Research on the Effect of Copper Slag as a Fine Aggregate on the Properties of Concrete

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Abstract— Copper slag is a rough blasting grit or a by-product acquired by the process of copper smelting and refining. These copper slags are recycled for copper recovery. In this paper, we analysed copper slag's feasibility and evaluate its total competence in M25 grade concrete. In this observation, a concrete mixture is applied with copper slag as a fine aggregate ranging from 0%, 20%, 40%, 60%, 80%, and 100% respectively. The strength of copper slag's implementation is accomplished on the basis of concrete's flexural strength, compressive strength and splitting tensile strength. From the obtained results, in concrete 40% percentage of copper slag is used as sand replacement. On 28 days, the modulus of elasticity increased up to 32%, the compressive strength increased up to 34% and flexural strength is increased to 6.2%. From this experiment, it is proved technically that replacing sand using copper slag as a fine mixture in M25 grade concrete.

Keywords—Cooper Slag, Aggregate, Concrete

1. INTRODUCTION

In recent years, the construction field has witnessed enormous growth. Construction is nothing but of infrastructure development by means of natural resources. Because of several reasons nowadays natural resources are becoming drained in the volume. Another concern is industrial wastes because of constructions were also gradually increased. The increasing quantity of waste materials enables the importance of solid waste management deeply. These industrial wastes are widely generated by several industries such as steel mills which produces blast furnace slag. Thermal power plants which deliver coal ash and integrated Iron. Cement industries produce silica fume and cement kiln dust. Next, the wastes like wood ash, tailings, and red mud were produced by industries like zinc, copper, iron, and aluminum. In order to fulfill the need for natural resources construction industries involved in using innovative materials, non-conventional materials and waste materials recycling. On the other aspect, it also preserves the environment. During the process of copper refining and matte smelting, a supplement product is obtained known as copper slag [1]. About 2.2–3 tons of copper slag is generated on the production of every ton of copper. These slags are currently used for metal recovering, recycling, disposing in slag dumps or stockpiles and on the manufacturing of value-added products. Storing of slags in the controlled landfills will lead to serious environmental problems including high cost. Another major problem is the shortage of wide lands especially in copper plants and industrial areas.

Till copper slag usage is widely increased by the major industries like cement, concrete, glass, tiles, abrasive, abrasive tools, railroad ballast, cutting tools, roofing granules, road-base construction, and asphalt pavements. By replacing Portland cement or as a substitute for aggregates with copper slag gives better results. This is because of chemical and mechanical properties of copper slag which enrich the material quality to be a well-suited by-product for concretes.

In recent years, various researchers indulged in analyzing of copper slag using as a fine and coarse aggregate for concretes. It also affects the mechanical and long-term characteristics of concrete and mortar.

Shoyaetal [2] stated on his work that the rate of bleeding is maximized on using copper slag. The major factors involved in the fine aggregate are volume fraction of slag, air content and volume of water to cement ratio. On this work, the author suggests using copper slag on less than 40% will minimize the bleeding to less than 5 l/m2. The specimen's shrinkage on copper slag mixtures is similar or below to the specimens without copper slag [2,3]. The main motto of this work is measuring the feasibility of using a copper mixture in M25 grade concrete. Additionally, we also analyze the effects of mechanical properties on using these Copper slags. The using of copper slag as a fine aggregate in concrete results in environmental benefits and prominent remunerations for all other related industries.

2. EXPERIMENTAL STUDY

2.1 Material and mixture proportion

In manufacturing concrete specimens the type 1 cement is used because it fulfills the standard of 12269:1987 (53 grades). In this experimental study coarse mixture with a nominal maximum size of 12.5 mm is used. Coarse aggregates satisfy the essential quality required for 12.5–4.75 mm size aggregates as per the IS: 2386:1963 [part 1]. The adequate mixture is the combination of river sand with 0.8% of water absorption along with 2.70 % of specific gravity. According to ISS (Indian Standard Specifications) IS 2386:1963 [part 1] one control mixture (CS-0) is designed in order to obtaining the 28-day compressive strength of 31.70MPa. The other concrete aggregates like CS-20, CS-40, CS-60, CS-80, and CS-100 are replaced by using fine copper slag of levels 20%, 40%, 60%, 80% and 100%. Table 1 shows the different materials mixture, designation, and quantities with their designed concrete mixture.

Revised Manuscript Received on July 22, 2019.

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Table 1 Mixture proportion of concrete

Mix Type	Copper Slag (%)	Cement (kg/m3)	Coarse aggregate (kg/m3)	Fine aggregate (kg/m3)	Copper Slag (kg/m3)
CS-0	0	438.13	1115.42	651.1	0
CS-20	20	438.13	1115.42	520.88	130.22
CS-40	40	438.13	1115.42	390.66	260.44
CS-60	60	438.13	1115.42	260.44	390.66
CS-80	80	438.13	1115.42	130.22	520.88
CS-100	100	438.13	1115.42	0	651.1

2.2 Preparation and casting of specimens

Materials required for preparing concrete specimens are cylindrical molds of size 100X300mm, prism size of 100X100X500 mm and Cubical molds of size 150X150 mm. These components determine the concrete elasticity as well as the compressive strength. All prepared concrete should meet the Indian Standard Specifications IS 516-1959 [4] requirements. Before casting, molds are perfectly oiled, cleaned and securely tightened as per the dimensions. Need concentration that no gap which reflects in avoiding the leakage from the slurry. The Concrete mixture begins with coarse mixing and fine aggregates for about 1 min. Next for another 1 min with dry mixing the cement is added and then slowly the water is mixed. To obtain a flexural strength, compressive strength test and modulus of elasticity this concrete are cast in 150×150×150mm, 150×300mm, and 100×100×500mm molds. In the molds, the specimens are cast in two layers, in which a vibrating table is used for consolidating each layer. These casting specimens should be done as per the IS: 516-1959 [4]. For the first 24 hours, these specimens were needed to be present in the steel mold at ambient conditions. Then it de-molded in a curing tank at ambient temperature with special care that the edges should not get broken. For curing the ambient temperature is 27°C and in this work each test results has three average replicate tests.

2.3 Specimens testing

Once the curing period is completed, the specimens were dried for a few hours and tested. The concrete control and copper slag's compressive strength is stated by testing three (03) cubes of different volumes 150×150 mm on compression testing machine with the capacity of 1000 kN. Table 2 gives the cubes average compressive strength. Then as per the IS: 516-1959 the modulus of elasticity test for three150×300 mm sized cylinders is done. It is tested on compression testing machine of capacity 3000 kN at loading pace of 0.3kN/sec respectively. Then testing on the prism of size 100 x 100 x 500 mm is cast and done according to IS: 516-1959.

3. TEST RESULTS AND DISCUSSION

In order to represent the specific gravity, water absorption of copper slag, sand, and chemical composition test was conducted. The obtained results state copper slag has 2.9 % of specific gravity which is higher than sand (2.6), the water absorption values is about 0.2% and sand with 1.4% respectively. From the observation, it is proved that copper slag substitution has more density values compare to concrete with sand only. On the other aspect, the low water absorption reveals that free water content present in the concrete mixtures maximize as copper slag content increases. This brings an increase of concrete mixtures workability with high copper slag percentages.

3.1 Compressive strength

Table 2 shows the copper slag substitution effect as a fine mixture on the aspect of concrete strength. Table 2 presented the cube compressive strength with average7, 14 and 28 days respectively. For all mixtures where ever there is an increase in the curing period, consequently, there is an increase in compressive strength along with the gain of strength that the early curing periods. Table 2 states the obtained comparable or higher compressive strength with the mixture (100% sand) for of all mixtures at all curing ages. When there is an increase in copper slag content the concrete cement compressive strength also increases up to 40%substitution of copper slag. Then the compressive strength decreases on the way with an increase in copper slag content. The mixture with the composition of 80% and 100%copper slag respectively (i.e. Mixtures CS-80 and CS-100), the compressive strength is minimized faster beyond the control mixture strengths. The composition of CS-40 with 40% copper slag content achieves a maximum 28-day compressive strength of 42.60 N/mm2. For the control mixture, it is compared with 31.70 N/mm2. By which the least compressive strength of25.20 N/mm2 is yield for Mixture CS-100 is with 100% of copper slag. The Mixture CS-100 obtained compressive strength is 20% lower to the control mix. In this concrete mixture with high copper slag contents, the compressive strength is reduced because of the maximization of free water content. On the other aspect in compare to sand, the compressive strength maximizes because of the low water absorption properties of copper slag. This maximizes the concrete work ability with a reduction on concrete strength as given in Table 2.

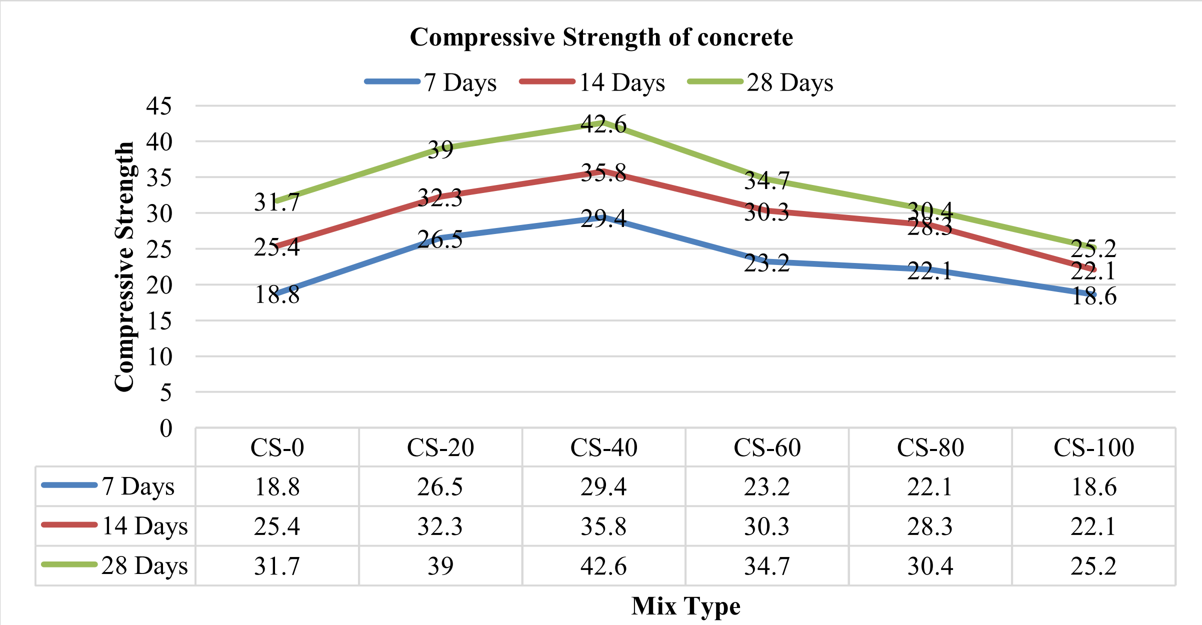
Table 2 Compressive Strength of concrete with different curing ages

S.NO	Mix Type	Compressive Strength (MPa)		
		7 Days	14 Days	28 Days
1	CS-0	18.80	25.40	31.70
2	CS-20	26.50	32.30	39.00
3	CS-40	29.40	35.80	42.60
4	CS-60	23.20	30.30	34.70
5	CS-80	22.10	28.30	30.40
6	CS-100	18.60	22.10	25.20

Wu et al. [5, 6] witnessed from his work by investigating the microstructure of the concrete specimen with various copper slag contents. As a result, the strength increased, it is because of 40% substitution credit to the copper slag physical properties. On comparing to sand the copper slag has good compressibility which minimizes the stress concentration. In copper slag particles, the angular sharp

edges increase the cohesion of the concrete matrix. Because of the rough
surface, the sand has good abrasion properties that maximize the cohesion between cement paste and coarse aggregate. Due to the effects of weathering sand's abrasion properties is weakened and making sand particles to have rounded edges. These rounded edges are harmful to the composite materials interlocking properties. In the copper slag particles, the presence of angular sharp edges has the capacity of compensating the adverse effects of sand and additionally develops the concrete cohesion. The negative aspect in the copper slag particles is the glassy surface texture which affects the cohesion. The copper slag's low absorption properties enable the excess water to stay in the concrete, that lead to unnecessary bleeding at higher copper slag content. In the concrete, the foundation of internal voids and capillary channels reduce its quality. Which states that lower copper slag contents the concrete strength is increased by the copper slags positive effects. If copper slag content goes beyond 40%, the concrete strength minimized considerably with cohesion deduction governed by copper slag.

Graph 1 Compressive Strength of concrete with different curing ages



3.2 Elastic modulus

Modulus of Elasticity of Concrete is stated as the slope of the line drawn from zero stress to a compressive stress of 0.45f'c.It shows that concrete resistance is continuously deformed whenever the stress applied. The concrete strength is reliant on the aggregate's modulus of elasticity and relative proportions. In the specimen, the modulus of Elasticity is evaluated by applying the empirical formula$E = 5000\sqrt{Fck}$ where Fck is 28 days cube compressive strength. It is as per the IS: 456-2000;

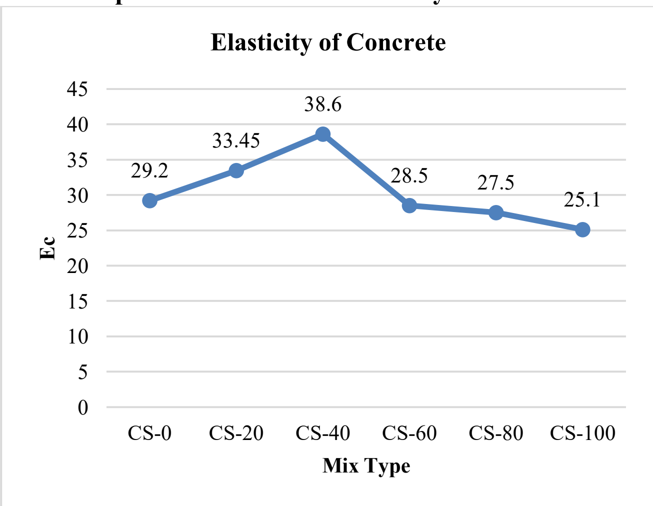
Table 3 Test result for Elasticity of concrete

S.NO	Mix Type	EC N/mm2
s1	CS-0	29.20
2	CS-20	33.45
3	CS-40	38.60
4	CS-60	28.50
5	CS-80	27.50
6	CS-100	25.10

The test results show that the modulus of elasticity goes on decreasing, on the implementation of copper slag as a replacement of natural sand it increases gradually. The modulus of Elasticity of control concrete was 31.70 N/mm2.

The modulus of elasticity for 20% and 40% replacement was increased by 14.55% and 32 % according to the control concrete. The modulus of elasticity for 60%, 80%, and 100% replacement was decreased from by 2%, 5% and 14% as compared to control concrete. The graph 2shows the variation in modulus of Elasticity for 28 days

Graph 2 Test result for Elasticity of concrete



3.3 Flexural strength

As per the IS 516:2002 under the third point loading conditions three prisms (beams) are tested for flexural strength. The obtained average modulus of rupture (flexural strength) is by the following expression:

$Fcr = PL/bd^2$

Where,

Fcr is the modulus of rupture;

b the average width of specimen; and

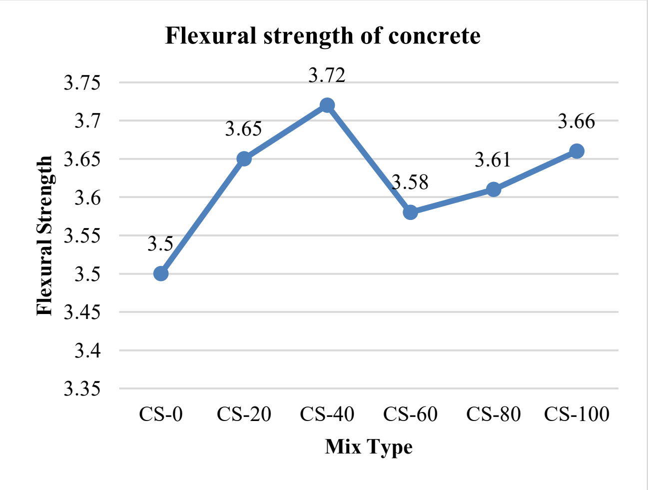
d the average depth of specimen.

Table 3 Test result for Flexural Strength

S.NO	Mix Type	Flexural Strength (N/mm^2)
1	CS-0	3.50
2	CS-20	3.65
3	CS-40	3.72
4	CS-60	3.58
5	CS-80	3.61
6	CS-100	3.66

According to IS: 456-2000 that is $Fcr = 0.75\sqrt{Fc}$ the experimental modulus of rupture is compared closely with the empirical expression. All mixtures modulus of rupture and its comparable behavior to the compressive strength results are stated in graph 3. From the obtained results the modified concrete mixes (CS-20, CS-40, CS-60, CS-80, and CS-100) reflects increased flexural strength values than the control concrete mix. On the reference to mixtures with experimentally detected on all ages, it is clear that the flexural strength is improved for the modified concrete mixes. On the comparison to reference sample CS-0, the achieved flexural strength of sample CS-2 0, CS-60, CS-80 and CS-100 is quite increased by 4.2%, 2.2%. 3% and 4.5% respectively. On which the mix CS-40 has observed the maximum increase in flexural strength of about 6.2% greater than the reference sample CS-0.

Graph 3 Test result for Flexural Strength



4. CONCLUSION

In this paper, the copper slag as a fine aggregate replacement for sand is discussed along with some concrete mechanical behaviors. From the obtained results it is proven that this kind of aggregate is a good substitute for natural sand. There are no previous statements exists in comparison to the significant changes in respect to the control mixes with natural concrete sand. The experiment is carried out on modulus of elasticity, compressive and flexural behavior of copper slag concrete. Based on which the conclusion is précised as follows;

1. In comparison to the control concrete. The copper slag concrete achieves more strength. The copper slag proportion of 10, 20, 30 and 40% is added with concrete. On which the strength is compared with normal mix concrete and results proved copper slag concrete replacing sand is stronger than normal mix.
2. The sand is replaced on copper slag in concrete by which there is an increase of compressive strength up to 34% than the conventional concrete.
3. On the comparison of modulus of elasticity, the copper slag concrete achieved 32% more than the plain concrete.
4. The flexural strength of concrete, on using copper slag concrete is significantly improved.

In the construction engineering field, concrete is a fundamental material and its mechanical properties can be improvised by implementing copper slag as fine aggregate. It begins a new era in the construction materials by maximizing the composite material usage with additional strong and durable structures. On other cases, the unconventional materials are suggested for concrete use. The usage of copper slag aggregate in concrete is according to the local economies. Certainly, nowadays due to the draining of natural aggregates, the implementation of suitable alternative aggregates obtained from the waste materials need to be cheered as a potential overall workable option.

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