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USE OF COPPER SLAG IN CONCRETE

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Abstract: *The present investigation assesses the incorporation of copper slag in concrete. The effect of copper slag as partial replacement of cement on the compressive strength of concrete has been investigated. The hydration of cement with copper slag was investigated through X-ray diffraction (XRD). Five concrete mixes (C0, C5, C10, C15 and C20) were made by replacing cement with 5%, 10%, 15% and 20% of copper slag by mass respectively. The water/cement ratio in all the mixes was kept at 0.43. Results showed that the compressive strength of concrete decreases as CS content increases for all curing ages. The reduction in compressive strength is minor up to 10% of CS but beyond 10% of CS, there is significant reduction in compressive strength due to the increase in free water content in mixes. XRD showed that the 10% of copper slag slightly reduces the hydration of cement, but 20% of copper slag significantly reduces the hydration of cement. It indicates that the copper slag can be utilized as supplementary cement replacement material in concrete. The optimum content of copper slag as replacement of cement is recommended as 10%.*

Keywords: *Alite, Compressive strength, Concrete, Copper slag, Hydration, Portlandite, Quartz, X-ray diffraction*

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1. INTRODUCTION

In view of global warming, efforts are on to reduce the emission of CO_2 to the environment. Cement industry is a major contributor in the emission of CO_2 as well as in using up high levels of energy resources in the production of cement. Researchers from all over the world are focusing on the ways of utilizing industrial waste, as supplementary cement replacement materials. This waste utilization would not only be economical, but may also help protecting the environment. Industrial wastes, such as slag, fly ash and silica fume are being used as supplementary cement replacement materials [1].

Copper slag is one of the material that is considered as a waste material which could have a promising future in construction industry as partial or full substitute of either cement or aggregates [2]. It is a by-product obtained during the smelting and refining of copper. During smelting, a molten pool of copper forms at the bottom of the furnace while a layer of impure metal form a less dense liquid floating on top of the copper melt, which is the slag. The molten slag is discharged from the furnace at 1000–1300°C. If the molten slag is water quenched, a glassy copper slag is obtained. To produce every ton of copper, approximately 2.2-3 tons copper slag is generated and approximately 24.6 million tons of slag is generated from the world copper industry [3]. Therefore, numerous contemporary researches have focused on the application of copper slag in cement and concrete production as a suitable path towards sustainable development. The use of copper slag in cement and concrete provides potential environmental as well as economic benefits for all related industries, particularly in areas where a considerable amount of copper slag is produced.

The present investigation encourages the utilization of industrial waste copper slag in concrete and studied its effect on the properties of concrete for obtaining a supplementary cement replacement material.

2. LITERATURE REVIEW

Many researchers have investigated the use of copper slag as partial replacement of ordinary Portland cement. The use of copper slag reduces the early age strength (1 day) while increasing it beyond 7 days [4]. The use of ground copper slag up to 15% by mass as a Portland cement replacement increased the strength significantly [5]. The addition of copper slag to cement increased its initial and final setting times [6]. The concrete batches with copper slag addition presented greater mechanical and durability performance [7].

Blends of copper slag with Portland cement generally possess properties equivalent to Portland cement containing fly ash [8].

3. MATERIALS AND METHODS

3.1 Materials used

Ordinary Portland cement (OPC) of 43 grade was used. It was conforming to BIS 8112 [9]. The physical properties of OPC are given in Table 1. The fine aggregate used was locally available river sand having a 4.75 mm nominal maximum size. The sand was conforming to grading zone II as per BIS 383 [10]. The coarse aggregate used was crushed stone having a 20 mm nominal maximum size. The physical properties of coarse aggregate and fine aggregate are given in Table 2. Fresh and clean tap water was used. The water was conforming to the requirements of water for concreting and curing as per BIS 456 [11]. Copper slag obtained from Synco Industries Limited (Jodhpur, Rajasthan) was used. The physical and chemical properties of copper slag are given in Table 3.

3.2 Concrete mixes and mix proportions

In this work, one control mix C0 was designed as per Indian Standard Specifications BIS 10262 [12] for M25 grade of concrete. The other four concrete mixes (C5, C10, C15 and C20) were made by replacing cement with 5%, 10%, 15% and 20% of copper slag by mass respectively. The water/cement (w/c) ratio in all the mixes was kept at 0.43. Mix proportions of concrete mixes are given in Table 4.

3.3 Preparation and casting of test specimens

Compressive strength of concrete is determined from cube specimens of 150 mm X 150 mm X 150 mm in size. All the specimens were prepared in accordance with Indian Standard Specifications BIS 516 [13]. After casting, test specimens were covered with plastic sheets and left in the casting room for 24 hours at a temperature of about 27±2^{o}C. The specimens were removed from the moulds after 24 hours of casting and put into a water-curing room until the time of the test.

3.4 Workability of concrete

Workability of concrete was tested using compacting factor test apparatus as per BIS 1199 [14]. The workability of concrete was determined immediately after preparing fresh concrete.

3.5 Compressive strength of concrete

Concrete cube of size 150 mm X 150 mm X 150 was tested for compressive strength as per BIS 516 [13]. For the compressive strength test, a loading rate of 2.5kN/s was applied. The test was performed at 3, 7, 14 and 28 days of curing. Specimens were tested immediately on removal from the water and while they are still in wet condition, surface water and grit shall be wiped off the specimens and tested.

3.6 X- ray diffraction test

The X- ray diffraction test was performed on samples of cementitious powder of mixes C0, C10, and C20. The samples of cementitious powder were collected from the remnant of concrete specimens after 28 days compressive strength test. The X-ray diffractograms of different samples were recorded on Panalytical X'Pert PRO with Bragg–Brentano geometry. Cu Kα radiation was used with a wavelength (λ= 1.54060 Å). X-ray tube was operated at 45 kV voltage and 40 mA current. Powder samples were loaded on aluminum sample holder having dimensions 2cm X 1·5cm X 0·2 cm. The measurements were carried out in a 2θ range of 10.0066° to 99.9846° with a step width of 0.0130°.

4. RESULTS AND DISCUSSION

4.1 Workability

The value of compacting factor for each mix is given in Table 4. The compacting factor of concrete with different replacement levels of copper slag is also shown in Figure 1. It can be observed that the workability of concrete increases as copper slag content increases as shown in Figure 1. The compacting factor for 0% copper slag was 0.849, while compacting factor for 20% copper slag was 0.925. The addition of copper slag increases the workability of concrete due to its glassy surface which reduces its water absorption. Due to the low water absorption of copper slag, free water content increases in the mix and hence, it is observed that workability of concrete has increased.

4.2 Compressive strength

The compressive strength of concrete was determined at the curing ages of 3, 7, 14 and 28 days. Results are given in Table 5 and shown in Figure 2. It can seen that the compressive strength of concrete decreases as copper slag content increases as shown in Figure 2. The percentage reduction in compressive strength for 5%, 10%, 15% and 20% of copper slag was 2.9528, 6.1381, 23.6224 and 34.2013 respectively after 28 days of curing. It can be seen that the reduction in compressive strength is minor up to 10% of copper slag replacement but beyond 10% of copper slag, there is significant reduction in compressive strength due to the increase in free water content in the mixes.

4.3 X- ray diffraction

The XRD patterns of mix C0, C10 and C20 are shown in Figure 3, Figure 4 and Figure 5 respectively. The XRD patterns are present in the form of diffracted peaks of different hydration products. The intensity of these diffracted peaks is plotted against the diffraction angle of 2θ (degrees). The intensity of diffracted peaks was measured in counts per second (cps). From Figure 3 to 5 it can be observed that all the mixes consist of the peaks of qrartz, portlandite and alite on 2θ scale. But the portlandite is the main hydration product during the hydration of cement. The peaks of portlandite in all mixes represent the degree of hydration of cement. The major peaks of portlandite were observed at 18.1° and 34.1°. The peak of portlandite at 18.1° was overlapped with the peak of alite. The peak of portlandite at 34.1° was the highest among all the peaks of portlandite. The portlandite peak of mix C0 was showed the highest intensity of 1029.0 (cps) at 34.1° in Figure 3. The mixes C10 and C20 shows the intensity of 947.0 (cps) and 738.0 (cps) in Figures 4 and Figure 5 respectively. The mixes C0 and C10 were having almost similar diffracted peaks of portlandite, but the intensity of portlandite peak in mix C20 was very less as compared to mixes C0 and C10. It indicates that the degree of hydration of mixes C0 and mix C10 were quite similar, but the degree of hydration in mix C20 was less than mixes C0 and C10. It is concluded that 10% of copper slag slightly reduce the hydration of cement, but 20% of copper slag significantly reduces the hydration of cement.

5. CONCLUSIONS

The following conclusions are drawn from this investigation:

i) The workability of concrete increases as CS content increases. For 20% of CS, the workability increases by 8.21%.

ii) The compressive strength of concrete decreases as CS content increases for all curing ages. The reduction in compressive strength is minor up to 10% of CS but beyond 10% of CS, there is significant reduction in compressive strength due to the increase in free water content in mixes.

iii) XRD showed that the degree of hydration of mixes C0 and mix C10 were quite similar, but the degree of hydration in mix C20 was less than mixes C0 and C10. The

10% of copper slag slightly reduces the hydration of cement, but 20% of copper slag significantly reduces the hydration of cement.

iv) Copper slag can be utilized as supplementary cement replacement material in concrete. The optimum content of CS as replacement of cement is recommended as 10%

TABLES

Table 1: Properties of OPC 43 grade cement

Characteristics	**Value Obtained experimentally**	**Values specified by BIS 8112**
Specific Gravity	3.15	-
Standard consistency	32%	-
Initial Setting time	146 minutes	30 minutes (min)
Final Setting time	244 minutes	600 minutes (max)
Compressive Strength 3 days 7 days 28 days	24.60 N/mm^2 35.87 N/mm^2 48.45 N/mm^2	23 N/mm^2 33 N/mm^2 43 N/mm^2

Table 2: Physical properties of coarse aggregate and fine aggregate

Property	**Fine aggregate**	**Coarse aggregate**
Specific Gravity	2.64	2.60
Fineness modulus	2.71	6.71
Water absorption %	0.5	1.0

Table 3: Physical and chemical properties of copper slag

Physical properties	**Copper slag**
Particle Shape	Irregular
Appearance	Black & glassy
Type	Air cooled
Specific gravity	3.51
Bulk density(g/cm^3)	1.9-2.4
Hardness	6-7mohs
Chemical component	**% of Chemical component**
SiO_2	28%
Fe_2O_3	57.5%
Al_2O_3	4%
CaO	2.5%
MgO	1.2%

Table 4: Mix proportions of concrete mixes

Mixes	Cement (Kg/m³)	Copper slag (Kg/m³)	Water (L/m³)	w/c ratio	Coarse aggregates (Kg/m³)	Fine aggregates (Kg/m³)	Compacting factor
C0	432	0	186	0.43	1167	548	0.849
C5	410.4	21.6	186	0.43	1167	548	0.865
C10	388.8	43.2	186	0.43	1167	548	0.871
C15	367.2	64.8	186	0.43	1167	548	0.900
C20	345.6	86.4	186	0.43	1167	548	0.925

Table 5: Test results for compressive strength of concrete

Mixes	Compressive strength (N/mm²)			
	3 days	7 days	14 days	28 days
C0	24.15	30.85	37.5	43.01
C5	22.35	30.6	35.45	41.74
C10	21.49	28.98	33.95	40.37
C15	16.90	23.34	27.11	32.85
C20	14.19	18.50	22.87	28.30

FIGURES

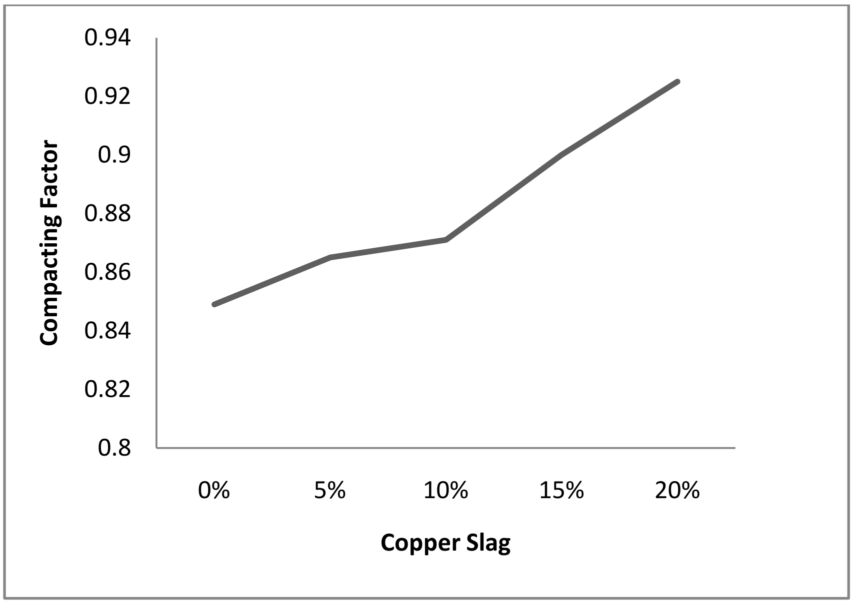

Figure 1: Compacting factor of concrete with different replacement levels of copper slag

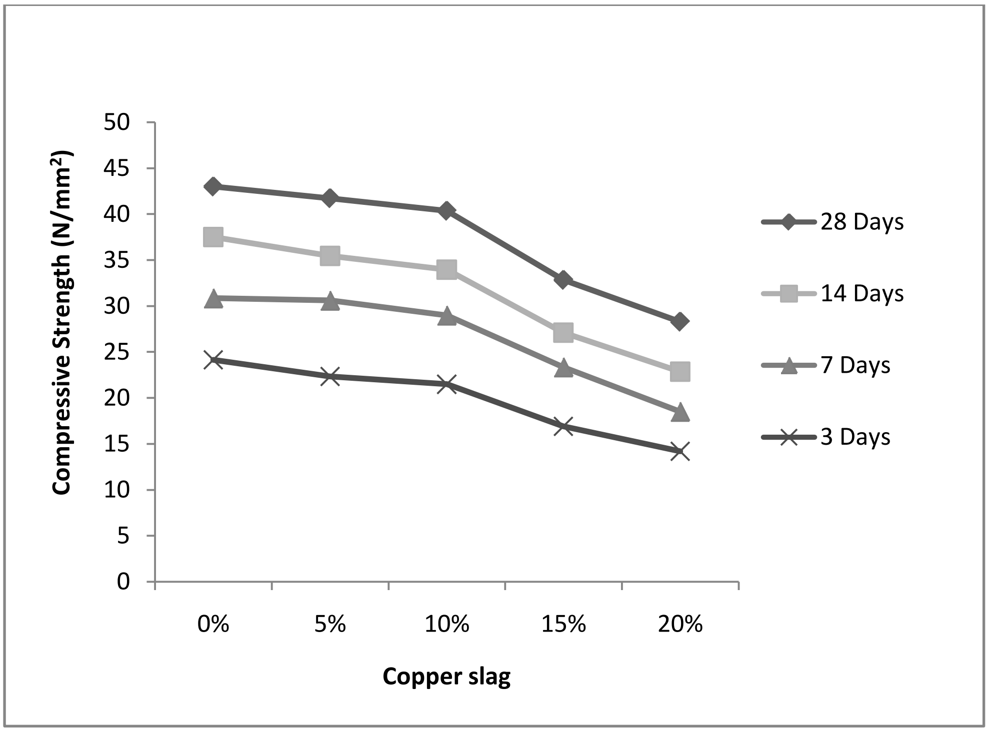

Figure 2: Compressive strength of concrete with different replacement levels of copper slag

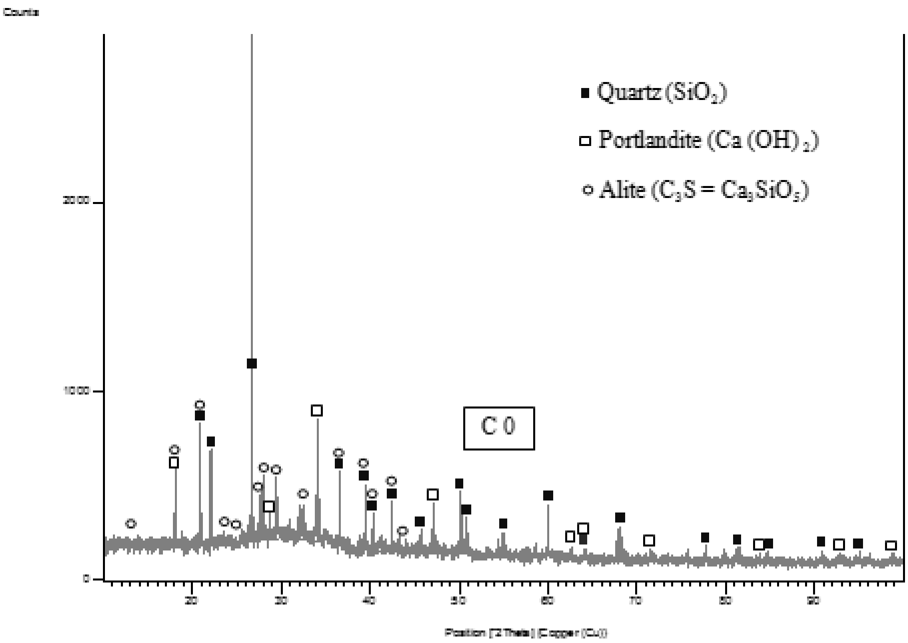

Figure 3: X-ray diffraction pattern of mix C0

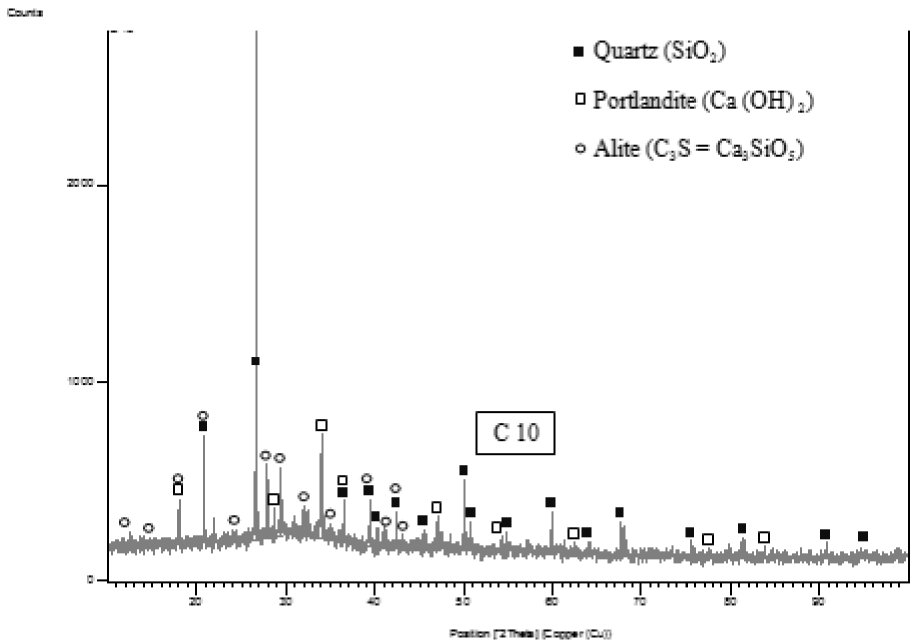

Figure 4: X-ray diffraction pattern of mix C10

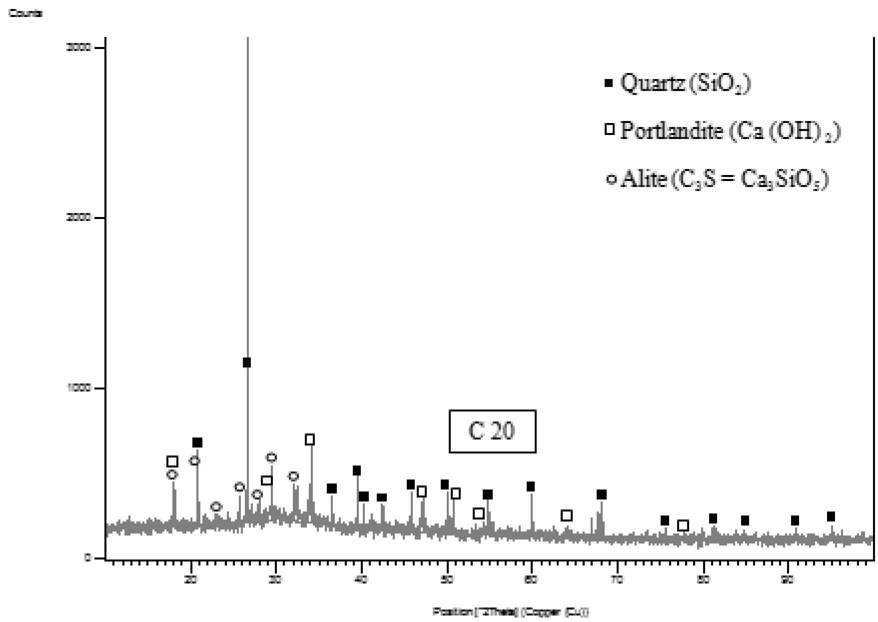

Figure 5: X-ray diffraction pattern of mix C20

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