

# Characteristic study on high performance hybrid fiber reinforced concrete using copper slag fine aggregate

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## Abstract

This study focuses on the effect on the mechanical characteristics of high performance concrete upon the utilization of copper slag in order to replace the fine aggregate. Copper slag has chemical and mechanical characteristics that can make the material a probable and efficient replacement material to river sand in concrete. On the other hand extraction of the sand from river bed in excess quantity is hazardous to the environment. River sand was partially and fully replaced (100%) by Copper slag in various proportions in the concrete. The concrete is also added with fibres in order to improve its mechanical properties. The addition of micro steel, hooked steel and polyester fibres in hybrid form with 1.0-1.25% to the total volume of concrete is found to be beneficial to the concrete. From the test results the concrete with 50% of its fine aggregate replaced with copper slag shows the better results; improved performance in compressive, split tensile, flexural strength, toughness and ductility. The addition of micro steel and hooked steel in the concrete produced a concrete of lower water absorption percentage.

**Keywords:** Copper Slag; Toughness; Ductility.

## 1. Introduction

A large quantity of waste is produced from the copper manufacturing Industries, these wastes are disposed off or sold cheaply by the industries. Copper Slag is the one of the byproducts that is obtained by smelting or refining of copper. Copper slag is one of the waste materials which come from copper Industries; this waste can be used in construction purpose as partial replacement for fine aggregate. Strength and workability of concrete will increase by partially replacing copper slag with river sand. Due to the presence of Iron oxide in copper, the density of the Copper slag is high. Due to the cost and transportation of river sand being high, the usage of copper slag as a partial replacement to river sand increases the economy of the project (Ambily.P.S et al, 2015). Usage of waste materials in concrete has been in practice for quote sometime now. Many wastes such as blast furnace slag, rice hush, sewage sludge and even iron slag, although the ferrous wastes have received much attention, the non ferrous ones have been almost totally neglected because of the less size of quantity of the material that is available (Ismail M. Madany et al.,1991). On the other hand quarry dust, Silica fume, GGBS, M-Sand can also be used in concrete as one of the mineral admixture or partial replacement to river sand to produce high performance concrete (Umamaheswaran.V et. al, 2015).

High performance concrete is a mix of concrete, which possesses high strength, high durability and lower permeability in comparison with conventional concrete. In High performance concrete, properties and the mix design of the concrete changes compared to conventional concrete. Hence, High performance concrete is a

special type of concrete which is primarily used in tunnels, bridges, and tall buildings for its strength, durability and high modulus of elasticity. A lot of materials are used in order to convert conventional concrete to high strength concrete. Many by-products have been proven to be successful in enhancing the properties of concrete. Among these materials are the different kinds of ashes, namely, fly ash, bottom ash and boiler ashes, all of which have been added to concrete to fruitful results. Their addition in concrete helps solve the problem of their disposal also, because they are harmful to the environment if not properly disposed (Carlo Collivignarelli and Sabrina Sorlini, 2002).

Waste material like copper slag makes it possible to produce High Performance Concrete (HPC) with mean compressive strength of greater than 150MPa at 28days. The incorporation of copper slag in concrete is capable of producing concrete of compressive strengths higher than 150 MPa. The total replacement of fine aggregates by copper slag results in the maximum decrease in 28-day compressive strength by about 15-25% (Ambily.P.S et. al,2015). The strength characteristics of concrete get enhanced by having copper slag as partial replacement to sand upto 40%. The durability of concrete is found to be less resistant to acid attack and more resistant to sulphate attack (BinayaPatnaik et. al, 2015). The flexural strength of the concrete follows a trend that is similar to the compressive strength, it increases until a certain percentage, after which it reduces again. The flexural strength is higher than the design mix till 50% replacement. The compressive and flexural strengths are increased because of the greater toughness of copper slag. A maximum increment in compressive strength of 55% was obtained with a 40% replacement of fine aggregate with copper slag (Chavan, R R and Kulkarni D B,

2013). To reduce the environmental pollution and for safe and efficient disposal of the waste material, replacement material like copper slag is added to the concrete material for the replacement of fine aggregates. In this, fibers are also added with the concrete material in order to enhance the flexure behavior of it (VimarshS.P, 2014). From the total weight of the concrete, steel fibre reinforcement varies from 0.5-1.75%. The micro steel fibres reduces the shrinkage cracks whereas macro fibres increases the post peak performance of the concrete (Kannan Rajkumar et al, 2018). The highest value of compressive strength is obtained when 1% of steel fibre is added to the concrete. The concrete which has the hooked end steelfibre added to it shows higher tensile, compressive and flexural strength compared to concrete added with crimped end fibre (Sakthieswaran.N and Ganesan.K , 2014). Partially replacing fine aggregate with copper slag not only increases the mechanical properties and durability of concrete, but also increases the density of concrete by almost 5 % with increment in the content of copper slag. The surface water decreases as copper slag quantity increases up to 40% replacement; a rapid increment of water absorption was observed beyond that replacement level (KhalifaS.Al-Jabri et. al, 2011). Hence the study focuses on partial and full replacement of fine aggregate with copper slag in high performance concrete containing hooked steel, micro-steel and polyester fibres in hybrid form to evaluate the mechanical properties such as compressive, split tensile, flexural strength, toughness and ductility. The durability of the concrete with respect to water absorption is also studied.

## 2. Material properties

### 2.1. Copper slag

The copper slag used was glassy, granular and black in nature. Particle size of the copper slag used is less than 4.75mm, because the size should be same as fine aggregate or river sand which typically ranges from 0 – 4.75mm. Specific gravity of Copper slag is 2.9. The Chemical composition of copper slag is given in Table 1 and the chemical characteristics of copper slag are given in Figure 1. The SEM results in Figure 2 shows that the copper slag is crystalline in nature.

### 2.2. Materials and methods

Ordinary Portland Cement which is of 53 grade has a specific gravity of 3.15 is used in this investigation. Silica Fume, otherwise known as micro silica, is a byproduct obtained due to the production of silicon metal or ferrosilicon alloys and it partially replaces cement because of its good binding properties and porosity. Silica Fume is also a very reactive pozzolon due to its chemical and mechanical properties. Addition of silica fume to concrete by partially replacing with cement is capable of producing concrete that is good in high strength and durability. Silica Fume used in this investigation was obtained from Elkem industries with a specific gravity of 2.2. Fine aggregates used were natural sand with most particles passing through a 4.76 mm sieve. The specific gravity of fine aggregate is 2.65 and also it lies under Zone II as per IS 383-1970. Granite rocks that were crushed in to small pieces of size 10-12.5mm were used as coarse aggregate in this investigation with a specific gravity of 2.8. Hooked Steel fibres of 35 mm length and 0.55mm diameter, micro steel fibres of size 13 mm length and 0.16mm diameter and polyester fibres of range 10-50 mm in length and 25-30  $\mu$ m diameter in hybrid form is used in the study. Super plasticizer is used in order to enhance the workability of high strength high performance concrete. In this study a polycarboxylic based ether with a solid content of 50% and a specific gravity of 1.077 was used (Francis Yakobu. K ET. Al, 2015).

### 2.3. Mix design

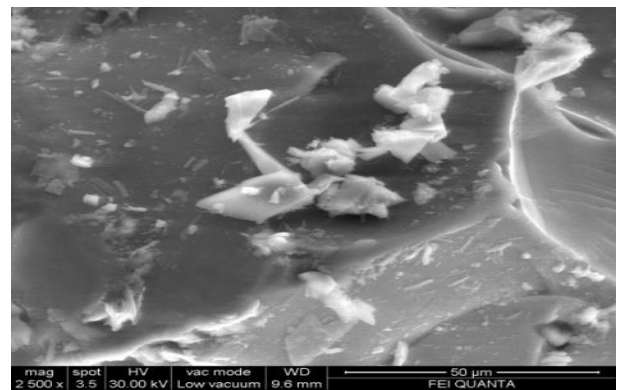
The mix design and material proportioning is in accordance with the ACI -211-one method. The content proportions used in the standard concrete mix are listed in Table 2. The replacement of river

**Table 1:** Chemical Composition of Copper Slag

Properties	UoM	Value
Appearance	-	Black Glassy Granules
Shape	-	Angular
Hardness	Moh	6.8
Chloride	PPM	< 500
Specific gravity	-	2.9
Bulk density	g/cc	2.2
Unit weight		2200
pH	-	6.8
Total moisture	%	< 5
Fe <sub>2</sub> O <sub>3</sub>	%	58
SiO <sub>2</sub>	%	30
Al <sub>2</sub> O <sub>3</sub>	%	< 6
CaO	%	2



**Fig. 1:** Chemical Properties of Copper Slag.



**Fig. 2:** SEM Image of Copper Slag.

Sand with copper slag as a fine aggregate was mixed in the following proportions; 0%, 25%, 50%, 75% and 100%. The variations in the mixes are carried out for the other mixes by changing the fine aggregate content and replacing it with an equal volume of copper slag. The fibres in hybrid form were mixed in concrete with two mix proportions viz., one with 0.75% of hooked steel and 0.25% of micro-steel and the other with 0.75% of Hooked Steel, 0.25% of Micro-steel and 0.25% of polyester. The proportions of fibre mixes are shown in Table 3.

**Table 2:** Mixture Proportioning of Various Mixes Containing Copper Slag and River Sand

Binder Content (kg/m <sup>3</sup> )	Cement, (kg/m <sup>3</sup> )	Silica fume (kg/m <sup>3</sup> )	FA (kg/m <sup>3</sup> )	CA (kg/m <sup>3</sup> )	Water (kg/m <sup>3</sup> )	SP (lit/m <sup>3</sup> )
600	510	90	683	1050	150	13.37

**Table 3:** Mixture of Hybrid Fibres in Concrete

Without fibre	Hooked steel	Micro steel	Polyester
CS	-	-	-
CS-H1	0.75	0.25	-
CS-H2	0.75	0.25	0.25

### 3. Test results and discussion

#### 3.1. Compressive strength

Compressive strength testing was experimented on 100 mm cubes. Testing procedure was followed according to IS 516-1959. Compressive test is performed by increasing the magnitude of load on the specimen gradually until it fails. The cubes were tested after 7 days, 14 days and 28 days of curing. The result of compressive strength is shown in the Table 4.

From the results, it is observed that compressive strength of concrete increases in partial replacement of fine aggregates with copper slag of 0%, 25% & 50%. Increment in the replacement percentage of copper slag (75% & 100%) caused a decrement in the compressive strength. The strength of the concrete increases by 2.7%, 2.8% in 25% and 50% of copper slag replacing fine aggregate and decreases by 9.9% and 12.25% in case 75% and 100% of replacement. The low water absorption capabilities of copper slag cause an increment in the workability of concrete, thereby reducing the strength of concrete. Fibres are added to increase the strength of the concrete. After adding 0.75% of hooked steel fibre and 0.25% of micro steel fibre, the concrete specimens were tested, the results show a 4.2% increment in strength when micro steel fibre and hooked steel when compared to concrete without fibres. While in hybrid fibre (hooked steel fibre, micro steel fibre and polyester) the strength of the concrete increases by 6.8% when compared to plain concrete. The results are similar to Ambily where the highest compressive strength obtained is 172 MPa when mixed with Ennore sand and 158 MPa when mixed with copper slag (Ambily.P.Set. al, 2015,).

**Table 4:** Compressive Strength Results

Specimen Designation	Replacement Percentage	7 days	14 days	28 days
CS(N/mm <sup>2</sup> )	0 %	63.08	72.99	83.68
	25 %	66.87	74.21	85.95
	50 %	67.95	75.98	86.03
	75 %	62.45	69.23	78.26
	100 %	57.35	67.55	76.64
CS-H1(N/mm <sup>2</sup> )	0 %	66.98	79.68	87.21
	25 %	69.12	80.65	88.94
	50 %	72.34	79.65	88.92
	75 %	65.06	72.19	80.66
	100 %	58.34	70.23	78.45
CS-H2(N/mm <sup>2</sup> )	0 %	67.56	79.92	89.24
	25 %	70.78	81.49	90.01
	50 %	71.04	83.28	91.34
	75 %	65.77	73.25	81.12
	100 %	60.05	71.01	79.45

#### 3.2. Elasticity modulus

Elastic Modulus gives us the stiffness of a material. A material is said to have a lower elastic modulus when the deformation is high at a very low load value. The materials with low elastic modulus are extremely sensitive to loads and often show staggering amounts of deformation at the slightest change in load. The technical definition of the elastic modulus is defined as the relationship between linear stress and linear strain. The elastic modu-

lus properties for various concrete mixes have been determined for the various grades of concrete. The initial tangent modulus of plain concrete is 33.5 GPa whereas for concrete with hybrid fibres in 50% replacement of river sand with copper slag is 36.6 GPa. The increase of elastic modulus is in the order of 9.25% when compared to the concrete without fibres. The elastic modulus of the various concrete is shown in Table 5. The results are compared with Patil's results of a similar experiment, where the modulus of elasticity increased by 1.16% to 14.37% for 10% to 70% replacement of copper slag. Increase in replacement of copper slag gives 7.35% in decrease when compared to control mix (M.V.Patil, 2015).

**Table 5:** Elastic Modulus of Concrete

S.NO	Mix ID	Cylinder Compressive Strength (MPa)	Strain at peak Stress	Initial tangent Modulus (GPa)
1.	CS0	67	0.002	33.5
2.	CS0-H1	69.76	0.002	34.8
3.	CS0-H2	71.3	0.002	35.65
4.	CS25	68.9	0.002	34.45
5.	CS25-H1	71.2	0.0021	33.90
6.	CS25-H2	72.3	0.0021	34.76
7.	CS50	69.2	0.0021	32.95
8.	CS50-H1	71.2	0.0021	33.90
9.	CS50-H2	73.2	0.002	36.6
10.	CS75	62.7	0.002	31.35
11.	CS75-H1	64.52	0.002	32.26
12.	CS75-H2	65.1	0.0021	31
13.	CS100	61.8	0.0021	29.42
14.	CS100-H1	62.6	0.0021	29.81
15.	CS100-H2	64.1	0.002	32.05

#### 3.3. Split tensile strength

Splitting tensile strength test was conducted on concrete cylinder of size 100 x 200 mm in accordance with IS 5816-1999. The test results at 28 days are shown in Table 6. The results show that the split tensile of concrete with the replacement of 0%, 25% and 50% of copper slag is increased by 0.41% and 0.20% when compared to concrete with river sand only. The additional replacement of copper slag decreases the strength of the concrete by 14.4% and 4.9% with the replacement of 75% and 100%. From the result, it is inferred that by the addition of fibres in hybrid form increases the tensile strength by 54 – 65%. The results are in trend with Binaya Patnaik where they have used M20 and M30 grade of concrete. The results show that the split tensile strength is increased from 11 -19% when river sand is replaced with 40% of copper slag when compared with conventional mix (Binaya-Patnaik, 2015).

**Table 6:** Split Tensile Strength Result

Replacement Percentage	CS(N/mm <sup>2</sup> )	CS-H1(N/mm <sup>2</sup> )	CS-H2(N/mm <sup>2</sup> )
0 %	4.81	7.32	7.45
25 %	4.83	7.46	7.55
50 %	4.84	7.48	7.57
75 %	4.22	6.98	7.05
100 %	4.01	6.46	6.62

#### 3.4. Flexural strength

Flexural strength test was done on 100 x 100 x 500 mm size prism specimens as followed by IS 516-1959. In this test, the beam is placed horizontally and is subjected to two-point loading with a span of 133mm until it fails. The load is applied gradually until the specimen is yielded. The beams were tested after 28

days of curing. The results for the Flexural strength test are given in Table 7.

**Table 7:** Flexural Strength Test Result

Replacement Percentage	CS(N/mm <sup>2</sup> )	CS-H1(N/mm <sup>2</sup> )	CS-H2(N/mm <sup>2</sup> )
0 %	7.4	10.92	11.44
25 %	8.22	11.89	12.16
50 %	9.84	12.16	12.92
75 %	6.52	10.56	10.88
100 %	6.16	10.08	10.52

The results obtained from the flexural test shows the flexural strength of the concrete is greater when the replacement with copper slag is 0%, 25% and 50%, whereas the flexural strength decreases at additional replacement with copper slag. Flexural strength increases upon adding fibres into concrete, due to which, sudden failure can be avoided and the strength is increased when compared to the plain concrete. The results show that there is an increase in the flexural strength when copper slag is replaced upto 50% and thereafter there is a decreasing trend in the results. The results were in trend with Binaya Patnaik showed that the maximum increase in flexural strength was obtained when 1.5% of crimped fibre is added to the concrete (Binaya Patnaik, 2015).

### 3.5. Ductility

A material which undergoes a large amount of deformation through elongation before failing is said to be ductile. Ductility is an important factor because a ductile material shows failure warning unlike a brittle material which fails suddenly upon the application of a load of high magnitude. The failure will be slow in case of a ductile material, often accompanied by a large amount of deformation before it actually fails. The ductility for the various mixes of concrete is given in Table 8. It can be inferred from the results that there is 1.5-25% increase in ductility

when fibres are added in the plain concrete and maximum ductility is obtained under CS H2 where 1.25% of fibres of total volume are added.

### 3.6. JSCE toughness

By performing this technique, we calculate the area under the load-deflection part under the length of Span/150. The magnitude of toughness factor is calculated by using the value of flexural toughness. The Flexural toughness has its unit of stress in a way that its value gives the post-matrix cracking residual strength of the material when the load is applied to a deflection of span/150. The results for the JSCE Toughness test are listed in Table 8. It can be observed that the toughness percentage is increased by 1650-2600% upon the addition of fibres. The maximum toughness is obtained for CS-H2 mix where 1.25% of fibres (0.75% hooked steel + 0.25% Micro Steel + 0.25% Polyester) is added.

### 3.7. UPV method

Ultrasonic pulse Velocity (UPV) is the one of the non-destructive testing methods used on concrete. This consists of transistor, receiver and pulse velocity machine. In this method, a pair of transistors is used and the velocity of the pulse is determined by the size of the specimen and the time taken. In this test the transmission of wave and the velocity of concrete are tested. The results obtained from performing the UPV Test have been tabulated in Table 9. From the results, a velocity gives good strength and lower velocity shows the quality of the concrete is bad. With addition of fibre in concrete, the velocity decreases. From CS-H1, the velocity of concrete decreased due to addition of steel fibres and in CS-H2, the velocity of concrete decreased more compared to the plain concrete. The results are compared with Binaya Patnaik et.al. showed that the UPV value of the concrete increases when 1% amount of fibres is added to the concrete.

**Table 8:** Toughness and Ductility

S.NO	Mix Designation	Flexural strength (MPa)	Yield displacement (mm)	Ultimate displacement (mm)	Ductility	% increase in Ductility	Flexural toughness (kN-mm)	% increase in toughness	Toughness Factor (MPa)
1.	CS0	7.4	0.26	0.3	1.15	-	3.25	-	.486
2.	CS0-H1	10.92	0.33	6.5	19.69	16.12	65.09	1902	9.75
3.	CS0-H2	11.44	0.3	7.2	24	19.86	70.078	2056	10.49
4.	CS25	8.22	0.27	0.31	1.14	-	3.742	-	0.560
5.	CS25-H1	11.89	0.33	6.9	20.90	17.33	66.35	1673	9.940
6.	CS25-H2	12.16	1.4	7.7	5.5	3.82	71.98	1823	1078
7.	CS50	9.84	0.28	0.32	1.142	-	4.24	-	.636
8.	CS50-H1	12.16	0.4	7.7	19.25	15.88	76.189	1694	11.41
9.	CS50-H2	12.92	0.6	8.1	13.5	10.8	79.1	1762	11.85
10.	CS75	6.52	0.26	0.28	1.076	-	2.721	-	0.407
11.	CS75-H1	10.56	0.25	5.7	22.8	20.18	61.017	2142	9.141
12.	CS75-H2	10.88	0.3	6.6	22	19.44	64.74	2279	9.698
13.	CS100	6.16	0.25	.27	1.08	-	2.324	-	0.348
14.	CS100-H1	10.08	0.23	5.4	23.47	20.73	62.635	2595	9.383
15.	CS100-H2	10.52	0.33	6.6	20	17.51	63.836	2647	9.563

**Table 9:** Ultrasonic Pulse Velocity result

Percentage of replacement of copper slag		CS (m/s)	CS-H1 (m/s)	CS-H2 (m/s)
0%	Velocity	4950	4762	4560
25%	Velocity	4545	4365	4545
50%	Velocity	4805	4650	4525
75%	Velocity	4450	4310	4398
100%	Velocity	4525	4397	4216

### 3.8. Water absorption

The total amount of water absorbed in concrete was calculated. In this study, the amount of absorption of water was calculated by immersing the specimen into the water for 24 hours, after immersing into the water, the specimen was

weighed, and after this weight has been noted, the specimen was oven dried for 24 hours, and this weight is also noted, the difference between the two weights gives us the total amount of water absorbed in the specimen. The final results of the water absorption test have been listed in Table 10. This result is compared with Khalifa S. Al-Jabri, show that there is a decrease in water absorption with increase in copper slag content up to 40% replacement, beyond that the water absorption rapidly increases (Binaya Patnaik et al, 2009).

**Table 10:** Water Absorption for Various Mixes

Replacement Percentage of Copper Slag	CS (%)	CS-H1 (%)	CS-H2 (%)
0 %	1.85	0.96	1.05
25 %	1.69	0.88	1.01
50 %	1.65	0.85	0.98
75 %	1.54	0.87	0.92
100 %	1.43	0.80	0.84

## 4. Conclusion

The following conclusions were made from this study:

- 1) The compressive strength test results show us that the value of compressive strength increases until a certain value of river sand replacement, which in this case is 50%, any further replacement caused a reduction in the value. From the results, we can see that among the types of specimens, CS-H2 gives us the specimen of highest compressive strength testing above 90 N/mm<sup>2</sup>.
- 2) The split tensile strength was also performed on the concrete specimens and the values obtained follow a similar pattern as that of the compressive strength values. The split tensile strength of concrete increases in value till the replacement of 50% of river sand with copper slag, further addition resulted in a reduction in the strength value. CS-H2 gives the specimen with the highest average split tensile strength.
- 3) The Flexural strength test results follow a similar trend to the compressive strength test results, where the value of flexural strength increases until the replacement of river sand with 50% of copper slag. The highest average split tensile strength value is once more obtained for CS-H2.
- 4) Ultrasonic pulse velocity on a cube is done to check the quality of the concrete, and upon inference of the results, it can be concluded that all the specimens are above the threshold limit, and hence are suitable for usage in construction activities.
- 5) From the results obtained through the water absorption test, it can be concluded that at specimens with 100% replacement of river sand with copper slag give the least water absorption value among the types of concrete, CS-H1, in which, hooked steel fibres and micro steel fibres are added, gives the least water absorption.

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