Combined Utilisation of Ground Granulated Blast Furnace Slag and Copper Slag in M30 Grade Concrete: Effect on Workability, Compressive Strength and Flexural Strength

Rajesh Gupta[1] S.K. Diwan[2]
[1]M.Tech Scholar [2]Assistant Professor
[1,2]Department of Civil Engineering (Construction Technology & Management)
[1,2]Oriental Institute of Science & Technology, Bhopal (M.P.), India

Abstract — River sand extraction is causing serious environmental damage, while cement production contributes a large share of global anthropogenic CO_2 emissions. This study examines the use of two industrial by-products, ground granulated blast furnace slag (GGBS) as a partial replacement of cement and copper slag (CS) as a partial replacement of natural fine aggregate, in M30 grade concrete designed according to IS 10262. GGBS was used at 0, 5, 10, 15 and 20% by weight of cement, and copper slag at 0, 10, 20, 30, 40 and 50% by weight of sand. Workability was measured by the slump test, compressive strength at 7, 14 and 28 days, and flexural strength at 28 days. Slump decreased from 74 mm to 64 mm as GGBS increased to 20%, and increased from 74 mm to 84 mm as copper slag increased to 50%. The optimum GGBS content was 10%, giving a 28-day compressive strength of 37.20 MPa (2.2% above the control) and a flexural strength of 4.21 MPa (7.9% above the control). For copper slag, the 28-day compressive strength peaked at 30% replacement (39.94 MPa, +9.7%) and the flexural strength peaked at 40% (4.68 MPa, +20.0%); strength fell below the control at 50%. A combined mix with 10% GGBS and 40% copper slag reached a 28-day compressive strength of 37.10 MPa. The results show that both by-products can be used in structural-grade concrete at moderate replacement levels, reducing both cement consumption and river sand demand.

Keywords: GGBS; Copper Slag; Partial Replacement; M30 Concrete; Compressive Strength; Flexural Strength; Sustainable Concrete

I. Introduction

Concrete is the most widely used construction material in the world, and its demand for cement and natural aggregate keeps growing. Cement manufacturing is one of the largest industrial sources of carbon dioxide and is estimated to account for up to 8% of global man-made CO_2 emissions [1]. At the same time, intensive extraction of sand from riverbeds causes bed degradation, bank erosion and loss of vegetation and legally available river sand now meets only a part of the annual demand of the construction sector [2]. Both problems call for alternative materials that are technically sound and environmentally acceptable.

Industrial by-products offer one such route. Ground granulated blast furnace slag (GGBS), a by-product of iron production, has a chemical composition similar to that of cement (lime, silica, alumina and magnesia) and can replace part of the cement without a major loss of strength. Copper slag, produced in large quantities during the smelting and refining of copper, is rich in iron and silica and has a particle size distribution suitable for use as fine aggregate; its disposal is otherwise a problem because it is generated in high volumes with few industrial applications [3,4]. Earlier studies have reported that moderate replacement of sand by copper slag can improve the properties of concrete, while high levels lead to bleeding, segregation and loss of strength [3–6].

Most reported work examines either a cementitious replacement or an aggregate replacement separately. This study investigates both in the same M30 base mix: first the optimum GGBS content is established, and then the optimum copper slag content, and finally a combined mix using both optima are evaluated. The objectives are:

1) To determine the optimum percentage of cement replacement with GGBS in M30 concrete.
2) To determine the optimum percentage of sand replacement with copper slag in M30 concrete.
3) To evaluate the workability, compressive strength and flexural strength of the resulting mixes.

II. Materials

- Cement. Ordinary Portland Cement of 53 grade (UltraTech), conforming to IS 12269, was used. Its fineness (90 µm sieve residue) was 8.0%, specific gravity 3.15, normal consistency 33%, initial and final setting times 35 min and 385 min, and 28-day compressive strength 51 MPa.
- GGBS. GGBS supplied by Ballarpur Industries Ltd. (Avantha), Erode, was used at 5, 10, 15 and 20% by weight of cement.
- Fine aggregate. Natural Narmada river sand conforming to grading Zone II of IS 383, with specific gravity 2.64, fineness modulus 2.80, bulk density 1645 kg/m³, water absorption 0.99% and silt content 2.93%.
- Coarse aggregate. Crushed natural stone aggregate of 20 mm and 10 mm nominal sizes (60:40 by weight), with specific gravity 2.70, bulk density 1600 kg/m³, water absorption 0.79%, aggregate impact value 13.50% and abrasion value 20.97%.
- Copper slag. Copper slag obtained from Hindustan Copper Limited, Jhagadia Industrial Estate, Bharuch, and Gujarat. It consists mainly of Fe_2O_3 (53.45%) and SiO_2 (33.05%), with Al_2O_3 2.79%, CaO 6.06%, MgO 1.56% and SO_3 1.89%; the sum of Al_2O_3, SiO_2 and Fe_2O_3 is 89.29%. Sieve analysis showed 100% passing 4.75 mm and 15.9% passing 150 µm.
- Superplasticizers- Master Glenium SKY 8233, a polycarboxylic-ether based, chloride-free admixture (relative density 1.08, pH > 6, chloride < 0.2%).

Material	Property	Value
OPC 53	Specific gravity / Fineness	3.15 / 8.0%
OPC 53	Initial / final setting time	35 min / 385 min

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River sand	Specific gravity / Fineness modulus	2.64 / 2.80
River sand	Water absorption / Silt content	0.99% / 2.93%
Coarse aggregate	Specific gravity / Water absorption	2.70 / 0.79%
Coarse aggregate	Impact value / Abrasion value	13.50% / 20.97%
Copper slag	Fe_2O_3 / SiO_2	53.45% / 33.05%

Table 1: Properties of the materials used

III. Mix Proportioning and Experimental Programmed

A. Mix design

The control M30 mix was designed according to IS 10262 with a characteristic strength of 30 MPa, standard deviation of 5 MPa and therefore a target mean strength of 30 + 1.65 × 5 = 38.25 MPa. The exposure condition was taken as severe, the nominal maximum aggregate size as 20 mm and the target slump as 80 mm. A water–cement ratio of 0.42 (below the IS 456 limit of 0.45) was selected on the basis of trial mixes. The adopted quantities per m³ were: cementitious material 390 kg, water 150 kg (water–cementitious ratio 0.385), fine aggregate 786 kg and coarse aggregate 1156 kg. The coarse aggregate fraction was increased and then reduced by 10% for pumpable concrete, giving a coarse-to-total aggregate volume ratio of 0.59.

B. Mixes studied

Ten mixes were prepared in two series (Table 2). In Series 1 (CR), GGBS replaced 5–20% of cement by weight; in Series 2 (SR), copper slag replaced 10–50% of sand by weight. In both series the total cementitious content, water content and coarse aggregate content were kept constant.

Mix ID	Cement	GGBS	Sand	Copper slag	Coarse aggregate
CONC0	390.0	0	786.0	0	1156
CR5	370.5	19.5	786.0	0	1156
CR10	351.0	39.0	786.0	0	1156
CR15	331.5	58.5	786.0	0	1156
CR20	312.0	78.0	786.0	0	1156
SR10	390.0	0	707.4	78.6	1156
SR20	390.0	0	628.8	157.2	1156
SR30	390.0	0	550.2	235.8	1156
SR40	390.0	0	471.6	314.4	1156
SR50	390.0	0	393.0	393.0	1156

Table 2: Mix proportions (kg/m³)

C. Testing

Workability was measured with the slump cone test. Compressive strength was determined on cubes at 7, 14 and 28 days in a compression testing machine, using the average of at least three specimens. Flexural strength was determined at 28 days on prisms of 700 × 150 × 150 mm by two-point loading at a rate of 400 kg/min, and calculated as $fb = 3Pl/(2bd^2)$ where P is the failure load, l the supporting span, and b and d the width and depth of the specimen. Tests followed IS 516 and IS 456.

IV. Results and Discussion

A. Workability

The slump of the control mix was 74 mm (Table 3). Increasing GGBS content progressively reduced slump to 64 mm at 20% replacement, a decrease of 13.5%. This is consistent with the finer particles and higher surface area of GGBS compared with cement, which increase water demand. In contrast, replacing sand with copper slag increased slump steadily to 84 mm at 50% replacement (+13.5%). Copper slag particles have a glassy, smooth surface and very low water absorption, so less mixing water is held by the aggregate and more is available for lubrication of the paste. All mixes remained within a workable range for structural concrete.

GGBS replacement	0%	5%	10%	15%	20%
Slump	74	72	69	66	64

Copper slag replacement	0%	10%	20%	30%	40%	50%
Slump	74	77	80	80	82	84

Table 3: Slump (mm)

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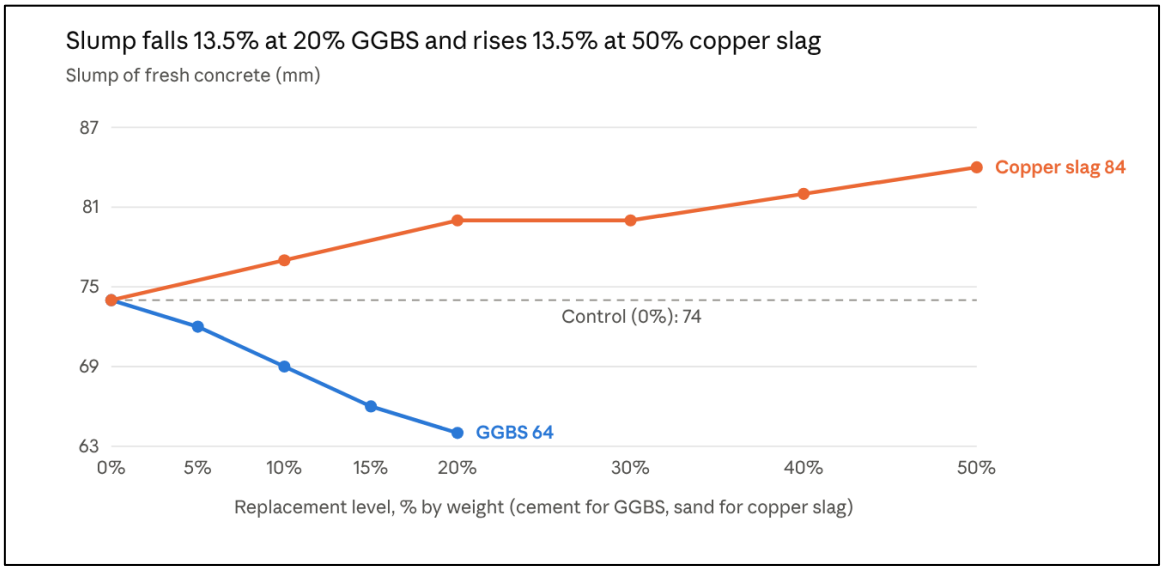


Fig. 1: Slump of concrete with GGBS (cement replacement) and copper slag (sand replacement).

B. Compressive strength

1) Effect of GGBS

Compressive strength rose slightly up to 10% GGBS and fell at higher contents (Table 4). At 28 days the 10% mix reached 37.20 MPa against 36.40 MPa for the control (+2.2%). At 15% the strength was 35.90 MPa (−1.4%) and at 20% it was 32.50 MPa (−10.7%). The early-age strength (7 days) was already lower than the control at 15% and 20%, which is typical of slag blends because of the slower pozzolanic and hydraulic reaction of GGBS. The strength gain at 10% can be attributed to the additional C–S–H formed by the reaction of GGBS with calcium hydroxide and to the filler effect of the fine slag particles; beyond this level, the reduced cement content dominates.

Age (days)	0%	5%	10%	15%	20%
7	23.20	24.70	24.80	23.60	20.80
14	29.50	30.30	30.45	27.60	26.00
28	36.40	36.90	37.20	35.90	32.50

Table 4: Compressive strength of GGBS mixes (MPa)

C. Effect of Copper Slag:

Replacing sand with copper slag improved strength up to 40% at early ages and up to 30% at 28 days (Table 5). The 28-day strength was 39.94 MPa at 30% replacement (+9.7%) and 39.11 MPa at 40% (+7.4%); at 50% it dropped to 34.64 MPa, 4.8% below the control. The improvement is related to the high strength and angular, dense particles of copper slag and to its favorable particle size distribution, which improves packing. The loss at 50% is likely due to the high free water and the tendency of the very workable mix to bleed and segregate, which weakens the paste–aggregate interface.

Age (days)	0%	10%	20%	30%	40%	50%
7	23.20	24.58	25.35	25.32	26.23	22.23
14	29.50	31.45	32.45	33.50	34.05	29.82
28	36.40	37.13	37.90	39.94	39.11	34.64

Table 5: Compressive strength of copper slag mixes (MPa)

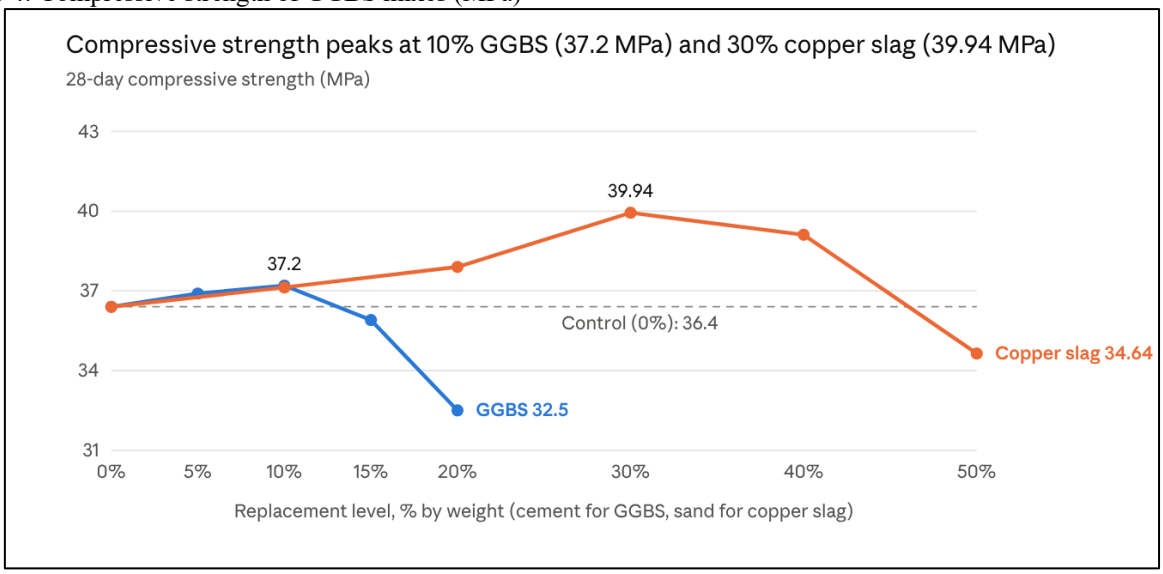


Fig. 2: 28day compressive strength against replacement level for GGBS and copper slag.

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D. Flexural strength

Flexural strength followed the same trend as compressive strength (Table 6). With GGBS, the 28-day flexural strength increased from 3.90 MPa to 4.15 MPa at 5% and 4.21 MPa at 10% (+7.9%), and decreased to 3.85 MPa and 3.45 MPa at 15% and 20% (−11.5%). With copper slag it increased continuously from 3.90 MPa to 4.68 MPa at 40% replacement (+20.0%) and then fell to 3.65 MPa at 50% (−6.4%). Flexural strength was therefore more sensitive to copper slag than compressive strength, which suggests an improved interfacial bond between the angular slag particles and the paste.

GGBS replacement	0%	5%	10%	15%	20%
Flexural strength	3.90	4.15	4.21	3.85	3.45

Copper slag replacement	0%	10%	20%	30%	40%	50%
Flexural strength	3.90	4.02	4.26	4.45	4.68	3.65

Table 6: 28days flexural strength (MPa)

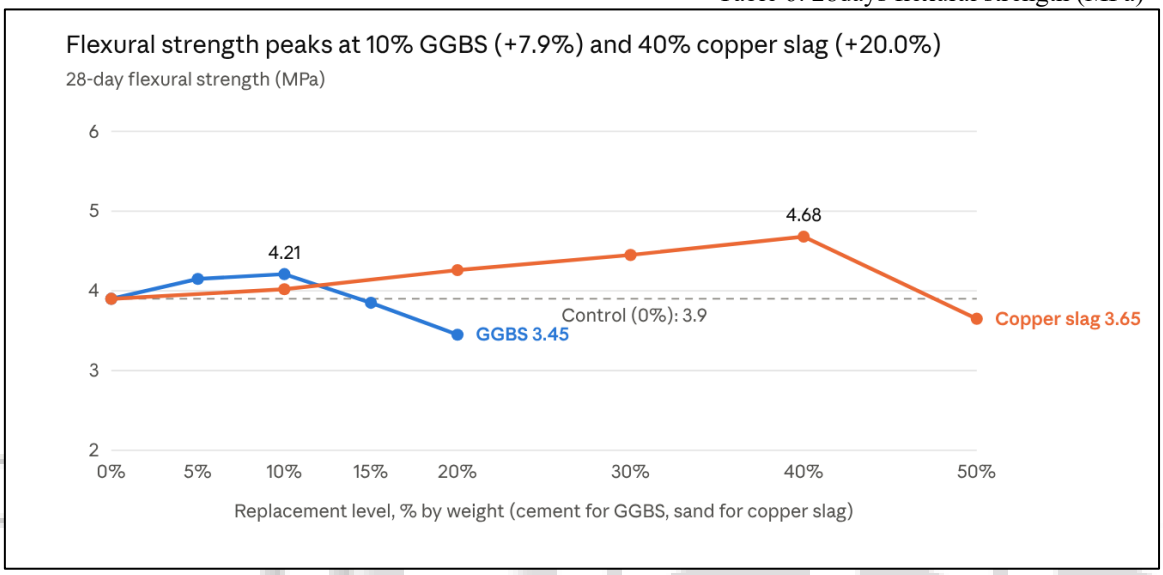


Fig. 3: 28day flexural strength against replacement level for GGBS and copper slag.

E. Combined Optimum Mix

The optimum levels were taken as 10% GGBS (best 28-day compressive and flexural strength in Series 1) and 40% copper slag (highest flexural strength and highest 7- and 14-day strength in Series 2, with 28-day compressive strength within 2% of the maximum at 30%). The combined mix reached a 28-day compressive strength of 37.10 MPa, which is 1.9% higher than the control (36.40 MPa), and a flexural strength of 3.78 MPa, 3.1% lower than the control (3.90 MPa) (Table 7). The combined mix therefore matches the control in compressive strength and exceeds the M30 target characteristic strength of 30 MPa, while reducing both cement and natural sand consumption. The mean strengths of the control (36.40 MPa) and of the 10% GGBS mix (37.20 MPa) are, however, below the 38.25 MPa target mean strength used in the mix design, whereas the copper slag mixes at 30% and 40% (39.94 and 39.11 MPa) exceed it. The small reduction in flexural strength relative to the control, in contrast to the gains seen when each material was used alone, indicates that the two replacements do not act additively and should be investigated further.

Mix	GGBS	Copper slag	Compressive strength (MPa)	Flexural strength (MPa)
Control	0%	0%	36.40	3.90
Combined	10%	40%	37.10	3.78

Table 7: Control mix versus combined optimum mix at 28 days

V. CONCLUSIONS

1) Slump decreased with increasing GGBS content (74 mm to 64 mm at 20%) and increased with increasing copper slag content (74 mm to 84 mm at 50%).
2) Compressive and flexural strength increased with GGBS up to 10% replacement of cement and decreased beyond it. The 10% mix gave 37.20 MPa and 4.21 MPa at 28 days.
3) With copper slag as partial replacement of sand, the 28-day compressive strength was highest at 30% (39.94 MPa) and the flexural strength highest at 40% (4.68 MPa). Replacement of 50% reduced both properties below the control.
4) A combination of 10% GGBS and 40% copper slag gave a 28-day compressive strength of 37.10 MPa, equal to the control, with a flexural strength of 3.78 MPa.
5) Using GGBS and copper slag together can lower cement and river sand consumption in M30 concrete and provides a use for two industrial by-products, supporting more sustainable concrete production.

Limitations and future work.

The study covers only one base mix, workability, compressive and flexural strength at limited ages. Durability (chloride penetration, sulphate attack, permeability), long-term strength, leaching of heavy metals from copper slag, and higher-strength grades should be examined before field adoption.

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