

Performance of Copper Slag Concrete Exposed to Elevated Temperature for Low Duration

Binaya Patnaik, Seshadri Sekhar T., Manong Zechariah Riek, Gathel Buony Nyuot

Abstract: River sand is the standard form of fine aggregate used in the concrete production. In this present era of rapid urbanization, to meet the increasing demand of natural sand by the construction industry, massive scale depletion of the river bed is being carried out which is causing a considerable negative impact on our environment. Hence it is highly imperative to find sustainable fine aggregates to meet the global demand without disturbing our ecosystem. Copper slag is one such sustainable material which has a promising future to be used as an alternative to river sand. This paper presents a study on finding the optimum dosage of copper slag (CS) as partial replacement sand in preparation of concrete. Further, as part of durability study, the impact of elevated temperature of 200^o C, 400^o C and 600^o C for 4 hours exposure period on strength characteristics of copper slag blended concrete has been presented and been compared with that of normal concrete. The results indicate that copper slag concrete has excellent resistance to weight and strength loss at an elevated temperature of 200^o C, 400^o C compared to normal concrete however at 600^o C copper slag concrete shows similar trends like normal concrete. In the present experimental study, M20 & M30 concrete grades were used.

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

I. INTRODUCTION

Copper slag (CS) is an industrial bi-product during the met-smelting process of copper production [1]. According to ICSG (International Copper Study Group), worldwide copper production is valued to be 20 million tonnes in 2017 [2]. For producing every tonne of copper about 2.2 ton of CS is generated [1], which creates a waste disposal issue for the copper manufacturing industries. Huge piles of CS can be seen around the industries, which is a major concern as it also creates environmental pollution. CS has been used a landfilling material, and also the preliminary strength studies have indicated that CS can be used as a partial replacement of sand in preparation of concrete. However, the durability of the concrete structures is a significant concern these days due to several types of deteriorations. A durable concrete is one that performs satisfactorily in the working environment

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during its anticipated exposure conditions during service. The type of materials, environment majorly influences the durability of concrete, and water to cement ratio. The other factors impacting the durability of concrete are curing, cover to reinforcement and compaction etc. This paper presents the preliminary experimental investigation results for finding the optimum percentage of CS as a partial replacement of sand in concrete. Further, the impact of elevated temperature on CS concrete (with an optimum percentage of copper slag) has been presented and been compared with that of normal concrete.

II. LITERATURE REVIEW

Balendran et al. [3] considered mainly strength and durability parameters of high performance concrete containing pulverised fuel ash, metakaolin and silica fume as pozzolans and exposed to elevated temperature. He observed that the addition of silica fume caused poor performance concerning spalling and strength at higher temperatures. The conclusion drawn was, the addition of metakaolin and pulverised fuel ash improves the residual strength and durability. Bo Wu et al. [4] studied the impact of elevated temperature varied from 100°C to 900°C on the residual mechanical characteristics of confined and unconfined high strength concrete. It was concluded that the elastic modulus decreases quickly at elevated temperature. Chakrabarti et al. [5] carried out an experimental investigation on concrete exposed to elevated temperature. The conclusion made was; the strength loss and lost strength recovery when exposed to a higher temperature are mainly due to the dehydration of concrete. Apart from that he also observed that at a temperature less than 100°C, the compressive strength increases due to the hydration of un-hydrated concrete. The 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 [6] did an experimental investigation to study the impact of high temperatures (50°C - 250°C) on various strength properties of high strength concrete 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. [7] did experiments to compare the durability and strength of high strength pozzolanic concretes and ordinary concrete at higher temperatures.

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He noticed that the pozzolanic concrete when compared to normal concrete, shows better performance. Above 400°C, both concrete loses their strength quickly. High deformation and spalling were found in both types of concrete.

III. MATERIAL PROPERTIES

The Portland cement used was **Ultratech-53 grade (Hyderabad, India)**, as classified by the BIS Specification IS: 12269-1987. Its chemical composition is presented in Table 1. Crushed angular granite metal with a maximum size of 20mm is used as coarse aggregate. The fineness modulus, specific gravity and water absorption were used 7.1, 2.637 and 1.1% respectively for the quartz sand. Quartz sand, composed by significant size fractions 1.2, 0.6, 0.3, and 0.15 each corresponding to 11.5, 18.7, 26.9, and 30.2 respectively

and 4mm aggregates was used as filler materials in the present investigation. The fineness modulus, specific gravity and water absorption were used 2.43, 2.601 and 1.2% respectively for the quartz sand. The compacted state bulk density was found to be 1550 kg/m³ and in loose state 1414 kg/m³. Apart from this, air-cooled, black glassy and irregular copper slag having fineness modulus 3.3, specific gravity 3.47 and water absorption 0.24% was used as a partial replacement of fine sand in the present investigation. The compacted state bulk density was found to be 2024 kg/m³ and in loose state 1898 kg/m³. Their chemical properties are presented in Table 2 as per the product data-sheet. The combined grading of aggregates has been presented in Figure 1 and Figure 2 presents the CS grading.

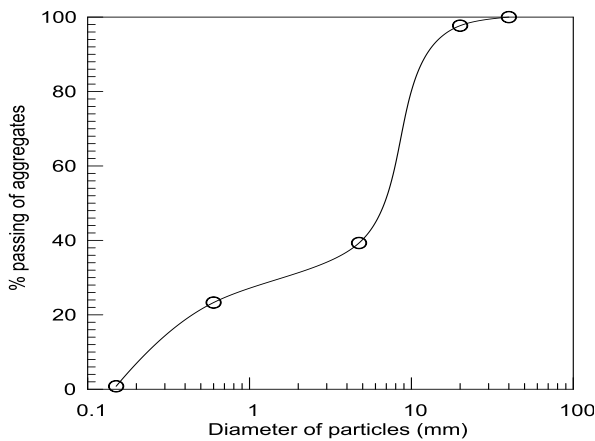


Fig. 1. Combined grading of Aggregates

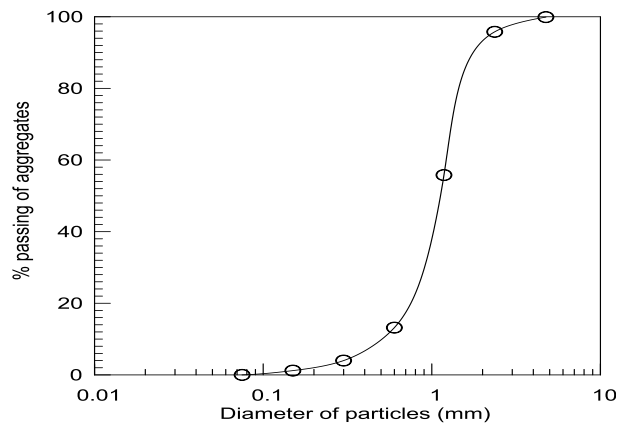


Fig. 2. Grading of Copper Slag

Table-I: Chemical Composition of Cement

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

Table-II: Chemical Composition of Copper Slag

S. No.	Composition	Contribution (in %)
1	Silica - SiO ₂	33.52
2	Iron - Fe ₂ O ₃	55.8
3	Aluminum - Al ₂ O ₃	3.8
4	Calcium - CaO	3.14
5	Magnesium - MgO	0.72
6	Sodium - Na ₂ O	0.4
7	Potassium - K ₂ O	0.76
8	Titanium - TiO ₂	0.5
9	Copper - Cu	0.99

IV. MIX DESIGN AND DIFFERENT MIXES

Two different types of concrete, M20 and M30, was designed as per IS 10262 – 2009. For predicting the optimum dosage of CS as a partial replacement of sand in concrete, six different mixes (CS0, CS10, CS20, CS30, CS40 and CS50) were considered by partially replacing sand from 0% to 50% with CS.

After identifying the optimum dosage of CS based on the compressive strength test, test specimens with an optimum percentage of CS were used to study the effect of elevated temperature and been compared with that of normal concrete. The mix proportions are presented in Table 3.

Table-III: Mix Proportions

Grade	Cement (Kg/m ³)	Fine Aggregate (Kg/m ³)	Coarse Aggregate (Kg/m ³)	W/C Ratio	Water (Kg/m ³)	Mix Proportion
M-30	350	703.6	1164	0.5	175	1:2.01:3.326
M-20	320	712	1178	0.55	176	1:2.225:3.68

V. CASTING AND TESTING PROCEDURE

The essential parameters for preparing a decent concrete are proper mixing, compaction and adequate curing which were practised during the concrete test sample casting process. Pan mixture was used for the mixing process, and the mixing time was kept for 3-4 minutes. Test samples were demoulded after 24 hours of casting and were adequately cured by using potable water for 28, 90 and 180 days. For studying the effect of elevated temperature, the concrete specimens were taken out after 28 days of curing and surface dried by a dry cloth followed by putting in an electric oven for 4 hours at specified temperatures (200⁰ C, 400⁰ C and

600⁰). The test specimens were taken out of the electric oven after 4 hours, and the loss of weight and strength were measured.

VI. DISCUSSION OF RESULTS

A. Effect of CS as a partial replacement of sand in concrete

The effect of partial replacement of sand with CS from 0% to 50% on compressive strength at various ages have been presented in Figure 3. The compressive strength test set up has been shown in Figure 4.

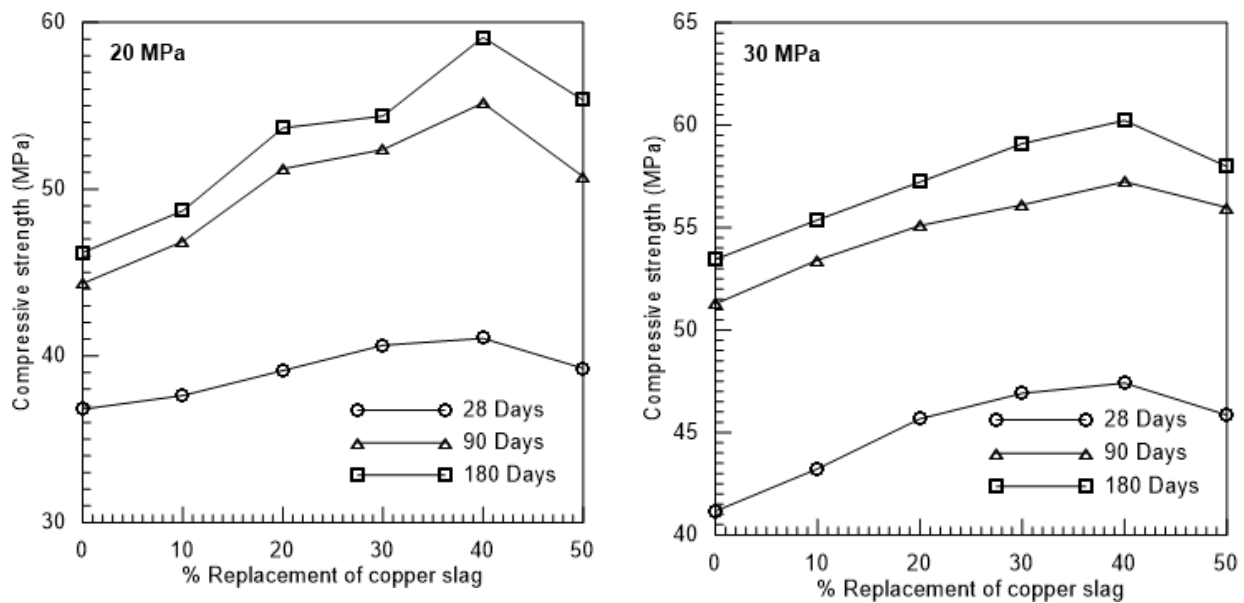


Fig. 3. Variation of strength with percentage replacement of CS

It can be observed that the compressive strength is increasing from OPCC (0% replacement) to 40% replacement of sand by copper slag. A further rise in replacement of sand by CS affects the compressive strength. Similar pattern was observed for concretes of grades M30 and M20. A similar trend of strength variation can be seen at different age of testing (28 days, 90 days and 180 days). The test results exhibited that the workability of concrete increases significantly with an

increase in CS content in the concrete mix due to the glassy surface, coarser particles and low water absorption of CS, thereby the strength properties also improved. Beyond 40% of copper slag replacement with sand the free water content increases in the concrete which results decreasing in the compressive strength. Based on this, it has been established that the optimum dosage of CS as a partial replacement of sand in preparation of concrete is 40%.



Fig. 4. Compressive Strength Test Setup in CTM

B. Effect of Elevated Temperature on Copper Slag Concrete

The effect on weight, UPV and compressive strength of various mixes of M20 and M30 grade OPCC and CSC when exposed to an elevated temperature of 200°C, 400°C and 600°C for 4 hours followed by dry cooling to room temperature are presented in Tables 4 and 5. The concrete test specimens subjected to elevated temperature have been shown in Figure 5. The graphical representation of impact on weight, UPV and compressive strength on copper slag concrete and normal concrete due to exposure to elevated temperature have been presented in Figure 6, Figure 7 and Figure 8. A copper slag concrete specimen after subjected to an elevated temperature of 600°C for 4 hours has been shown in Figure 9. It was clearly depicted from the Tables 4 and 5 that, when OPCC and CSC concrete are subjected to elevated temperature of 200°C, 400°C and 600°C for 4 hours and 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 CS concrete is found to be comparatively lesser than that of OPCC. Similar pattern can be witnessed for concrete grades M30 and M20.

It can be observed that, when OPCC and CSC concrete are subjected to the elevated temperature of 200°C, 400°C and 600°C for 4 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 CS 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. Similar pattern can be seen for both concrete grades (M30 and M20).

When OPCC and CSC concrete are subjected to elevated temperature of 200°C, 400°C and 600°C for 4 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. Similar pattern can be seen for both concrete grades (M30 and M20).

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. Sever 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.

Table-IV: Variation in Wt., UPV and Comp. St. of M20 Grade concrete at Elevated Temperature

Mix	Temp (°C).	Initial wt. (kg)	Final wt. (kg)	% of loss in wt	Initial UPV (km/s)	Final UPV (km/s)	% of loss in UPV	Initial Comp. Strength	Final Comp. Strength	% of loss in Compressive 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

Table-V: Variation in Wt., UPV and Comp. St. of M30 Grade concrete at Elevated Temperature

Mix	Temp (°C).	Initial wt. (kg)	Final wt. (kg)	% of loss in wt	Initial UPV (km/s)	Final UPV (km/s)	% of loss in UPV	Initial Comp. Strength	Final Comp. Strength	% of loss in Compressive Strength
M30-CS-S FRC-0-0	200	2.497	2.43	2.68	4.43	3.489	21.24	41.16	38.94	5.39
	400	2.508	2.427	3.23	4.428	2.906	34.37	41.16	36.27	11.88
	600	2.545	2.436	4.28	4.434	1.862	58.01	41.16	33.12	19.53
M30-CS-S FRC-40-0	200	2.496	2.442	2.16	4.48	3.675	17.97	47.41	45.24	4.58
	400	2.574	2.499	2.91	4.478	3.026	32.43	47.41	43.53	8.18
	600	2.723	2.632	3.34	4.483	1.725	61.52	47.41	37.57	20.76



Fig. 5. Concrete Specimens Subjected to Elevated Temperature

VII. CONCLUSION

- CS concrete found to have significant resistance to weight loss when subjected to elevated temperature.
- CS concrete has excellent resistance to strength loss at an 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 the low transition temperature of copper slag.
- Outside 400°C, both normal and copper slag concrete lose their strength quickly.
- Use of the optimum percentage of copper slag (40%) gives the best results to enhance compressive strength at room temperature because of its dense microstructure. The dense microstructure is highly impermeable, and under elevated temperature, the internal moisture creates high pore pressure to escape. This results in the development of micro-cracks fast followed by the occurrence of spalling and deterioration of strength.

- The higher percentage of loss in compressive strength at 600°C temperature is also attributed to the high thermal expansion of copper slag.

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