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Effective Utilization of Copper Slag as a Sustainable Building Material at Elevated Temperature

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Abstract: *This paper presents a study on the mechanical properties of copper slag admixed concrete along with the effect of elevated temperature on copper slag admixed concrete. An attempt has been made to find the optimum percentage of copper slag as a partial replacement of sand in preparation of concrete and further the effect of elevated temperature of 200^0 C, 400^0 C and 600^0 C for 12 hours exposure period on copper slag admixed concrete with optimum percentage of copper slag has been studied. Finally the results of copper slag concrete have been compared with that of normal concrete. In the present experimental study, M20 concretes grades was used.*

Keywords: Copper Slag, Elevated Temperature, Compressive Strength, UPV

Introduction

Copper slag is an industrial waste produced during the metal smelting process of copper production. According to ICSG (International Copper Study Group), the world wide copper production is valued to be 19.1 million tonnes in 2017. For producing 1 kg of copper about 2.5 kgs of copper slag is produced which creates a waste disposal issue for the copper manufacturing industries. Huge piles of copper slag can be seen around the industries which is a major concern as it also creates environmental pollution. Copper slag have been used a land filling material and also the preliminary strength studies have indicated that copper slag can be used as a partial replacement of sand in preparation of concrete. However, durability of the concrete structures is a major concern these days due to several types of deteriorations produced by manmade as well natural environmental conditions. In past, for concrete, strength was the only factor which drew the attention of the engineers and researchers. Late it was recognized that durability was also a substantial factor as that of the strength factor. In general, durability of concrete may be defined as the ability of concrete to resist weathering action, abrasion and chemical attack without compromising its required strength properties. A durable concrete is one that performs satisfactorily in the working environment during its anticipated exposure conditions during service. Durability of concrete is majorly influenced by the type of materials, environment, and water to cement ratio. The other factors impacting the durability of concrete are curing, cover to reinforcement and compaction etc. So, this paper presents the preliminary experimental investigation results for finding the optimum percentage of copper slag as partial replacement of sand in concrete. Further the effect of elevated temperature of *200^0 C, 400^0 C and 600^0 C for 12 hours* on copper slag concrete (with optimum percentage of copper slag) have been presented and been compared with that of normal concrete.

Literature Review

Balendran et al. [1] studied the strength and durability properties of high performance concrete having pulverized fuel ash, metakaoline and silica fume as pozzolans and exposed to elevated temperature. Addition of silica fume caused poor performance with respect to spalling and strength at higher temperatures. The conclusion drawn was, addition of metakaoline and pulverized fuel ash improves the residual strength and durability. **Bo Wu et al. [2]** investigated the effect of elevated temperature varied from 100°C to 900°C on the residual mechanical properties of confined and unconfined high strength concrete. It was concluded that the elastic modulus decreases quickly at elevated temperature. **Abha Mittal et al. [3]** carried out experimental investigation on concrete exposed to elevated temperature. The conclusion made was; the strength loss and lost strength recovery when exposed to higher temperature is mainly due to the dehydration of concrete. It was also observed that at a temperature less than 100°C, the compressive strength increases due to the hydration of un-hydrated concrete. Compressive strength of concrete at higher temperatures is severely affected which also depends on the extent of exposure. It was seen that with

rehydration up-to 80% of the original strength is regained. **Srinivasa Rao K et al [4]** did experimental investigation to study the effect of high temperatures (50°C - 250°C) on various strength properties of high strength concrete (HSC) made with portland pozzolana cement and ordinary Portland cement at different ages. It was observed that portland pozzolana cement concrete performs superior to ordinary Portland cement concrete by holding more residual compressive strength. **Chi-Sun Poon et al. [5]** did experiments to compare the durability and strength of high strength pozzolanic concretes and ordinary concrete at higher temperatures. It was concluded that pozzolanic concrete when compared to normal concrete shows better performance. Above 400°C, both normal and high strength concrete loses their strength quickly. High deformation and spalling was found in both types of concrete.

Materials used and Properties

Cement

Portland cement (53 grade) having normal consistency 32%, specific gravity 3.09 and fineness modulus 4.62% was used. The cement quality was confirmed as per IS 4031-1988.

Coarse Aggregate

Crushed angular granite metal of size 20 mm having fineness modulus 7.1, specific gravity 2.637 and water absorption 1.1% was used. The compacted state bulk density was found to be 1550 kg/m^3 and in loose state 1414 kg/m^3.

Fine Aggregate

River sand having fineness modulus 2.43, specific gravity 2.601 and water absorption 1.2% was used. The compacted state bulk density was found to be 1700kg/m^3 and in loose state 1597 kg/m^3. The aggregate combined grading is presented in the figure 1.

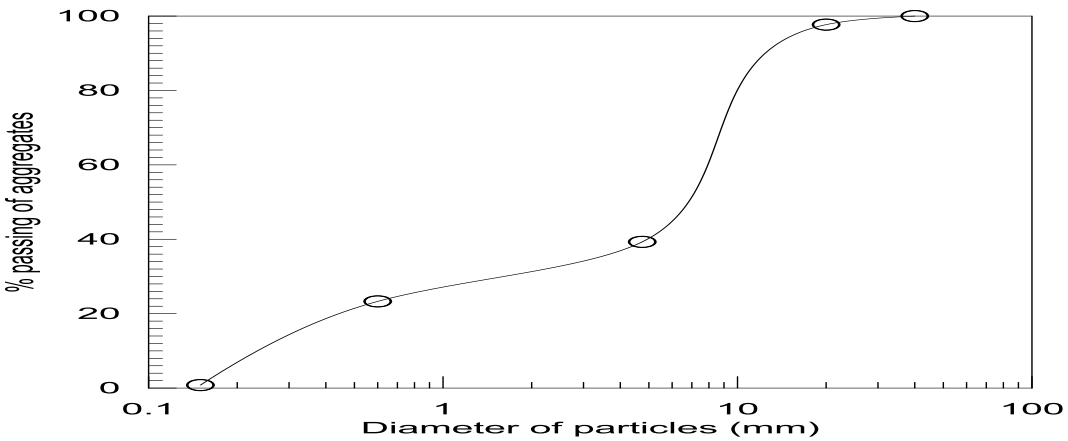

Figure 1 - Combined grading of Aggregates

Copper Slag

Air cooled, glassy black and irregular copper slag having fineness modulus 3.3, specific gravity 3.47 and water absorption 0.24% was used. The compacted state bulk density was found to be 2024 kg/m^3 and in loose state 1898 kg/m^3. Copper slag grading has been presented in figure 2.

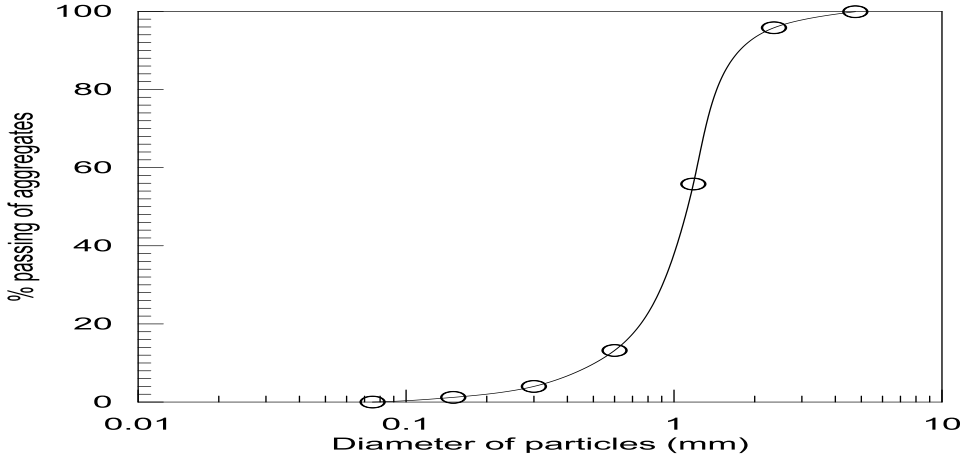

Figure 2 - Grading of Copper Slag

Mix Design and Different Mixes

Confirming to code book IS: 10262 –1979, the mix design was carried out for M20 grade mix and the quantity of materials were calculated. The quantities of various materials for M20 grade concrete mixes are presented in table 1. For finding the optimum percentage of copper slag as a partial replacement of sand in concrete, six different mixes (CS0, CS10, CS20, CS30, CS40 and CS50) were prepared by partially replacing sand from 0% to 50% with copper slag. After finding the optimum percentage of copper slag from compressive strength test, test specimens were again casted with optimum percentage of copper slag for studying the effect of elevated temperature and been compared with that of normal concrete.

Table 1- Mix Design and Proportion of M20 Grade Concrete

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

Experimental Procedure

In this current investigation, for finding the compressive strength of concrete, after the concrete cubes were cured for 28, 90 and 180 days, those were taken out of the curing tank, surface dried, weighed and tested for compressive strength in a 2000 KN digital compression testing machine. The load application rate was 140 kg/cm^2/minute as per IS 516-1959. The load at which the cube specimen failed was recorded. The compressive strength was obtained by dividing the ultimate compressive load by its area of cross section. Figure 3 shows the experimental set up for measuring the compressive strength of concrete cubes.

For studying the effect of elevated temperature, the test cube specimens after 28 days of water curing taken out of the water tank and surface dried then placed in muffle furnace allowing to heat at an elevated temperature for a specified time interval. After the specified time interval the concrete specimens were removed from the furnace the specimens were allowed to cool to room temperature then weighted and tested for pulse velocity and compressive strength to see the loss on weight, UPV and compressive strength. Figure 4 shows the view of muffle furnace used for testing the concrete cubes under elevated temperatures. Figure 5 show the view of specimens after exposed to 600^0 C temperature.

Figure 3: Compressive Strength Test Setup in CTM

Figure 4: Concrete Specimens Subjected to Elevated Temperature

Figure 5: Concrete Specimens after Exposed to 600°C Temperature

Discussion of Results

Effect of copper slag as a partial replacement of sand in concrete

The effect of partial replacement of sand with copper slag from 0% to 50% at various ages has been presented in table 2. The graphical representation of variation of strength with increase in percentage of copper slag in concrete is presented in figure 6.

Table 2: Effect of copper slag as a partial replacement of sand 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%	2560	-	-	-	-	20.49	25.54
	10%	2575	2.23	5.68	5.41	-	24.56	29.45
	20%	2582	6.3	15.52	16.17	-	30.93	37.19
	30%	2681	10.41	18.11	17.71	-	28.89	33.84
	40%	2684	11.55	24.42	27.92	-	34.4	43.97
	50%	2710	6.66	14.46	19.78	-	29.3	40.99

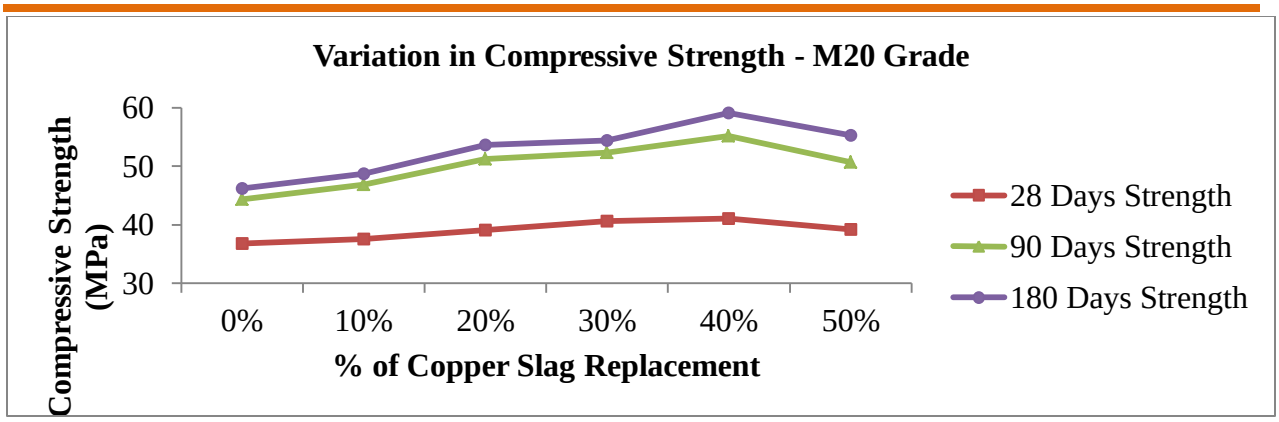

Figure 6: Variation in Compressive Strength of CSC (M20 Grade)

It can be observed that, the compressive strength of CS40 mix is increasing by 11.55% at 28 days, 24.42% at 90 days and 27.92% at 180 days when compared to its normal concrete. The compressive strength of CS40 mix is increasing by 34.4% and 43.97% at 90 and 180 days respectively compared to its 28 days compressive strength. For normal concrete the compressive strength is increasing by 20.49% and 25.54% at 90 and 180 days respectively compared to its 28 days compressive strength. For the above test results it has been established that the optimum percentage of copper slag as a partial replacement of sand in preparation of concrete is 40%.

Copper slag has a relatively lower water absorption capacity compared to sand. The test results exhibited that the workability of concrete increases significantly with increase in copper slag content in the concrete mix due to the glassy surface, coarser particles and low water absorption of copper slag, thereby the strength properties also improved. Beyond 40% of copper slag replacement with sand the free water content increases in the concrete there by decreasing in the compressive strength.

Effect of elevated temperature on copper slag concrete

The effect on weight, UPV and compressive strength of various mixes of M20 grade OPCC and CSC when exposed to elevated temperature of 200°C, 400°C and 600°C for 12 hours followed by dry cooling to room temperature are presented in tables 3.

Table 3: Variation in Weight, UPV and Compressive Strength of M20 Grade OPCC and CSC Subjected to Elevated Temperature (12 hours heating followed by Dry Cooling)

Mix	Temp.	Initial Weight (kg)	Final Weight (kg)	% of loss in weight	Initial UPV (Km/S)	Final UPV (Km/S)	% of loss in UPV	Initial Comp. Strength (MPa)	Final Comp. Strength (MPa)	% of loss in Comp. Strength
M20-CS-SFRC (0-0)	200°C	2.157	2.071	3.99	4.26	2.61	38.73	36.8	32.82	10.82
	400°C	2.437	2.328	4.47	4.256	1.612	62.12	36.8	28.72	21.96
	600°C	2.315	2.196	5.14	4.276	0.486	88.63	36.8	23.52	36.09
M20-CS-SFRC (40-0)	200°C	2.26	2.178	3.63	4.462	2.822	36.8	41.05	37.29	9.16
	400°C	2.262	2.169	4.11	4.451	1.788	59.83	41.05	33.18	19.17
	600°C	2.271	2.164	4.71	4.458	0.392	91.21	41.05	25.28	38.42

From the tables 3, it can be observed that, when OPCC and CSC concrete are subjected to elevated temperature of 200°C, 400°C and 600°C for 12 hours followed by dry cooling to room temperature, the percentage of loss in weight is increasing with the increase in temperature and the loss of weight in case of copper slag concrete is found to be comparatively lesser than that of OPCC.

From the tables 3, it can be observed that, when OPCC and CSC concrete are subjected to elevated temperature of 200°C, 400°C and 600°C for 12 hours followed by dry cooling to room temperature, the percentage of loss in UPV is increasing with the increase in temperature. It can also be observed that at 200°C and 400°C exposure, the percentage of loss of UPV in case of copper slag concrete is found to be comparatively lesser than that of OPCC while at 600°C the percentage of loss of UPV of CSC is higher than that of OPCC.

From the tables 3, it can be observed that, when OPCC and CSC concrete are subjected to elevated temperature of 200°C, 400°C and 600°C for 12 hours followed by dry cooling to room temperature, the percentage of loss in compressive strength is increasing with the increase in temperature. It can also be observed that at 200°C and 400°C exposure the percentage of loss in compressive strength in case of copper slag concrete is comparatively lesser than that of OPCC while at 600°C the percentage of loss of compressive strength of CSC is higher than that of OPCC.

The higher percentage of loss in UPV and compressive strength for CSC at 600°C compared to OPCC is due to; at higher temperature the thermal expansion of copper slag concrete is more than OPCC. Therefore thermal cracks are developed on the surface of CSC due to higher thermal strain resulting in higher loss of UPV and compressive strength compared to OPCC. Severe spalling and deformation are found in copper slag concrete when exposed to a temperature higher than 600°C which is mainly attributed to the high pore pressure generated by the internal moisture in the highly impermeable and dense copper slag concrete.

Conclusion

Base on the experimental investigation following conclusions have been made.

- The optimum percentage of copper slag as a partial replacement of sand in preparation of concrete is found to be 40%.
- Beyond 40% the strength of copper slag concrete decreases because of increase in the free water content in the mix.
- Copper slag concrete found to have good resistance to weight loss when subjected to elevated temperature.
- Copper slag concrete has a good resistance to strength loss at elevated temperature of 200°C and 400°C compared to normal concrete, however at 600°C temperature, copper slag concrete shows similar trend like normal concrete due to low transition temperature of copper slag.
- Outside 400°C, both normal and copper slag concrete lose their strength quickly.
- Use of optimum percentage of copper slag (40%) give best results to enhance compressive strength at room temperature because of its dense micro-structure. The dense micro-structure is highly impermeable and under elevated temperature the internal moisture creates high pore pressure to escape. This results in development of micro-cracks fast followed by occurrence of spalling and deterioration of strength.
- The higher percentage of loss in compressive strength at 600°C temperature is also attributed to high thermal expansion of copper slag.

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