An Experimental Study on the Partial Replacement of Sand with Copper Slag in Cement Concrete

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Abstract — **Copper slag is a by-product obtained during matte smelting and refining of copper. The common management options for copper slag are recycling, recovering of metal, production of value added products such as abrasive tools, roofing granules, cutting tools, abrasive, tiles, glass, road-base construction, railroad ballast, asphalt pavements. Despite increasing rate of reusing copper slag, the huge amount of its annual production is disposed in dumps or stockpiles to date. One of the greatest potential applications for reusing copper slag is in cement and concrete production. Many researchers have investigated the use of copper slag in the production of cement, mortar and concrete as raw materials for clinker, cement replacement, coarse and fine aggregates. 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.**

This paper studied the engineering characteristics of copper slag and its effects on the properties of cement concrete. When copper slag is used as a raw material for clinker production, it can act as both iron adjusting and mineralizing component. Further, it also improves the grindability of the clinker. When it is used as a cement replacement or an aggregate replacement, the cement concrete containing different forms of copper slag have good performance in comparison with conventional concrete. Compressive strength of concrete at 0% copper slag is 29.98 N/mm^2, 10% copper slag is 31.67 N/mm^2, 20% copper slag is 36.90 N/mm^2, 30% copper slag is 39.42 N/mm^2, 40% copper slag is 45.07 N/mm^2, 50% copper slag is 28.80 N/mm^2 and for 60% copper slag is 35.65 N/mm^2. Split tensile strength of concrete at 0% copper slag is 2.80 N/mm^2, 10% copper slag is 3.12 N/mm^2, 20% copper slag is 3.51 N/mm^2, 30% copper slag is 3.87 N/mm^2, 40% copper slag is 3.93 N/mm^2, 50% copper slag is 3.60 N/mm^2 and for 60% copper slag is 3.45 N/mm^2. Flexural strength of concrete at 0% copper slag is 3.99 N/mm^2, 10% copper slag is 4.11 N/mm^2, 20% copper slag is 4.20 N/mm^2, 30% copper slag is 4.46 N/mm^2, 40% copper slag is 4.57 N/mm^2, 50% copper slag is 4.29 N/mm^2 and for 60% copper slag is 4.08 N/mm^2. The study reveals that when copper slag is added in concrete partially replaced with sand, the properties of concrete are satisfactory up to 40% of copper slag. But when percentage of copper slag is increases, the compressive strength, split tensile strength and flexural strength of concrete is decreases. The effect of using copper slag in concrete by partially reducing quantities of sand reduces cost of concrete work. Compressive strength and flexural Strength is increased due to high toughness of copper slag. As the percentage of Copper slag increases the density of concrete is increased.

Index Terms— **Concrete, Copper Slag, Split Tensile Strength, Flexural Strength, Compressive Strength, Permeability, Chemical Resistance, etc.**

I. INTRODUCTION

Copper slag is a by-product of copper extraction by smelting. During smelting, impurities become slag which floats on the molten metal. Slag that is quenched in water produces angular granules which are disposed of as waste or utilized as discussed below. Slag from ores that are mechanically concentrated before smelting contain mostly iron oxides and silicon oxides.

Copper slag is an abrasive blasting grit made of granulated slag from metal smelting processes (also called iron silicate). Copper slag is a by-product created during the copper smelting and refining process. As refineries draw metal out of copper ore, they produce a large volume of non-metallic dust, soot, and rock. Collectively, these materials make up slag, which can be used for a surprising number of applications in the building and industrial fields. This material represents a popular alternative to sand as a blasting medium in industrial cleaning. Using blasting or high-pressure spraying techniques, companies can use copper slag to clean large smelting furnaces or equipment. Slag blasting is also used to remove rust, paint, and other materials from the surface of metal or stone. This helps to prepare the surface for painting, or simply to remove unwanted finishes or residue. Copper slag abrasive is suitable for blast cleaning of steel and stone/concrete surfaces, removal of mill scale, rust, old paint, dirt etc.

Copper slag blasting grit is manufactured of the granulated slag of copper refineries and used for blast-cleaning of metal surface. In different industries it is called different names - abrasive powder, grit, copper slag grit, mineral grit, grinding grains, etc. - but its main use is still for surface blast-cleaning. Blasting the grit at the surface is the most advanced approach for metal surface cleaning before paint spraying. The blasting media manufactured from copper slag brings less harm to people and environment then sand. The product meets the most rigid health and ecological standards. Copper slag can also be used as a building material, formed into blocks. Such use was common in areas where smelting was done.

Due to its high strength/ weight ratio copper slag is used as filling materials in construction works. Copper slag can be used as a best alternative to sand. Copper slag has also gained popularity in the building industry for use as a fill material. Unlike many other fill materials, copper slag poses relatively little threat to the environment. This means it can be used to build up the earth to support roads, buildings, or other surfaces. Contractors may also use copper slag in place of sand during concrete construction.

Fig. 1: Copper Slag

The slag serves as a fine, or binding agent, which helps hold the larger gravel particles within the concrete together. When used in this manner, the slag helps to improve the properties of the concrete, and also serves as a form of recycling. One of the primary advantages to copper slag is the low risk it poses to health and the environment. Silica sand, which represents the most popular blasting medium and concrete fine currently in use, poses serious health risks when inhaled. It may also contribute to pollution and other environmental concerns.

Copper slag also has a high strength-to-weight ratio, making it an effective option in concrete, or as a fill material under the roadway. When added to concrete, it makes the paved surface less porous, which minimizes problems with moisture and freezing. It also makes concrete more fire resistant and helps to slow the spread of heat and flames. This material also has several limitations that users should be aware of before using copper slag. Some versions may contain heavy metal traces, which can contribute to air and water pollution.

It's commonly classified as hazardous waste due to this risk. Another issue to consider is the Sheer volume of slag produced during copper refining. Typically, refineries end up with two units of slag for every one unit of copper produced during smelting.

A. Physical Properties of Copper Slag

Table 1: Physical Properties of Copper Slag

Sr. No.	Type	Property
1	Color	Black
2	Form	Granular
3	Purity (%)	95
4	Usage/Application	Shot blasting
5	Grade	Chemical Grade
6	Hardness (Mohr's Scale)	5 to 7
7	Specific Gravity	3.2 to 3.7
8	Type	Metallic Abrasive
9	Electric Conductivity	4.8 ms/m
10	Chloride Content	< 0.0002
11	Particle Size	0.2mm up to 3mm
12	Granular Size	Angular, sharp edges, multifaceted

B. Chemical Properties of Copper Slag

Table 2: Chemical Properties of Copper Slag

Sr. No.	Type	Property
1	Copper (Cu)	0.60 - 0.70
2	Ferrous Oxide (FeO)	42 - 48
3	Silicon Dioxide (SiO_2)	26 - 30
4	Aluminium Oxide (Al_2O_3)	1.0 – 3.0

5	Sulfur (S)	0.2 – 0.3
6	Calcium Oxide (CaO)	1.0 – 2.0
7	Magnesium Oxide (MgO)	0.8 – 1.5
8	Iron Oxide (Fe_3O_4)	1.0 – 2.0
9	Electric Conductivity	4.8 ms/m
10	Chloride Content	< 0.0002
11	Particle Size	0.2mm up to 3mm
12	Granular Size	Angular, sharp edges, multifaceted

II. METHODOLOGY

A. Problem Statement

The use of industrial solid waste to concrete production is environmentally friendly because it contributes to reducing the consumption of natural resources, the pollution concrete production generates and the power it consumes.

B. Aim of the Study

The main aim of the study is to investigate the copper slag used concrete. And the achievement of an acceptable probability that concrete being designed will perform satisfactorily during their intended life. With an appropriate degree of safety, they should sustain all the loads and deformations of normal construction and use and have adequate durability and adequate resistance to the effects of heat. The realization of design objectives requires compliance with clearly defined standards for materials, production, workmanship and also maintenance and use of structure in service.

C. Objectives of the Study

The reported work has aimed at the development and verification of a systematic methodology for process planning and optimization for most efficient method. The objectives of this study are as follows:

1. To study the effect of copper slag on compressive strength of concrete with partial replacement of sand by 10%, 20%, 30%, 40%, 50% and 60% for 28 days of water curing for M25 grade of concrete,
2. To study the effect of copper slag on split tensile strength of concrete with partial replacement of sand by 10%, 20%, 30%, 40%, 50% and 60% for 28 days of water curing for M25 grade of concrete,
3. To study the effect of copper slag on flexural strength of concrete with partial replacement of sand by 10%, 20%, 30%, 40%, 50% and 60% for 28 days of water curing for M25 grade of concrete,
4. To compare compressive strength of concrete, split tensile strength of concrete and flexural strength of concrete with normal grade of concrete for 28 days of water curing for M25 grade of concrete. (i. e. 0% of copper slag),
5. To find permeability of concrete for 10%, 20%, 30%, 40%, 50% and 60% of partial replacement of sand,
6. To find chemical resistance i.e., carbonation of concrete.

D. Methodology

1. Review of existing literatures by different researchers.
2. Significance of research.
3. Data collection.
4. Selection of type of material and mix proportion.
5. Testing.
6. Data analysis & Conclusion.
7. References

E. Formation of Copper Slag

Copper slag is a by-product obtained during the matte smelting and refining of copper. The major constituent of a smelting charge are sulphides and oxides of iron and copper. The charge also contains oxides such as SiO_2, Al_2O_3 CaO and MgO, which are either present in original concentrate or added as flux. It is Iron, Copper, Sulphur, Oxygen and their oxides which largely control the chemistry and physical constitution of smelting system. A further important factor is the oxidation/reduction potential of the gases which are used to heat and melt .As a result of this process copper- rich matte (sulphides) and copper slag (oxides) are formed as two separate liquid phases. The addition of silica during smelting process forms strongly bonded silicate anions by combining with the oxides. This reaction produces copper slag phase, whereas sulphide from matte phase, due to low tendency to form the anion complexes. Silica is added directly for the most complete isolation of copper in matte which occurs at near saturation concentration with SiO_2. The slag structure is stabilized with the addition of lime and alumina. The molten slag is discharged from the furnace at 1000-1300ºC. When liquid is cooled slowly, it forms a dense, hard crystalline product, while a granulated amorphous slag is formed through quick solidification by pouring molten slag.

Copper slag is a by-product obtained during the mattes smelting and refining of copper. Copper slag used in this work was brought from Sterlite Industries Ltd (SIL), Tuticorin, Tamil Nadu, India. SIL is producing Copper slag during the manufacture of copper metal. Currently, about 2600 tons of copper slag is produced per day and a total accumulation of around 1.5 million tons. It is a by-product obtained during the matte smelting and refining of copper. To produce every ton of copper, approximately 2.2–3.0 tons copper slag is generated as a by-product material. Utilization of copper slag in applications such as Portland cement substitution and/or as aggregates has threefold advantages of eliminating the costs of dumping, reducing the cost of concrete, and minimizing air pollution problems.

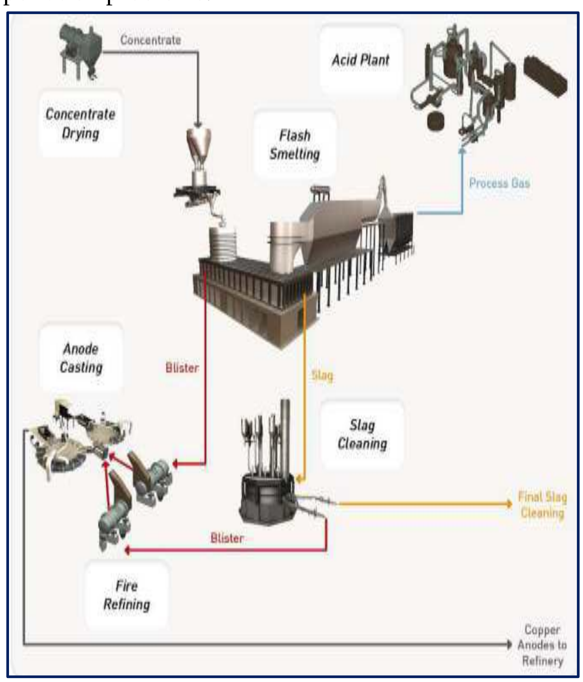


Fig. 2: Preparation of Copper Slag

E. Identification of Samples

Table 3: Identification of Samples

% of Copper Slag	Sample Number (S1/S2/S3)	Compressive Strength Test	Split Tensile Strength Test	Flexural Strength Test	Permeability Test
0%	S1	C0S1	S0S1	F0S1	P0S1
	S2	C0S2	S0S2	F0S2	P0S2
	S3	C0S3	S0S3	F0S3	P0S3
10%	S1	C10S1	S10S1	F10S1	P10S1
	S2	C10S2	S10S2	F10S2	P10S2
	S3	C10S3	S10S3	F10S3	P10S3
20%	S1	C20S1	S20S1	F20S1	P20S1
	S2	C20S2	S20S2	F20S2	P20S2
	S3	C20S3	S20S3	F20S3	P20S3
30%	S1	C30S1	S30S1	F30S1	P30S1
	S2	C30S2	S30S2	F30S2	P30S2
	S3	C30S3	S30S3	F30S3	P30S3
40%	S1	C40S1	S40S1	F40S1	P40S1
	S2	C40S2	S40S2	F40S2	P40S2
	S3	C40S3	S40S3	F40S3	P40S3
50%	S1	C50S1	S50S1	F50S1	P50S1
	S2	C50S2	S50S2	F50S2	P50S2
	S3	C50S3	S50S3	F50S3	P50S3
60%	S1	C60S1	S60S1	F60S1	P60S1
	S2	C60S2	S60S2	F60S2	P60S2
	S3	C60S3	S60S3	F60S3	P60S3

III. EXPERIMENTAL STUDY

A. Test Results on Cement

Table 5: Summary of Test Results on Cement

Sr. No.	Description of Test	Results
1	Fineness of Cement (Residue on IS sieve No.9)	2.65 %
2	Specific Gravity	3.17
3	Standard Consistency of Cement	32 %
4	Setting Time of Cement Initial Setting Time Final Setting Time	42 min 585 min
5	Soundness Test of Cement (with Le-chatelier's mould)	9.0 mm
6	Compressive Strength of Cement (28 Days of curing)	54.22 N/mm^2

B. Test Results on Fine Aggregates

Table 6: Summary of Test Results on Fine Aggregates

Sr. No.	Property	Results
1	Particle Shape, Size	Round, 4.75 mm down
2	Fineness Modulus	2.683
3	Silt Content	3.3 %
4	Specific Gravity	2.94
5	Bulk Density	1723 kg/m^3
6	Surface Moisture	Nil

C. Test Results on Coarse Aggregates

Table 7: Summary of Test Results on Coarse Aggregates

Sr. No.	Property	Results

1	Particle Shape, Size	Angular, 10 mm down
2	Fineness Modulus	6.0
3	Specific Gravity	2.69
4	Water Absorption	2.835 %
5	Moisture content	Nil
6	Bulk Density	1620 kg/m^3

D. Mix Design of Concrete for M25 Grade

Table 8: Mix Design of Concrete for M25 Grade

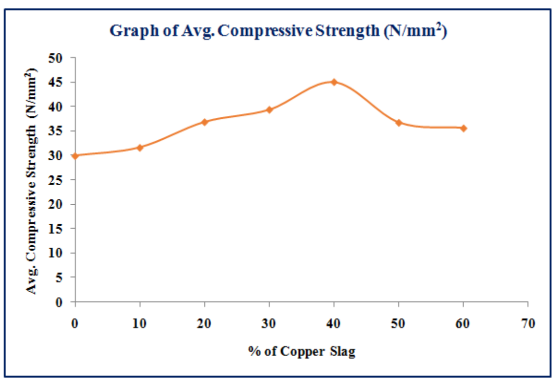
W/C	Mixture Proportion (kg/m^3)			
	Cement	Fine Aggregate	Coarse Aggregate	Water
0.45	437	654	1125	197

Cement : Fine Aggregate : Coarse Aggregate = 1 : 1.49 : 2.57

E. Results of Compressive Strength Test on Concrete

Table 9: Results of Compressive Strength Test for 28 Days of Curing with different % of Copper Slag

Sr. No.	% of Copper Slag	Avg. Compressive Strength (N/mm^2)
1	CS 0%	29.98
2	CS 10%	31.67
3	CS 20%	36.90
4	CS 30%	39.42
5	CS 40%	45.07
6	CS 50%	36.78
7	CS 60%	35.65

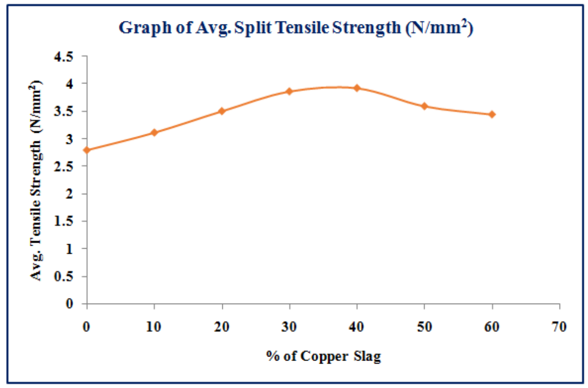


Graph 1: Compressive Strength Test Results for 28 Days of Curing with different % of Copper Slag

F. Results of Split Tensile Strength Test on Concrete

Table 10: Results of Split Tensile Strength Test for 28 Days of Curing with different % of Copper Slag

Sr. No.	% of Copper Slag	Avg. Tensile Strength (N/mm^2)
1	CS 0%	2.80
2	CS 10%	3.12
3	CS 20%	3.51
4	CS 30%	3.87
5	CS 40%	3.93
6	CS 50%	3.60
7	GW 60%	3.45

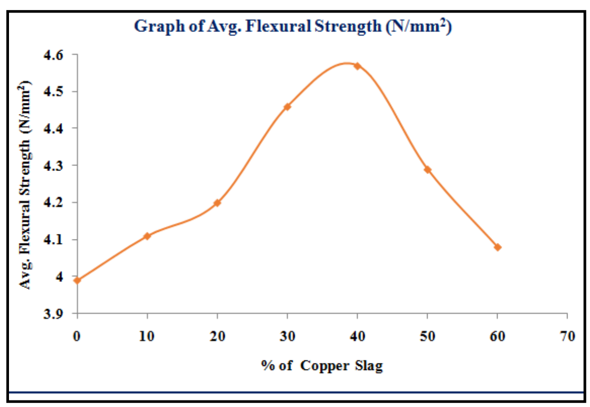


Graph 2: Split Tensile Strength Test Results for 28 Days of Curing with different % of Copper Slag

G. Results of Flexural Strength Test on Concrete

Table 11: Results of Flexural Strength Test for 28 Days of Curing with different % of Copper Slag

Sr. No.	% of Copper Slag	Avg. Flexural Strength (N/mm^2)
1	CS 0%	3.99
2	CS 10%	4.11
3	CS 20%	4.20
4	CS 30%	4.46
5	CS 40%	4.57
6	CS 50%	4.29
7	CS 60%	4.08



Graph 3: Flexural Strength Test Results for 28 Days of Curing with different % of Copper Slag

H. Results of Permeability Test on Concrete

Table 12: Results of Permeability Test for 28 Days of Curing

Sample No.	Discharge Q (ml)	Time T (Hrs)	Head of Water H (m)	Average Coefficient of Permeability k (m/sec)
P0S1	16	18	68.67	
P0S2	15	18	71.12	24.85
P0S3	18	18	71.55	
P10S1	12	18	73.58	
P10S2	14	18	76.03	25.29
P10S3	13	18	75.5	
P20S1	11	18	66.22	
P20S2	12	18	78.48	26.63
P20S3	10	18	72.65	
P30S1	7	18	68.67	
P30S2	9	18	73.58	28.60
P30S3	10	18	74.95	
P40S1	11	18	66.22	
P40S2	10	18	78.48	30.54
P40S3	11	18	73.65	
P50S1	8	18	68.67	
P50S2	9	18	73.58	32.08
P50S3	8	18	72.15	
P60S1	7	18	70.25	
P60S2	9	18	72.15	32.38
P60S3	8	18	71.25	

I. Results of Chemical Resistance Test Carbonation on Concrete

This test is carried out to determine the depth of concrete affected due to combined attack of atmospheric carbon dioxide and moisture. It causes a reduction in level of alkalinity of concrete. To conduct this test, I have drilled a hole on the concrete surface of different depths up to cover concrete thickness. Then I have removed the dust and spray phenolphthalein with physician's injection. A spray of 0.2% solution of phenolphthalein is used as pH indicator.

The change of color of concrete is pink indicates that the concrete is in good health.

IV. CONCLUSION

It can be concluded that:

[1] Compressive strength of concrete at 0% copper slag is 29.98 N/mm^2, 10% copper slag is 31.67 N/mm^2, 20% copper slag is 36.90 N/mm^2, 30% copper slag is 39.42 N/mm^2, 40% copper slag is 45.07 N/mm^2, 50% copper slag is 28.80 N/mm^2 and for 60% copper slag is 35.65 N/mm^2.

[2] Split tensile strength of concrete at 0% copper slag is 2.80 N/mm^2, 10% copper slag is 3.12 N/mm^2, 20% copper slag is 3.51 N/mm^2, 30% copper slag is 3.87 N/mm^2, 40% copper slag is 3.93 N/mm^2, 50% copper slag is 3.60 N/mm^2 and for 60% copper slag is 3.45 N/mm^2.

[3] Flexural strength of concrete at 0% copper slag is 3.99 N/mm^2, 10% copper slag is 4.11 N/mm^2, 20% copper slag is 4.20 N/mm^2, 30% copper slag is 4.46 N/mm^2, 40% copper slag is 4.57 N/mm^2, 50% copper slag is 4.29 N/mm^2 and for 60% copper slag is 4.08 N/mm^2.

[4] The study reveals that when copper slag is added in concrete partially replaced with sand, the properties of concrete are satisfactory up to 40% of copper slag. But when percentage of copper slag is increases, the compressive strength, split tensile strength and flexural strength of concrete is decreases.

[5] The effect of using copper slag in concrete by partially reducing quantities of sand reduces cost of concrete work.

[6] Compressive strength and flexural Strength is increased due to high toughness of copper slag. As the percentage of Copper slag increases the density of concrete is increased.

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