HCl solution measured at various ages are presented in Table 6.

Table 6: Impact on Compressive Strength of Copper Slag Concrete due to HCL Acid Solution attack

M 20 Grade	Percentage decrease in Comp. Strength at 30 Days	Percentage decrease in Comp. Strength at 60 Days	Percentage decrease in Comp. Strength at 90 Days
CS0	8	27	29
CS40	41	53	55

It can be observed that normal concrete (CS0) has lower loss of compressive strength compared to copper slag concrete (CS40) when exposed to HCl. The percentage decrease is observed to be increasing in correspondence with time as well. CS0 specimens showed higher resistance to HCl acid attack than CS40 specimens. Deterioration of concrete does not occur due to HCl attack.

Impact on Compressive Strength Due to H2SO4 Acid Attack

The impact on compressive strength of M20 grade copper slag concrete after immersing in H_2SO_4 solution measured at various ages are presented in Table 7.

Table 7: Impact on Compressive Strength of Copper Slag Concrete due to H_2SO_4 Acid Solution attack

M20 Grade	Percentage decrease in Comp. Strength at 30 Days	Percentage decrease in Comp. Strength at 60 Days	Percentage decrease in Comp. Strength at 90 Days
CS0	19	38	42
CS40	51	65	68

It can be observed that normal concrete (CS0) has lower loss of compressive strength compared to copper slag concrete (CS40) when exposed to H_2SO_4. The percentage decrease is observed to be increasing in correspondence with time as well. CS0 specimens showed higher resistance to H_2SO_4 acid attack than CS40 specimens.

The concrete prepared with copper slag showed relatively higher mass change. Although both control and copper slag concrete suffered slight mass losses during the early periods, the overall loss in mass of the copper slag replaced specimens was much higher. The outer portion of cubes got destroyed and there was a maximum reduction of 3 mm at all sides for all specimens.

Impact on Compressive Strength Due to Sulphate Attack

The percentage decrease in compressive strength of M20 grade of CS0 and CS40 mixes after immersing in Na_2SO_4 is found to be nil at 30, 60 and 90 days. This indicates that copper slag concrete has good resistance against Na_2SO_4 solution.

6. Conclusions

- Copper slag can be used as a sustainable building material in form of fine aggregate by partially replacing sand in preparation of concrete.
- The use of copper slag as a building material helps in reducing the environmental impacts also the industrial waste dumping issues of copper manufacturing plants can be resolved to some extent.
- The optimum percentage of copper slag as partial replacement of sand is concrete is found to be 40%.
- Beyond 40% of copper slag replacement, the free water content increases there by causing reduction in compressive strength.
- The weight loss of copper slag concrete is less compared to normal concrete at high temperature.
- The resistance to strength loss of copper slag concrete found to be better than normal concrete at 200°C and 400°C. At 600°C both normal and copper slag concrete performs almost similarly.
- The strength loss in normal and copper slag concrete is quick beyond 400°C.
- In general the compressive strength of concrete with optimum percentage of copper slag is better due to the dense microstructure making it extremely impermeable. At high temperature, high pore pressure is developed due to the dense microstructure causing micro cracks and spalling which attributes to spalling and loss of compressive strength.
- High thermal expansion also attribute to the loss in compressive strength at 600°C.
- Concrete containing copper slag is low resistant to the H_2SO_4 and HCl attack than the control concrete.
- Copper slag concrete is higher resistant to HCl attack as compared to H_2SO_4 attack.
- Copper slag concrete has good resistance against Na_2SO_4 solution.

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