International Journal of Research
Available at https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 07 Issue 02
February 2020

Experimental Investigation Of Effective Replacement Of Cement and Fine Aggregate By Copper Slag

Kattubadi Supriya[1], M. Mujahid Ahmed[2]
[1]P.G. Scholar, [2]Guide, Head of the Department
[1,2] Department : Civil Department - Structural Engineering
[1,2] Geethanjali College Of Engineering And Technology, Nannur (V), Kurnool-Dt.
Email: [1] ksupriya561@gmail.com, [2]mujahidahmedcivileng@gmail.com

ABSTRACT

Copper slag is considered as one of the waste materials which can have a promising future in construction industry as partial or full substitute of either cement or aggregates. For each ton of copper production, about 2.2 tonnes of copper slag is generated. This slag is currently used for many purposes like land filling, construction of abrasive tools, roofing granules, cutting tools and rail road ballast material, which are not very high value added application. These applications utilize only about 15% to 20% of copper slag generated and remaining material is dumped as a waste. In order to reduce the accumulation of copper slag and also to provide an alternative material for sand and cement an approach has been done to investigate the use of copper slag in concrete for the partial replacement of sand and cement.

Many researchers have already found it possible to use copper slag as a concrete aggregate, because copper slag has similar particle size characteristics likely to that of sand. Fine grained powder of copper slag can be used as a supplementary cementing material to concrete and in cement clinker production.This research was performed to generate specific experimental data on the potential use of copper slag as sand and cement replacement partially in concrete.

This research work mainly consists of two main parts. M20 concrete was used to determine various mechanical properties. First part of the thesis consists of substituting sand partially by copper slag in concrete. For sand replacement, seven test groups (including control mixture) were constituted with replacement of 0% (control specimen), 10%, 20%, 30%, 40%, 50% and 60% copper slag with sand in each series. Concrete cubes, cylinders, RCC beams and Columns were cast and tested in laboratories. The optimum proportion of replacement was found by conducting the following tests.

1.1 Compressive strength test on concrete cubes
1.2 Split tensile strength test on cylinders

Similarly the second part of the thesis evaluates the potential application of copper slag in concrete as a partial substitute for Portland cement. Five test groups were prepared with replacement of 0%, 5%, 10%, 15% and 20% finely ground copper slag with cement in each series. To improve the strength and reduce the setting time of concrete, hydrated lime is used as an activator to pozzolanic reaction. The following tests was performed to study the various mechanical behavior of copper slag admixed concrete for cement.

- Compressive strength test on concrete cubes
- Split tensile strength test on cylinders

The above said tests have been

performed to study the various mechanical behavior of copper slag admixed concrete for both sand and cement. The mix proportion used for this research was 1: 1.66: 3.76 and the W/C ratio was taken as 0.45. Since the water absorption capacity of copper slag is lesser than sand, the reduced W/C ratio was used.

INTRODUCTION

The utilization of industrial waste or secondary materials has encouraged the production of cement and concrete in construction field. New by-products and waste materials are being generated by various industries. Dumping or disposal of waste materials causes environmental and health problems. Therefore, recycling of waste materials is a great potential in concrete industry. For many years, by-products such as fly ash, silica fume and slag were considered as waste materials. Concrete prepared with such materials showed improvement in workability and durability compared to normal concrete and has been used in the construction of power, chemical plants and under-water structures. Over recent decades, intensive research studies have been carried out to explore all possible reuse methods. Construction waste, blast furnace, steel slag, coal fly ash and bottom ash have been accepted in many places as alternative aggregates in embankment, roads, pavements, foundation and building construction, raw material in the manufacture of ordinary Portland cement pointed out by Teik thye luin et al (2006).

Copper slag is an industrial by-product material produced from the process of manufacturing copper. For every ton of copper production, about 2.2 tonnes of copper slag is generated. It has been estimated that approximately 24.6 million tons of slag are generated from the world copper industry (Gorai et al 2003). Although copper slag is widely used in the sand blasting industry and in the manufacturing of abrasive tools, the remainder is disposed of without any further reuse or reclamation.

Copper slag possesses mechanical and chemical characteristics that qualify the material to be used in concrete as a partial replacement for Portland cement or as a substitute for aggregates. For example, copper slag has a number of favourable mechanical properties for aggregate use such as excellent soundness characteristics, good abrasion resistance and good stability reported by (Gorai et al 2003). Copper slag also exhibits pozzolanic properties since it contains low CaO. Under activation with NaOH, it can exhibit cementitious property and can be used as partial or full replacement for Portland cement. The utilization of copper slag for applications such as Portland cement replacement in concrete, or as raw material has the dual benefit of eliminating the cost of disposal and lowering the cost of the concrete. The use of copper slag in the concrete industry as a replacement for cement can have the benefit of reducing the costs of disposal and help in protecting the environment. Despite the fact that several studies have been reported on the effect of copper slag replacement on the properties of Concrete, further investigations are necessary in order to obtain a comprehensive understanding that would provide an engineering base to allow the use of copper slag in concrete.

BACKGROUND OF COPPER SLAG

KB Exports International, Vijaywada is the principal subsidiary of Vedantha Resources public limited company (PLC), a diversified and integrated FTSE 100 metals and mining company, with principal operations located in India.

The annual turnover of KBEI, Vijaywada, India is Rs.13, 45 crores. KBEI, a leading producer of copper in India, pioneered the manufacturing of continuous cast copper roads and established India s largest copper smelting and refining plant for production of world class refined copper. KBEI is the producer of copper slag (Figure 1.1) during the manufacture of copper metal. Presently, about 1500 tons of copper slag is produced per day and a total accumulation of around 1.1 million tons.

Figure 1.1 Appearance of copper slag sample

This slag is currently being used for many purposes. It is a glassy granular material with high specific gravity particle sizes. The various myths about copper slag is shown in Table 1.1. The size of the particle is of the order of sand and can be used as a fine aggregate in concrete. To reduce the accumulation of copper slag and also to provide an alternative material for sand and cement, an approach has been done to investigate the use of copper slag in concrete for the partial replacement of sand and cement.

Table 1.1 Concerns/ myths over copper slag

S.No	Myths over copper slag	Performance in real
1.	Toxic material	Non-toxic material
2.	Durability	High durability
3.	Decreases concrete strength	Improves concrete strength
4.	Bleeding	No bleeding of concrete up to 40-50% replacement
5.	Leaching	Leaching levels are insignificant

PRODUCTION OF COPPER SLAG

Copper slag is a by-product obtained during the matte smelting and refining of copper has been reported by Biswas and Davenport (2002). The major constituent of a smelting charge are sulphides and oxides of iron and copper. The charge also contains oxides such as SiO2, Al2O3 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 the charge stated by Gorai et al (2002). 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 SiO2.

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.

ADVANTAGES OF COPPER SLAG

- Reduces the construction cost due to saving in material cost.
- Reduces the heat of hydration.
- Refinement of pore pressure.
- Reduces permeability.
- Reduces the demand for primary natural resources.

Reduces the environmental impact due to quarrying and aggregate mining.

USE OF COPPER SLAG IN VARIOUS FIELDS

Use of Copper Slag in Cement Clinker Production

Since the main composition of copper slag is vitreous FeSio3, it has low melting point and could reduce the calcination temperature for cement clinker. Thus, the use of copper slag to replace iron powder as iron adjusting material facilitates cement production and reduces or eliminates the need of mineralizes has been pointed out by (Huang 2001). The performance testing results indicated that cement produced by using copper slag performed even better than using iron powder.

Use of Copper Slag in Blended Cement

The use of copper slag as a pozzolanic material for ordinary Portland cement and its effects on the hydration reactions and properties of mortar and concrete have been reported in several applications (Al-Jabri et al 2006, Tata et al 2007, Malhotra 1993, Tixier et al 1997, Ariro and mobasher 1999). The copper slag in corporation into the cement mortar does not cause an increase in the leached elements reported by Sanchez de Rojas et al (2004). Another work showed that the amounts of leached elements of copper slag are significantly lower than the regulatory levels determined by United States Environmental Protection Agency (USAPA) (Alter 2005). Arino and mobasher (1999) suggested that upto 15% of copper slag can be used as a cement replacement with constant w/c ratio of 0.4. This gives higher compressive strength than ordinary cement.

Use of Copper Slag in Concrete

Several researchers have investigated the possible use of copper slag as a fine and coarse aggregate and cement in concrete and its effects on the different mechanical and long term properties of mortar and concrete. Hwang and Laiw (1989) evaluated the compressive strength development of mortars and concrete containing fine copper slag aggregate with different water cement ratios. The strength of mixtures with 20-80% substitution of copper slag was higher than that of control specimens. Shoya et al (1997) reported that the amount and rate of bleeding increased by using copper slag fine aggregate depending on the water to cement ratio and also they recommended using less than 40% copper slag as partial replacement of aggregate to control the amount of bleeding to less than 5 l/m2. Therefore copper slag can be replaced 40% with that of sand.

The pozzolanic activity of copper slag has been investigated by Pavez et al 2002. The effect of copper slag on hydration of cement was investigated by Mobasher et al and Tixier et al 1997. Upto 15% by weight of copper slag was used as a Portland cement replacement together with 1.5% of hydrated lime as an activator to pozzolanic reaction. Result indicated a significant increase in the compressive strength.

Although there are many studies that have been reported by investigators from other countries on the use of copper slag in cement concrete, not much research has been carried out in India concerning the incorporation of copper slag in concrete and also its durability effects. Therefore to generate specific experiment data on the potential use of copper slag as sand and cement replacement in concrete, this research was performed.

In this research work, an extensive study using copper slag has been carried out to investigate the following.

1. To find the optimum proportion of copper slag that can be used as a

replacement/ substitute material for cement and fine aggregate.
2. To evaluate compressive and tensile strength of copper slag replaced concrete specimens.

COPPER SLAG REPLACEMENT FOR SAND

The use of slag from copper smelting as a fine aggregate in concrete was investigated by Akihiko and Takashi (1996). Copper slag was also used by Ayano et al (2000) as a fine aggregate in concrete. They described the strength, setting time and durability of concrete mixtures made with copper slag. The fundamental properties of concrete using copper slag and class II fly ash as fine aggregates were investigated by Ishimaru et al (2005). It was concluded that up to 20% (in volume) of copper slag or class II fly ash as fine aggregates substitution can be used in the production of concrete. To control the bleeding in concrete mixtures when incorporating copper slag as fine aggregates, Ueno et al (2005) suggested a grading distribution of fine aggregate based on particle density.

The study investigated the maximum size of slag fine aggregate that does not significantly influence the amount of bleeding and the required plastic viscosity of paste to control the amount of bleeding by the variation of water-to-cement ratios. Shi et al (2008) presented a comprehensive review on the use of copper slag in cement, mortars and concrete. The paper was focused on the characteristics of copper slag and its effects on the engineering properties of cement, mortars and concrete. Wu et al (2010) investigated the mechanical properties of copper slag and reinforced concrete under dynamic compression. The results showed that the dynamic compressive strength of copper slag reinforced concrete generally improved with the increase in amounts of copper slag used as a sand replacement upto 20%, compared with the control concrete, beyond which the strength was reduced. Wu et al (2010) also investigated the mechanical properties of high strength concrete incorporating copper slag as a fine aggregate. The results indicated that the strength of concrete, with less than 40% copper slag replacement, was higher than or equal to that of the control specimen. The microscopic view demonstrated that there were limited differences between the control concrete and the concrete with less than 40% copper slag content.

Based on above investigations, this research study was conducted to investigate the performance of concrete made with copper slag as a partial replacement for fine aggregate. Seven test groups were constituted with replacement: 0%, 10%, 20%, 30%, 40%, 50%, and 60% of copper slag with sand in each series. The following tests have been conducted to find the mechanical properties of concrete and structural members.

1. Compressive strength on concrete cube
2. Compressive strength on cylinders

COPPER SLAG REPLACEMENT FOR CEMENT

The effect of copper slag on the hydration of cement-based materials was investigated by Mobasher et al (1996) and Tixier et al (1997). Up to 15% copper slag, by weight of cement was used as a Portland cement replacement together with 1.5% of hydrated lime. It was used as an activator for pozzolanic reactions. The results indicated a significant increase in the compressive strength for up to 90 days of hydration. Also, a decrease in capillary porosity and an increase in gel porosity were observed. Moura et al (1999) reported that the copper slag could be a potential alternative to admixtures used in concrete and mortars. Al-Jabri et al (2002) studied the effect of copper slag (CS) and cement by-pass dust (CBPD) replacements on the strength of cement mortars. Experimental results indicated that the mixture containing 5% CBPD + 95% cement yielded the highest 90 days compressive strength of 42 MPa in comparison with 40 MPa for the mixture containing 1.5% CBPD + 13.5 CS + 85% cement. The optimum CS and CBPD used was 5%. In addition, it was determined that using CBPD as an activating material would operate better than using lime.

The second part of this research deals with the application of copper slag as partial replacement of cement in concrete and RCC structures. Thereby, copper slag were finely ground in ball mills and partially replaced with Portland cement during the production of concrete. Five test groups were constituted with replacement: 0%, 5%, 10%, 15% and 20% of copper slag with cement in each series. To improve the strength of concrete and to activate pozzolanic reactions in cement, hydrated lime was added. 0.5% of hydrated lime was added for 5% replacement of cement with copper slag. Similarly 1%, 1.5% and 2% was added for 10%, 15% and 20% replacement. The following tests were conducted to find the mechanical behaviours of various concrete specimens at 28 days.

i) Compressive strength test on concrete cube specimens
ii) Compressive strength test on cylinders
iii) Split tensile strength test on cylinders

GENERAL

Copper slag is considered as one of the waste material which can have a promising future in construction industry as partial or full substitute of either cement or aggregates. Many researchers have already found it possible to use copper slag as a concrete aggregate. But not much research has been carried out in India concerning the incorporation of copper slag in concrete and RCC members. Therefore this research was performend to create specific experimental data on the potential use of copper slag in concrete and RCC members.

AIM

The main aim of this research work was to investigate effective replacement of sand and cement by copper slag in concrete and RCC structural elements and its applications to reduce seismic earth pressure. To achieve this, an extensive study has been carried out to investigate the following using copper slag.

- To find the optimum proportion of copper slag that can be used as a replacement/ substitute material for cement and fine aggregate.
- To evaluate compressive and tensile strength of copper slag admixed concrete specimens.
- To investigate flexural strength of copper slag replaced structural members.

SCOPE

The government of India has targeted the year 2010 and 2011 for providing housing for all. Such large scale housing construction activities require huge amount of money. Out of the total cost of house construction, building materials contribute to about 70 percent costs in developing countries like India. Therefore the need of hour is replacement of costly and scarce conventional building materials by innovative, cost effective and environment friend by alternate building materials.

Since copper slag concrete showed an enhanced mechanical performance and also has non substance deemed as toxic was leached, it can be used as a building raw materials. Therefore in this investigation, possibilities of using copper slag for various purposes were examined and reported.

MATERIALS INVESTIGATION AND MIX PROPORTION

GENERAL

The materials used in the present investigation and their properties are briefly discussed below.

CEMENT

An OPC 43 Grade Ramco cement was used in this investigation. The quantity required for this work was assessed and the entire quantity was purchased and stored properly in casting yard. The following tests were conducted in accordance with IS codes.

Specific gravity (Le Chatelier flask) (IS: 1727-1967) Standard consistency (IS: 4031 1988 Part 4)

Initial setting time (IS: 4031 1988 Part 5)

Final setting time (IS: 4031 1988 Part 5)

The results of the tests on cement sample are listed in Table 4.1.

Table 4.1 Tests on cement

1.	Specific Gravity	3.10
2.	Standard consistency	31.5%
3.	Setting time	
	(i) Initial setting time	57 minutes
	(ii) Final setting time	4 hours
4	Soundness test (Le- Chatelier's test)	0.95 mm

FINE AGGREGATE

The fine aggregate used in this investigation was clean river sand and the following tests were carried out on sand as per IS: 2386-1968 (III).

Specific gravity
Sieve Analysis and Fineness Modulus
Water absorption

Table 4.2 Tests on fine aggregate

1.	Specific gravity	2.56
2.	Percentage of voids	33.00%
3.	Fineness modulus	2.39
4.	Water absorption	1.25%
5.	Bulk density	1.71
6.	Sieve analysis	ZONE II

COARSE AGGREGATE

In the present investigation, locally available crushed blue granite stone aggregate of size 20 mm and down, was used and the various tests, carried out on the aggregates, are given below.

Specific gravity (IS: 2386-1968 Part 3)

Bulk density (IS: 2386-1968 Part 3)

Sieve analysis and Fineness modulus (IS: 2386-1968 Part 3)

Crushing value (IS: 2386 1968 Part 4)

The results of the tests on coarse aggregate are given in Table 4.3.

Table 4.3 Tests on coarse aggregate

1.	Specific gravity	2.74
2.	Fineness modulus	7.12
3.	Percentage of voids	39.02%
4.	Crushing value	27.07%

WATER

In the present investigation, potable water was used.

COPPER SLAG

Copper slag is a by-product material produced from the process of manufacturing copper. As the copper settles down in the smelter, it has a higher density, impurities stay in the top layer and then are transported to a water basin with a low temperature for solidification. The end product is a solid, hard material that goes to the crusher for further processing. Copper slag used in this work was bought from KB Exports International, Vijaywada, Andhra Pradesh,

International Journal of Research
Available at https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 07 Issue 02
February 2020

India.
Physical Properties of Copper Slag

Copper slag is black glassy and granular in nature and has a similar particle size range like sand. The specific gravity of Indian slag lies between 3.4 and 4.1. The bulk density of copper slag varies between 1.9 to 2.15 kg/m3 which is almost similar to the bulk density of conventional fine aggregate. Table 4.5 shows physical properties of copper slag. The free moisture content present in slag was found to be less than 0.5%. Gradation test was conducted on copper slag and sand showed that both copper slag and sand had comparable particle size distribution as shown in Table 4.4 However, it seems that sand has higher fines content than copper slag.

Tests to determine specific gravity and water absorption for copper slag and sand were carried out in accordance with ASTM C128. The results presented in Table 4.2 shows that copper slag has a specific gravity of 3.91 which is higher than that of sand (2.57) and OPC (3.12) which may result in production of HPC with higher density when used as sand substitution. Table 4.4 shows sieve analysis report for various proportions of sand by copper slag. Table 4.5 shows that the measured water absorption for copper slag was 0.16% compared with 1.25% for sand. This suggests that copper slag would demand less water than that required by sand in the concrete mix. Therefore, it is expected that the free water content in concrete matrix will increase as the copper slag content increases which consequently will lead to increase in the workability of the concrete.
The presence of silica in slag is about 26% which is desirable since it is one of the constituents of the natural fine aggregate used to normal concreting operations. The fineness of copper slag after grinding was calculated as 125 m2 /kg. The Table 4.5 shows physical properties of copper slag.

Table 4.4 Sieve analysis report of copper slag

S.No	Sieve Size (mm)	% of weight passing for different proportions of replacements of sand by copper slag					Grading for zone – II as per IS:383 (1970)
		0%	20%	30%	40%	100%	
1	4.75	100	100	100	100	100	90-100
2	2.36	99.8	95.00	94.60	95.20	95.00	75-100
3	1.18	80.4	76.6	71.80	70.20	68.40	55-90
4	0.60	37.6	47.80	40.00	36.00	32.00	35-39
5	0.30	9.20	10.40	5.80	5.80	5.60	8-30
6	0.15	0	3.60	1.20	0.80	2.40	0-20
7	≤0.075	0.00	0.00	0.00	0.00	0.00	≤15

Table 4.5 Physical properties of copper slag

Physical Properties	Copper slag
Particle shape	Irregular
Appearance	Black and glassy
Type	Air cooled
Specific gravity	3.91
Percentage of voids %	35
Bulk density g/cc	2.08
Fineness modulus	3.47
Angle of internal friction	51° 20'
Ultimate shear stress kg/cm^2	0.4106
Water absorption %	0.16
Moisture content %	0.1
Fineness m^2 /kg (after grinding)	125

Chemical Analysis of Copper Slag

Copper slag has high concentrations of SiO_2 and Fe_2O_3 compared with OPC. In comparison with the chemical composition of natural pozzolans of ASTM C 618-99, the summation of the three oxides (silica, alumina and iron oxide) in copper slag is nearly 95%, which exceeds the 70% Percentile requirement for Class N raw and calcined natural pozzolans. Therefore, copper slag is expected to have good potential to produce high quality pozzolans. Table 4.6 shows the chemical composition of copper slag which was obtained from National council for cement and building materials, Ballabgarh, India, 2010.

Table 4.6 Chemical properties of copper slag

S.No	Chemical Component	% of chemical component
1.	SiO_2	25.84
2.	Fe_2O_3	68.29
3.	Al_2O_3	0.22
4.	CaO	0.15
5.	Na_2O	0.58
7.	K_2O	0.23
9.	Mn_2O_3	0.22
10.	TiO_2	0.41
11.	SO_3	0.11
12.	CuO	1.20
13.	Sulphide sulphur	0.25
14.	Insoluble residue	14.88

Table 4.8 Mix proportion by weight

WATER L/m3	CEMENT Kg/m3	SAND Kg/m3	COARSE AGGREGATE Kg/m3
155	340	567	1280
0.45	1	1.66	3.76

The following mix identifications are used for various proportions of copper slag with sand and cement.

CC	-	Control Concrete (0%)
S10	-	10% of sand replaced by copper slag
S20	-	20% of sand replaced by copper slag
S30	-	30% of sand replaced by copper slag
S40	-	40% of sand replaced by copper slag
S50	-	50% of sand replaced by copper slag
S60	-	60% of sand replaced by copper slag
C05	-	5% of cement replaced by copper slag
C10	-	10% of cement replaced by copper slag
C15	-	15% of cement replaced by copper slag
C20	-	20% of cement replaced by copper slag

NUMBER OF SPECIMENS

The number of specimens cast for this research was given in Table 4.9.

i) For Sand Replacement

Concrete cube compressive strength - 42 Nos.

Compressive strength on cylinders - 12 Nos.

Split tensile strength on cylinders - 21 Nos.

ii) For Cement Replacement

Concrete cube compressive strength - 12 Nos.

Split tensile strength on cylinders - 12 Nos.

EXPERIMENTAL SETUP AND PROCEDURES

GENERAL

The experimental setup and procedures for conducting various tests on concrete and RCC elements are discussed here.

EXPERIMENTAL SETUP FOR CONCRETE SPECIMENS

Concrete Cubes

To determine the compressive strength of concrete, 150 mm × 150 mm × 150 mm size concrete cubes were cast and tested in accordance with IS: 516-1959. All strength tests were conducted using 2000kN compression testing machine. Cube moulds of size 150x150x150 mm were used. They were cleaned thoroughly using a waste cloth and then properly oiled along its faces. Concrete was then filled in mould and then compacted using a standard tamping rod of 60 cm length having a cross sectional area of $25mm^2$. Concrete mixtures with different proportions of copper slag ranging from 0% to 60% replacement for sand and 0% to 20% for cement were prepared and tested.

Concrete Cylinders

The size of cylinder used for split tensile strength and durability studies was 150mm diameter and 300mm height. This test was conducted in accordance with IS: 5816-1999. The crude oil was applied along the inner surfaces of the mould for the easy removal of specimens from the mould. Concrete was poured throughout its length and compacted well.

EXPERIMENTAL PROCEDURES

Compressive Strength Test

Concrete cubes of size 150mm×150mm×150mm were cast with and without copper slag. During casting, the cubes were mechanically vibrated using a table vibrator. After 24 hours, the specimens were demoulded and subjected to curing for 28 days in portable water. After curing, the specimens were tested for compressive strength using compression testing machine of 2000KN capacity. The maximum load at failure was taken. The average compressive strength of concrete and mortar specimens was calculated by using the following equation 5.1.

$$\text{Compressive strength (N/mm}^2\text{)} = \frac{\text{Ultimate compressive load (N)}}{\text{Area of cross section of specimen (mm}^2\text{)}} \qquad (5.1)$$

The tests were carried out on a set of triplicate specimens and the average compressive strength values were taken.

Split Tensile Strength Test

Concrete cylinders of size 150 mm diameter and 300mm length were cast with incorporating copper slag as partial replacement of sand and cement. During casting, the cylinders were mechanically vibrated using a table vibrator. After 24 hours, the specimens were demoulded and subjected to curing for 28 days in portable water. After curing, the cylindrical specimens were tested for split tensile strength using compression testing machine of 2000kN capacity. The ultimate load was taken and the average split tensile strength was calculated using the equation 5.2.

$$\text{Split tensile strength (N/mm}^2\text{)} = \frac{2P}{\Pi LD} \qquad (5.2)$$

Where,
P=Ultimate load at failure(N)
L=Length of cylindrical specimen (mm)
D=Diameter of cylindrical specimen (mm)

RESULTS AND DISCUSSIONS

GENERAL

Several researchers have investigated the possible use of copper slag as fine and coarse aggregates in concrete and its effects on the different mechanical and long-term properties of mortar and concrete (Tan et al 2000, Taeb et al 2002, Tang et al 2000, Zong et al 2003). While most of the reports point to benefits of using copper slag as fine aggregates, in some stray cases some negative effects such as delaying of the setting time have also been reported (Ueno et al 2005, Premchand et al 2000). Although there are many studies that have been reported by investigators from other countries on the use of copper slag in cement concrete, not much research has been carried out in India concerning the incorporation of copper slag in concrete. Even though there are various research studies have been reported by investigators about copper slag, its physical properties and chemical composition varies country wide and hence its mechanical performance also varies according to that. Therefore, this research was performed to generate specific experimental data on potential use of copper slag replacement in concrete.

M20 concrete was used to perform this investigation. This chapter has been divided into two main parts.Mechanical performance of concrete and RCC members incorporating copper slag as partial replacement of sand (0 to 60% replacement). Mechanical performance of concrete and RCC members incorporating ground copper slag as partial replacement of cement (0 to 20% replacement).

COPPER SLAG REPLACEMENT FOR SAND

The following tests were conducted to examine the mechanical behaviors of concrete incorporating copper slag as partial replacement of sand.

1. Compressive strength test concrete cube specimens
2. Split tensile test on concrete cylinders of size 150mm diameter and 300mm height.

Compressive Strength Test

Compressive strength test on concrete cubes

The effect of copper slag substitution as a fine aggregate on the strength of concrete is given in Table 6.2, which presents the average 7 and 28 day cube compressive strength of concrete. A total number of 42 mortar specimens were cast and tested shown in Figure 6.1. The unconfined compressive strength values of concrete mixtures with different proportions of copper slag tested at 7 and 28 days are also plotted in Figure 6.2.

Compressive Strength Test

Compressive strength test on mortar cubes

The measured compressive strength values are presented in Table 6.1.

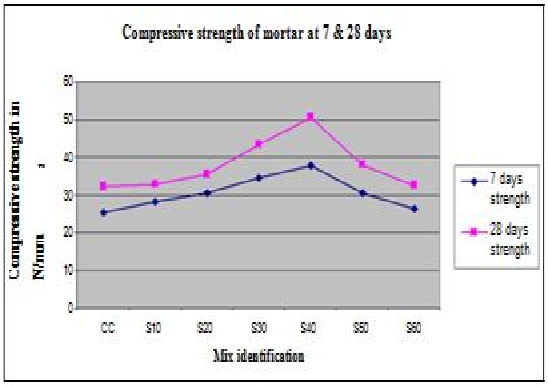


Figure 6.1A Compressive strength of mortar cubes

Table 6.1 compressive strength of mortar cubes

S.No.	Mix Identity	Ultimate load kN		Average ultimate load kN		Comp. strength N/mm²		% increase in strength at 28 days
		7 Days	28 Days	7 Days	28 Days	7 Days	28 Days	
1.	CC	126	152	126.00	160.33	25.21	32.08	–
		120	150					
		132	179					
2.	S10	130	152	140.67	164.67	28.14	32.94	2.68
		135	162					
		157	180					
3.	S20	140	160	152.33	176.67	30.47	35.34	10.16
		152	180					
		165	190					
4.	S30	167	200	172.33	216.67	34.48	43.35	38.26
		165	210					
		185	240					
5.	S40	175	235	188.33	251.67	37.68	50.35	56.95
		202	290					
		188	230					
6.	S50	158	201	152.33	190.00	30.47	38.01	18.48
		137	167					
		162	202					
7.	S60	132	175	130.67	162.33	26.14	32.48	1.25
		130	160					
		130	152					

Results and discussions

A total number of 42 mortar specimens were cast and tested for 7 days and 28 days strength shown in Table 6.1. The results indicated that all mixtures yielded comparable or higher compressive strength than the control mixture for all curing ages. Furthermore, as copper slag content increases the compressive strength of cement mortars increases upto 40%

substitution of copper slag. Beyond that, the compressive strength decreased with an increase in copper slag content. S40 mixture yielded the highest average 28 day compressive strength of 50.35 N/mm2, almost 57% higher than the compressive strength of the control mix (Figure 6.1A). Although all mixtures yielded a higher compressive strength than the control mixture, it can be said that the replacement of 40% copper slag as sand replacement will give the highest compressive strength with more than 50% improvement in mortar s strength. An increase of 34% of compressive strength was obtained at 28 days for S40 specimens, compared to 7 days strength. But for control specimens, the increase in strength was only 27% compared to 7 days strength. Therefore, it can be understood that, for longer curing periods most of the samples showed no detrimental effect (i.e. a strength reversal) when using copper slag.

Compressive strength test on concrete cubes

The effect of copper slag substitution as a fine aggregate on the strength of concrete is given in Table 6.2, which presents the average 7 and 28 day cube compressive strength of concrete. A total number of 42 mortar specimens were cast and tested shown in Figure 6.1. The unconfined compressive strength values of concrete mixtures with different proportions of copper slag tested at 7 and 28 days are also plotted in Figure 6.2.

Figure 6.1 Compression test on CC and S40 specimens

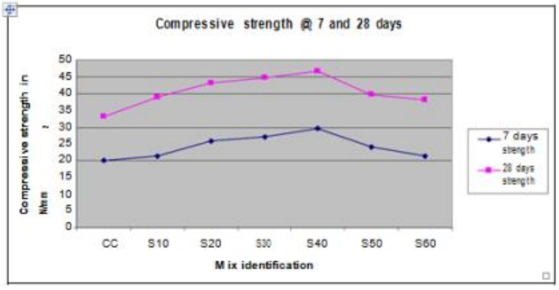


Figure 6.2 Compressive strength of concrete cubes

Table 6.2 Compressive strength test on concrete specimens

S.No	Mix Identity	Ultimate load kN		Average ultimate load kN		Comp.strength N/mm²		% increase in strength at 28 days
		7 Days	28 Days	7 Days	28 Days	7 Days	28 Days	
1.	CC	460	770	453.33	745	20.15	33.11	–
		480	720					
		500	750					
2.	S10	580	850	480	876.66	21.33	38.96	17.67
		600	880					
		560	900					
3.	S20	620	960	580	970.00	5.78	43.11	30.20
		630	970					
		650	980					
4.	S30	680	980	633.33	1006.67	27.15	44.77	35.00
		650	1000					
		675	1040					
5.	S40	560	1160	668.33	1055.00	29.70	46.8	41.34
		540	950					
		520	1055					
6.	S50	480	940	540.00	893.33	24.00	39.70	19.99
		465	860					
		490	880					
7.	S60	460	880	478.33	860	21.26	38.22	15.43
		480	840					
		500	860					

Results discussions

The test results indicate that for mixtures prepared using upto 40% copper slag replacement, the compressive strength of concrete increased. However, for mixtures with S40 and S50 copper slag, the compressive strength decreased rapidly. Mixture S40 yielded the highest 28 day compressive strength of 46.8N/mm^2

compared with 33.11 N/mm^2 for the control mixture, whereas the lowest compressive strength of 38.22 N/mm^2 was obtained for mixture S60 with 60% copper slag. Here, the compressive strength yielded by mixture S60 is almost equal to that of S10 mix. Still, the values are greater than control mix. This reduction in compressive strength for concrete mixtures with high copper slag contents is due to increase in the free water content that results from the low water absorption characteristics of copper slag in comparison with sand. This causes a considerable increase in the workability of concrete and thus reduces concrete strength.

Wu et al 2010 observed that, after examining the microstructure of concrete specimens with different copper slag contents, the strength improvement with 40% substitution was mainly attributed to the physical properties of copper slag. Copper slag has a better compressibility than sand, which can partially relieve the stress concentration, if the sand is still as the dominant fine aggregate holding the concrete matrix together. The angular sharp edges of copper slag particles can improve the cohesion of the concrete matrix. On the other hand, the glassy surface texture of copper slag particles has a negative effect on the cohesion. The low absorption properties of copper slag can leave excess water in concrete which can cause excessive bleeding at higher copper slag content.

This results in the formation of internal voids and capillary channels in the concrete, causing a reduction in its quality. Therefore, the strength of concrete with lower copper slag contents can be improved by the positive effect of copper slag, whereas if copper slag content exceeds 40%, the strength of concrete decreases substantially with reduction in cohesion governed by copper slag.

Split Tensile Strength Test on Concrete Cylinders

Split tensile strength is defined as a method of determining the tensile strength of concrete using a cylinder which splits across the vertical diameter. The effect of copper slag substitution as a fine aggregate on split tensile strength of concrete is given in Table 6.3.

Table 6.3 Split tensile strength test on cylinders

S.No	Mix identity	Ultimate load (kN)	Average ultimate loads (kN)	Split tensile strength at 28 days (N/mm^2)	Percentage increase in strength
1.	CC	250	236.66	3.35	---
		240			
		220			
2.	S10	290	280	3.96	18.20
		270			
		280			
3.	S20	240	283.33	4.01	19.71
		330			
		280			
4.	S30	300	286.67	4.05	22.72
		280			
		280			
5.	S40	270	296.6	4.19	25.07
		280			
		340			
6.	S50	290	280	3.96	18.20
		270			
		280			
7.	S60	280	283.33	4.00	16.72
		280			
		290			

Results & Discussion

The results showed that the average split tensile strength of copper slag admixed concrete specimens (Figure 6.6) increased upto 40% replacement. The reason for improvement of strength was, copper slag has a better compressibility than sand, which can partially relieve the stress concentration, if the sand is still as the dominant fine aggregate holding the concrete matrix together. It is known that the sand has good abrasion properties because of its rough surface, which can improve the cohesion between cement paste and coarse aggregate. However, the abrasion properties of sand is weakened with time after years of weathering causing sand particles to have rounded edges, which are detrimental to the interlocking properties of composite materials. The angular sharp edges of copper slag particles have the ability to compensate to some extent the adverse effects of sand and, thus, further

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 07 Issue 02
February 2020

improve the cohesion of concrete. This leads to improve the mechanical performance of copper slag admixed concrete.

It can be seen from Table 6.3 that the 28 day split tensile strength of S10, S20, S30, S40, S50, and S60 specimens is 18.20%, 19.71%, 22.72%, 25.07%, 18.2% and 16.72% higher than that of control specimens. The maximum increase in strength was obtained at 40% replacement of copper slag with sand. This showed that the copper slag admixed concrete are not only increased the compressive strength of concrete but also increased the split tensile strength values.

COPPER SLAG REPLACEMENT FOR CEMENT

General

The use of copper slag as a pozzolanic material for a partial substitute for ordinary Portland cement, its effects on the hydration reactions and properties of mortar and concrete have been reported in several publications (Al-Jabri et al 2006, Taha et al 2007, Malhotra 1993, Tixier et al 1997, Arino and Mobasher, 1999, Douglas and Mainwaring 1986, Deja and Malolepszy 1989). Moura et al 1999 investigated the compressive and flexural strength of concrete containing copper slag as 10% of the cement by mass. Mobasher et al 1996 reported that the addition of lime at the higher percentages of copper slag (15% copper slag and 1.5% lime as activator), the compressive strength increased from 30 N/mm^2 at the 28th day to 61 N/mm^2 at the 90th day, reflecting a 100% increase. Washington Almeida Moura et al 2008 reported that the ground form of copper slag can be utilised for the replacement for cement in concrete.

Therefore, finely ground copper slag was used as replacement for cement in this investigation. Here copper slag has been replaced at a maximum percentage of twenty to the weight of cement. As per the investigations of Mobasher et al, to activate pozzolanic reactions in copper slag mixed concrete, S type hydrated lime was used. The following tests were conducted to examine the mechanical behaviours of concrete for various proportions of copper slag replaced with cement.

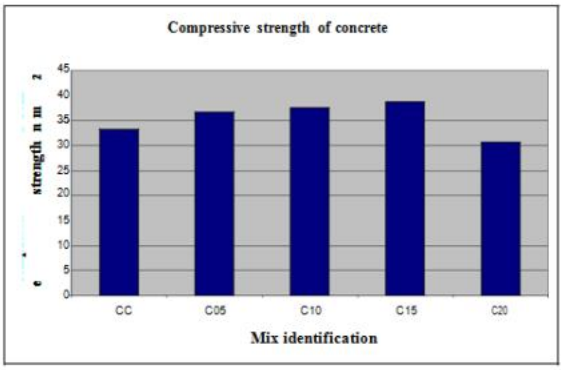
1. Compressive strength test concrete cube specimens
2. Split tensile test on concrete cylinders of size 150mm diameter and 300mm height.

Compressive Strength Test on Concrete Cubes for Cement Replacement

A total number of 15 concrete cube specimens were cast and tested for 28 days strength. The effect of copper slag substitution as a fine aggregate on the strength of concrete is given in Table 6.8. The unconfined compressive strength values of concrete mixtures with different proportions of copper slag cured at 28 days is plotted in Figure 6.27.

Table 6.8 Compressive strength of concrete cubes for cement Replacement

S.No	Mix identity	Ultimate loads (kN)	Average ultimate load (kN)	Compressive strength at 28 days (N/mm^2)	% increase in strength
1.	CC	770 720 750	746.67	33.11	--
2.	C05	800 830 840	823.33	36.66	10.72
3.	C10	820 840 870	843.33	37.48	13.20
4.	C15	880 860 870	870.00	38.50	16.28
5.	C20	750 670 770	690.00	33.01	-0.3



Results and discussions
The highest compressive strength was achieved with 15% replacement of copper slag with cement, which was found about 38.5 N/mm2 compared with 33.11 N/mm2 for the control mixture. This means that there is an increase in strength of about 16.28 % compared to the control mix. However, mixtures with 20% gave slightly low compressive strength around 33.01 N/mm2 which is almost 0.3% lower than the strength of the control mix. An addition of hydrated lime in concrete to the weight of cement activates the pozzolanic action of copper slag. Therefore, the compressive strength of copper slag admixed specimens are increased at a maximum rate of 17%, with that of control specimens. An addition of hydrated lime improves the strength gain in all mixes.

This difference in the strength improvement between cement mortars and aggregates may be attributed to the bonding between the particles within the cement paste. The increased porosity in concrete weakens the bond between the concrete components, which is one of the determining factors for the strength of concrete. Therefore in this investigation, Water- cement ratio maintained for M20 concrete was maintained as 0.45.

Split tensile strength test on cylinders for cement replacement
Split tensile strength is defined as a method of determining the tensile strength of concrete using a cylinder which splits across the vertical diameter. Table 6.9 shows the results of split tensile strength of cylindrical specimens.

Table 6.9 Split tensile strength results of cylinders for cement replacement

S.No	Mix identity	Ultimate loads kN	average ultimate load kN	Split tensile strength at 28 days (N/mm^2)	% increase in strength
1.	CC	250	236.66	3.35	--
		240			
		220			
2.	C05	250	250	3.53	5.37
		240			
		260			
3.	C10	250	260	3.67	9.56
		270			
		260			
4.	C15	260	273.33	3.86	15.23
		280			
		280			
5.	C20	220	210	2.97	-11.34
		200			
		210			

Results and Discussions
Due to additions of copper slag in concrete, the density of concrete was increased from 5 to 7% for the water-cement ratio of 0.45. This is probably due to the higher specific gravity of copper slag. It can be seen from Table 6.9 that the 28 day split tensile strength of C05, C10 and C15 specimens are 5.37%, 9.56% and 15.23% higher than that of control specimens. After that, the reduction of strength occurred. The reduction in split tensile was due to the low absorption properties of copper slag. It can leave excess water in concrete, which can cause excessive bleeding at higher copper slag content and therefore the strength reduced.

Therefore, it can be concluded that, the copper slag addition has increased split tensile strength up to 15% replacement with cement, but decreased with 20% replacement. There is an increase of strength of almost 15.3% for C15 specimens compared to the control CC mix, while 20% replacement gave the lowest splitting tensile strength.

CONCLUSION AND SCOPE FOR

FUTURE WORKS

GENERAL

The present study investigated the effectiveness of using copper slag for the partial replacement of sand and cement. The elements considered for study were

Concrete cubes of size 150 mm × 150 mm × 150 mm

Concrete cylinder of 150mm diameter and 300mm height

CONCLUSION

Based on the investigations, the following conclusions were drawn.

The utilisation of copper slag in concrete provides additional environmental as well as technical benefits for all related industries. Partial replacement of copper slag in fine aggregate and cement reduces the cost of making concrete.

Replacement of copper slag (100% replacement with sand) increases the self weight of concrete specimens to the maximum of 15-18%.

The initial and final setting time of copper slag admixed concrete is higher than control concrete.

The results of compressive, split tensile strength test have indicated that the strength of concrete increases with respect to the percentage of copper slag added by the weight of fine aggregate up to 40% (S40). Further additions of copper slag caused reduction in strength due to an increase of free water content in the mix.

Utilisation of copper slag as Portland cement replacement in concrete and as a cement raw material has the dual benefit of eliminating the costs of disposal and lowering the cost of the concrete.

The maximum compressive, split tensile strength was achieved at 15% (C15) replacement to the weight of cement. There is an increase of compressive strength was achieved around 15.13% compared to control mixes. But, this is 26% lower than S40 specimens. Similarly, for split tensile strength test, the strength was increased to 15.23% for C15 specimens compared to control mixes, whereas this is 10% lower than S40 specimens.

It was observed that, the copper slag replacement for sand is more effective than cement.

For higher replacement of copper slag in cement (greater than 20%) and sand, (greater than 50%) the compressive and split tensile strength decreases due to an increase of free water content in the mix.

SCOPE FOR FUTURE WORKS

This research was intended to examine the influence of copper slag additions in concrete and RCC elements for M20 mixes. The same word can be extended to higher grades of concrete mixes with varing water/cement ratio

Copper slag can be effectively replaced in making bricks, hollow blocks and pavement blocks

Since copper slag has higher shear strength value it can be used for soil stabilization.

Copper slag can be replaced along with fly ash, silica fume and granulated blast furnace slag in concrete and RCC members which can be tested for mechanical performances

REFERENCES

1. Akihiko, Y. and Takashi, Y. Study of utilisation of copper slag as fine aggregate for concrete , Ashikaya Kogyo Daigaku Kenkyu Shuroku, Vol. 23, pp. 79-85, 1996.
2. Al-Jabri, K. and Makoto Hisada. Copper slag as sand replacement for high performance concrete , Cement & Concrete Composites, Vol. 31, pp. 483-488, 2009.
3. Al-Jabri, K., Taha, R. and Al-Ghassani, M. Use of copper slag and cement by-

pass dust as cementitious materials Cement, Concrete Aggregates, Vol. 24, No.1, pp. 7-12, 2005.
4. Al-Jabri, K.S., Abdullah, H., Al-Saidy and Ramzi Taha. Effect of copper slag as a fine aggregate on the properties of cement mortars nd concrete , Construction and Building Materials, Vol. 25, pp. 933-938, 2011.
5. Al-Jabri, K.S., Taha, R.A., Al-Hashmi, A. and Al-Harthy, A.S. Effect of copper slag and cement by-pass dust addition on mechanical properties of concrete , Construction and building materials, Vol. 20, pp. 322-331, 2006.
6. Alpa, I. and Deveci, H. Utilization of flotation wastes of copper slag as raw material in cement production , Journal of hazard materials, Vol. 159, No. 2, pp. 390-395, 2008.
7. Al-Jabri, K.S., Makoto Hisada, Abdulla, H.A. and Al-oraini, S.K. Performance of high strength concrete made with copper slag as a fine aggregate , Construction and building materials, Vol.23,pp. 2132-2140, 2009.
8. Arino, A.M. and Mobasher, B. Effect of copper slag on the strength, and toughness of cementitious mixtures , ACI Materials Journal, Vol. 96, No. 1, pp. 68-75, 1999.
9. ASTM C-1202-09--Standard test method for electrical indication of concrete s ability to resist chloride ion penetration: Annual Book of
10. ASTM C642-97, Standard test method for density, absorption, and voids in hardened concrete. West Conshohocken (PA): ASTM Internationa, 1997.
11. ASTM C-876-09, Standard test method for corrosion potentials of uncoated reinforcing steel in concrete. Annual Book of ASTM standards (Philadelphia).
12. ASTM D5233-1995d, Standard Test Method for Single Batch Extraction Method for Wastes: ASTM International, 1992.
13. Awad Al-Karni, and Abdulhafiz Alshenawy, Modeling of Stress-Strain Curves of Drained Triaxial Test on Sand , American Journal of Applied Sciences, Vol. 3, No. 11, pp. 2108-2113, 2006.
14. Ayano Toshiki, Kuramoto Osamu, and Sakata Kenji, Concrete with copper slag fine aggregate , Society of Materials Science, Vol. 49, pp. 1097-1102, 2000.
15. Ayano, T. and Sakata, K. Durability of concrete with copper slag fine aggregate , Proceedings of the fifth ACI international conference on durability of concrete, Vol.192, pp.141-158, 2000.
16. Ayano, T., Kuramoto, O. and Sakata, K. Concrete with copper slag as fine aggregate , Jounal of Society Material Science Japan, Vol. 49, No. 10, pp. 1097-1102, 2000.
17.Behnood, A. Effects of high temperatures on high-strength concrete incorporating copper slag aggregates , Proceedings of seventh international symposium on high-performance concrete, pp. 1063-1075, 2005.
18. Bipra Gorai, Jana, R. K. and Premchand, Characteristics and utilisation of copper slag-a review , Resources, Conservation and Recycling, Vol. 39, No. 4, pp. 299-313, 2002.