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Experimental Investigation on Partial Replacement of Fine Aggregates by Copper Slag in Concrete

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ABSTRACT: Now-a-days there is a rapid growth in the construction industry and it involves the use of natural resources for the development of the infrastructure. Therefore, to reduce the dependence on natural aggregates as the main source of aggregate in concrete, artificially manufactured aggregates and artificial aggregates generated from industrial wastes provide an alternative for the construction industry. In this study copper slag is used as a partial replacement to fine aggregates in concrete.

Copper slag is one of the materials that are known as a waste material and which could have a bright future in construction industry as partial substitute of fine aggregates. It is a by-product obtained during the matte smelting and refining of copper. To manufacture every ton of copper, approximately 2.2–3.0 tons copper waste or slag is generated as a by-product material.

The aim of the present work is to examine or explore the potentiality of replacing the fine aggregates by copper slag. An attempt is made to conform the effectiveness of copper slag as a partial replacement of fine aggregates. Because of the storing issues, the slag negatively affects the environment. To solve this trouble, fine aggregates was substituted up to 40% copper slag and determining its compressive and splitting tensile strength of concrete and also the performance of copper slag on strength properties as a partial replacement of fine aggregate in concrete mix design.

The percentage replacement of sand by granulated copper slag were 10%, 20%, 30% and 40%. The compressive strength was observed to increase by about 30-35%, flexural strength by 45-50% and split tensile strength by 40-45%.

KEYWORDS: Copper Slag, Fine Aggregates, Compressive Strength, Split Tensile Strength, Environment

I. INTRODUCTION

Granulated copper slag (or) Copper Slag is a by-product obtained from the smelting of copper. For every ton of metal production, about 2.2-3 ton of waste slag is generated. Dumping or disposal of such massive quantities of slag cause environmental and space troubles. During the past two decades, attempts have been made by many researchers and copper manufacturing units all over the globe to investigate the practicable utilization of copper slag. The mechanical and physical properties of copper slag demonstrate that it can be used to produce products like fine aggregates, cement, fill, roofing granules, etc.

The unsatisfactory performance of conventional concrete under aggressive environmental conditions has necessitated the researchers and engineers to look for new concrete composites. The innovative use of concrete must examine explorations of areas, in use of new shapes, materials and technique of construction. Concrete is such a versatile material that such attempts of observation are quite possible. In modern age, without concrete construction is likely to be impossible. Plain concrete has two major deficiencies; a low tensile strength and low strain at fracture. The tensile strength of concrete is very low because plain concrete normally contains numerous micro cracks. Copper slag

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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 favorable mechanical properties for aggregate.

II. PROPERTIES OF MATERIALS USED

2.1 Cement

In this experimental work, Ordinary Portland Cement (OPC) 53 grade conforming to IS: 12269–2013 was used.

Table 2.1: Properties of Cement (OPC 53)

Sl. No.	Material Property	Results Obtained	Requirements as Per IS 12269 - 2013
1.	Specific Gravity	3.18	3.15
2.	Fineness	5.10%	Not more than 10%
3.	Normal Consistency	33%	Not more than 35%
4.	Initial Setting Time	55 minutes	Not less than 30 min
5.	Final Setting Time	355 minutes	Not more than 600 min
6.	Compressive Strength at: 3 – Days (MPa) 7 – Days (MPa) 28 – Days (MPa)	32.50 39.50 56.20	27 37 53

2.2 Fine Aggregate

Locally available river sand belonging to zone I of IS 383-1970 was used for the project work.

Table 2.2: Sieve Analysis and Physical Properties of Fine Aggregate

Sl. No.	Sieve No.	Mass Retained in grams	% Mass Retained	% Passing	Cumulative % Retained 'F'	Specifications for Zone I As Per IS:383-1970
1	4.75mm	0.0	0.0	0.0	100	90-100
2	2.36mm	50	5.0	5.0	95	60-95

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3	1.18mm	540	54.0	59.0	41	30-70
4	0.60mm	240	24.0	83.0	17	15-34
5	0.30 mm	80	8.0	91.0	9	5-20
6	0.15mm	50	5.0	96.0	4	0-10
7	0.075 mm	30	3.0	99.0	1	-
8	Pan	10	1.0	100.0	0	-
9	Specific Gravity = 2.66					
10	Bulk Density = 1290 Kg/m³					
11	Water absorption = 1.0%					
12	Fineness Modulus = 2.67					

2.3 Coarse Aggregate

Locally available Crushed aggregates confirming to IS 383-1970 are used in this dissertation.

Table 2.3: Sieve Analysis and Physical Properties of Coarse Aggregate

Sl. No.	IS Sieve Size	Percentage Passing of Coarse Aggregates		Percentage Passing of Different Fractions			Specifications as Per IS:383-1970		
		I (20 mm)	II (12.5 mm)	I 60%	II 40%	Combined 100%	Graded	Single Sized	
								I	II
1.	20 mm	100	100	60	40	100	95-100	85-100	--
2.	12.5 mm	0	98.5	0	0	0	--	--	85-100
3.	10 mm	0	35.2	0	29.5	29.5	25-55	0-20	0-45

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4.	4.75 mm	0	8.4	0	4.1	4.1	0-10	0-5	0-10
5.	Specific Gravity = 2.64								
6.	Bulk Density = 1382 Kg/m³								
7.	Water absorption = 0.5%								

2.4 Copper Slag

Copper Slag is a totally inert material and its physical properties are similar to natural sand. The slag is a mixture of lime, silica, and alumina of almost same proportion.

Table 2.4: Chemical Composition of Copper Slag

Sl. No	Chemical Compounds	% of Compounds
1	Fe ₂ O ₃	68.29
2	SiO ₂	25.84
3	Al ₂ O ₃	0.22
4	CaO	0.15
5	MgO	0.2
6	Na ₂ O	0.58
7	K ₂ O	0.23
8	Mn ₂ O ₃	0.22
9	TiO ₂	0.41
10	CuO	1.2
11	LOI	6.59
12	Insoluble residue	6.59

Table 2.5: Sieve Analysis and Physical Properties of Copper Slag

Sl.No.	Sieve No.	Mass retained in grams	% Passing	Cumulative % Retained 'F'	Specifications for Zone I As Per IS:383-1970
1.	4.75mm	10	1.0	99	90-100
2.	2.36mm	71	7.1	91.9	60-95
3.	1.18mm	320	32.0	59.9	30-70
4.	0.6mm	300	30.0	29.9	15-34

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5.	0.3mm	220	22.0	78	5-20
6.	0.15mm	22	2.2	7.9	0-10
7.	0.075mm	14	1.4	6.5	-
8.	Pan	10	1.0	5.5	-
9.	Specific Gravity = 4.0				
10.	Fineness modulus= 3.19				

III. EXPERIMENTAL DETAILS

3.1 Compressive Strength

A total of 60 cubical specimens of standard dimensions 150 x 150 x 150 mm were tested in the present study. M25 grade of concrete was used for all. The percentage replacement of fine aggregate by copper slag was 0, 10, 20, 30 and 40. A constant water cement ratio of 0.50 was adopted for making concrete mixtures. The aggregate used for this study was crushed stone from quarry with the nominal size of 20mm. The cube specimens were tested at 3, 7, 14 and 28 days. Table 3.0 gives concrete mix designs details. Table 3.1, 3.2, 3.3 and 3.4 gives the 3 days, 7 days, 14 days and 28 days cube compressive strength respectively.

Table 3.0: Concrete Mix Design Details

Sl. No.	Cement Kg/m ³	% of Slag Added	F.A kg/m ³	Slag kg/m ³	C.A kg/m ³	Water kg/m ³
1.	394	0	830.82	0	967.98	197
2.	394	10	747.74	124.94	967.98	197
3.	394	20	664.66	249.87	967.98	197
4.	394	30	581.58	374.81	967.98	197
5.	394	40	498.49	499.74	967.98	197

Table 3.1: 3 Days Cube Compressive Strength

Sl. No.	% Replacement of Fine Aggregate by Copper Slag	Compressive Strength at 3 days	% Increase in Compressive Strength
1.	0	17.60	-
2.	10	18.01	2.33
3.	20	21.59	22.67
4.	30	23.58	33.98
5.	40	22.52	27.95

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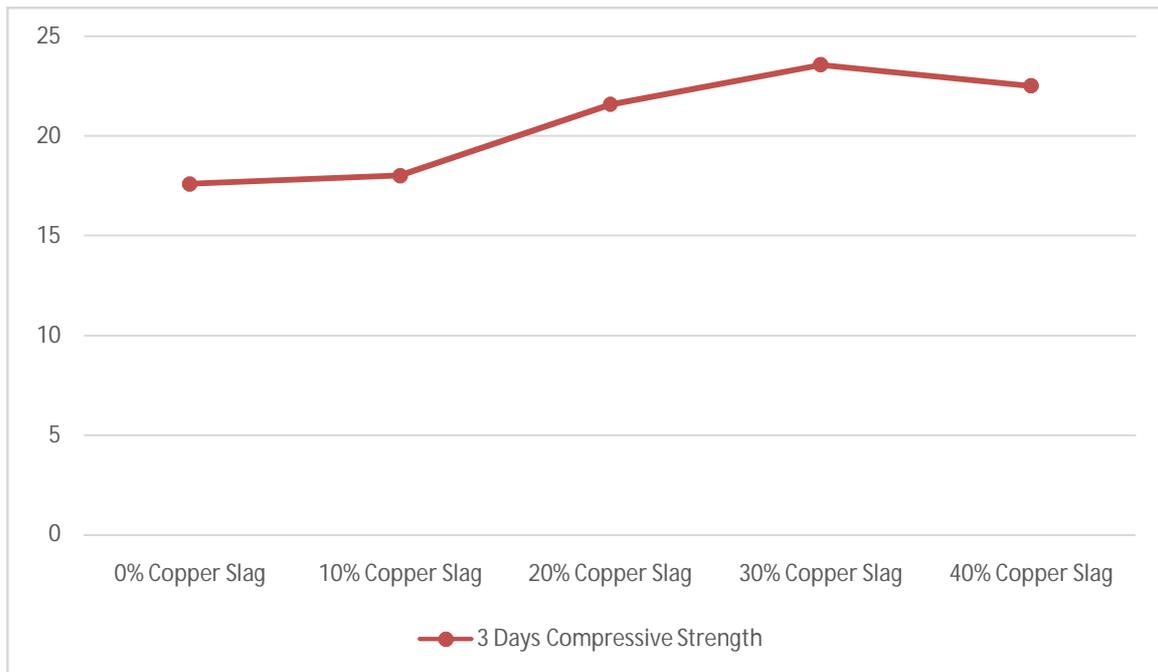


Fig. 3.1: 3 Days Cube Compressive Strength in MPa

Table 3.2: 7 Days Cube Compressive Strength

Sl. No.	% Replacement of Fine Aggregate by Copper Slag	Compressive Strength at 7 days	% Increase in Compressive Strength
1.	0	24.01	-
2.	10	26.02	8.37
3.	20	26.48	10.29
4.	30	27.71	15.41
5.	40	24.91	3.75

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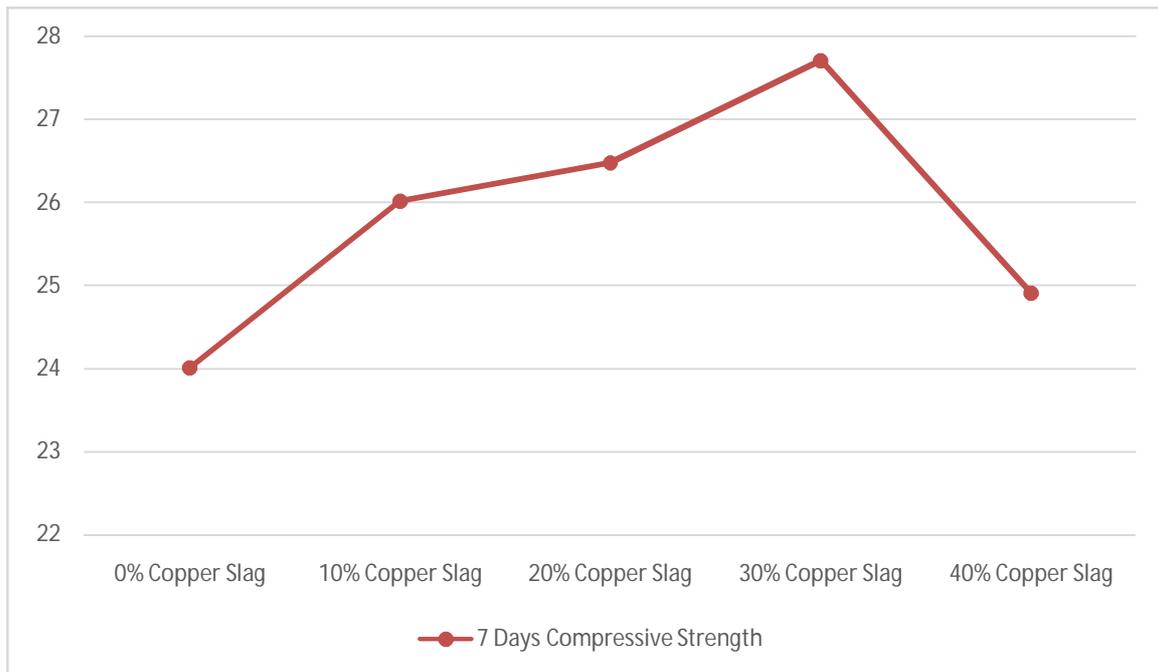


Fig. 3.2: 7 Days Cube Compressive Strength in MPa

Table 3.3: 14 Days Cube Compressive Strength

Sl. No.	% Replacement of Fine Aggregate by Copper Slag	Compressive Strength at 14 days	% Increase in Compressive Strength
1.	0	29.75	-
2.	10	30.85	3.70
3.	20	32.06	7.76
4.	30	32.90	10.59
5.	40	30.74	3.33

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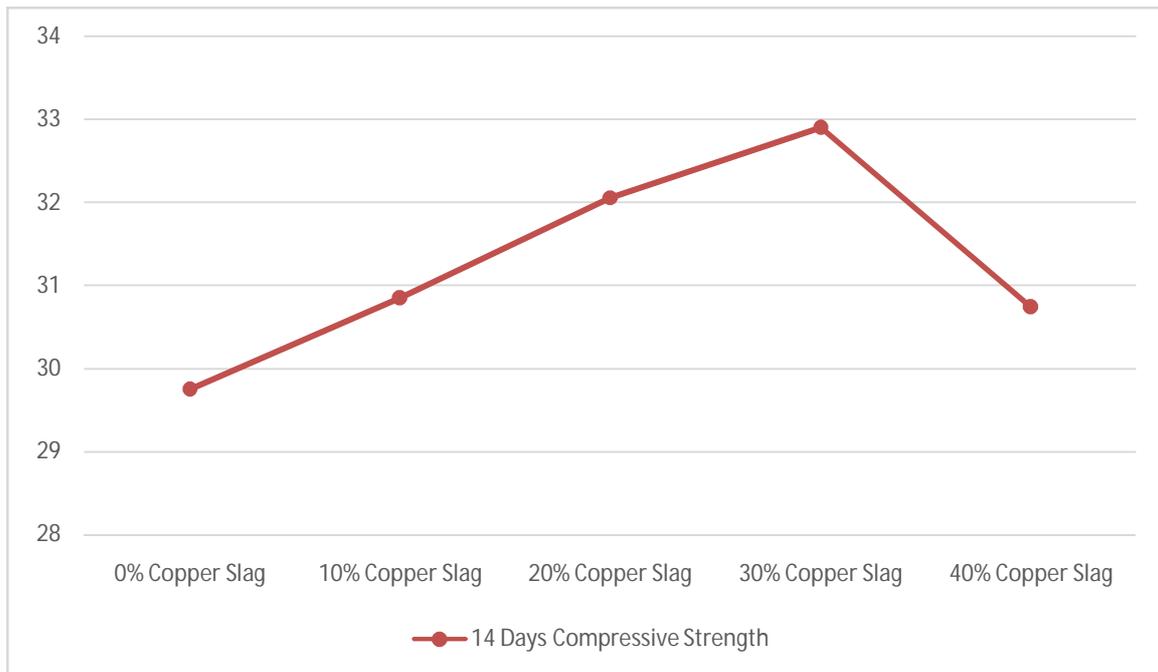


Fig. 3.3: 14 Days Cube Compressive Strength in MPa

Table 3.4: 28 Days Cube Compressive Strength

Sl. No.	% Replacement of Fine Aggregate by Copper Slag	Compressive Strength at 28 days	% Increase in Compressive Strength
1.	0	33.05	-
2.	10	36.38	10.07
3.	20	39.99	21.00
4.	30	42.90	29.80
5.	40	38.66	16.97

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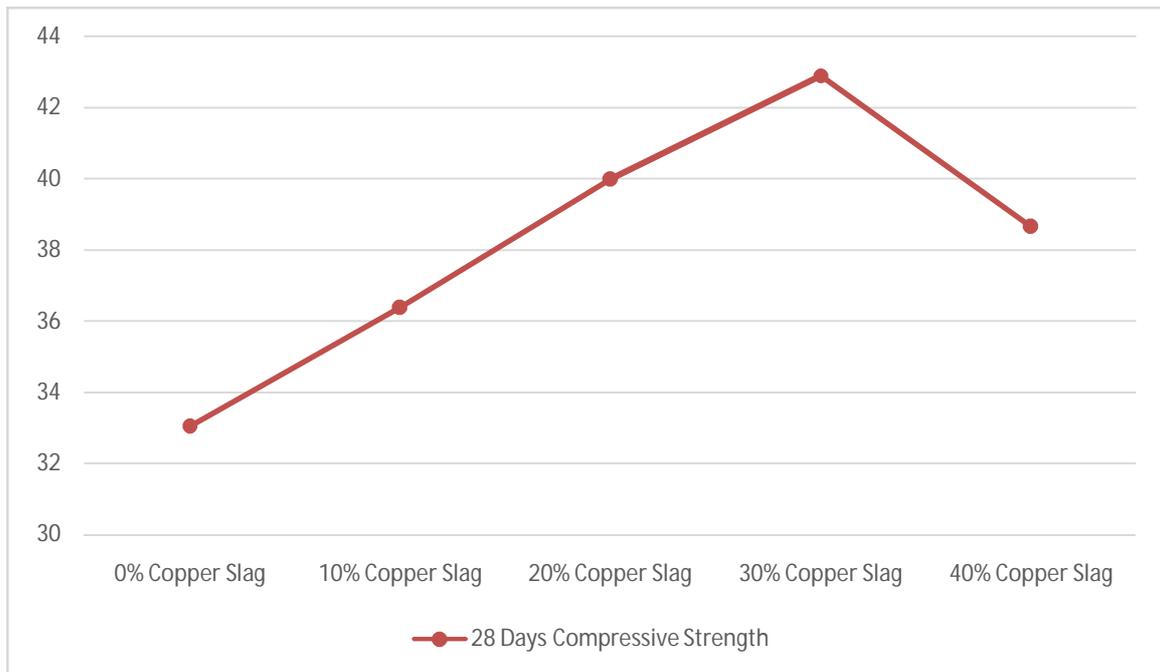


Fig. 3.4: 28 Days Cube Compressive Strength

3.2 Split Tensile Strength

To determine the split tensile strength of concrete, cylindrical specimens (150mm dia x 300mm depth) were cast with 0%, 10%, 20%, 30% and 40% replacement of fine aggregate by granulated copper slag under standard conditions. The cylinder moulds were de-moulded after 24 hours and transferred to curing tank for 28 days. Load was applied gradually at a uniform rate to the cylinder without causing any sudden failure until the dial gauge reading recedes in the reverse direction. Table 6 gives the results of split tensile test. The split tensile strength of concrete is calculated by using the formula:

$$f_{st} = \frac{2P}{\pi ld}$$

Where,

P- Maximum load at failure.

L - Length of cylindrical specimen in mm.

d-Diameter of cylindrical specimen in mm.

Table 3.5: Split Tensile Strength

% Replacement of Fine Aggregate by Copper Slag	Days	Failure Load (KN)	Split Tensile Strength (MPa)	% Increase in Split Tensile Strength
0% Copper Slag	28	288	4.07	-
10% Copper Slag	28	315	4.45	9.34
20% Copper Slag	28	368	5.20	27.76

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30% Copper Slag	28	412	5.83	43.24
40% Copper Slag	28	425	5.74	41.03

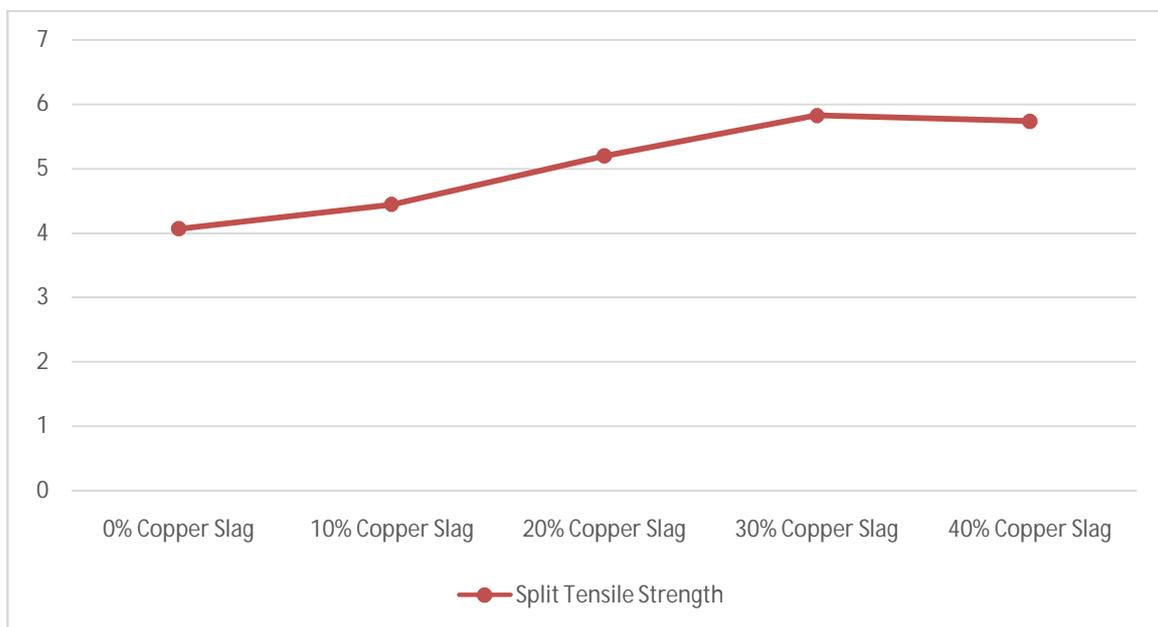


Fig. 3.5: Split Tensile Strength in MPa

3.3 Flexural Strength

To determine the flexural strength of copper slag specimen, beam of size of 150 mm X 150 mm X 700mm has been used in this experimental work. The beams specimens of different proportions were tested after 28 days of curing in water. The strength of the specimens are shown table 3.6 below.

Table 3.6: Flexural Strength

% Replacement of Fine Aggregate by Copper Slag	Days	Failure Load (KN)	Flexural Strength (MPa)	% Increase in Flexural Strength
0% Copper Slag	28	27	4.16	-
10% Copper Slag	28	31	4.77	14.66
20% Copper Slag	28	35	5.39	29.57
30% Copper Slag	28	40	6.16	48.08
40% Copper Slag	28	37	5.69	36.78

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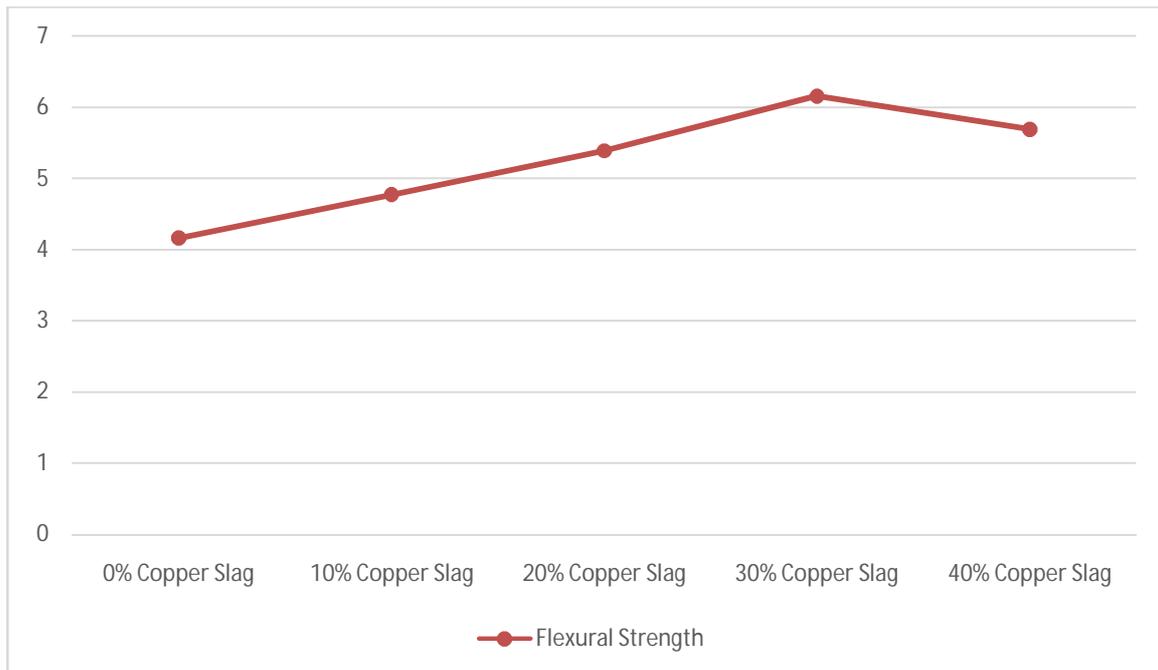


Fig. 3.6: Flexural Strength in MPa

IV. CONCLUSION

The use of copper slag in concrete provides additional environmental as well as technical benefits for all related industries. As the copper slag is an industrial waste, hence, partial replacement of copper slag in fine aggregate reduces the cost of making concrete.

The water absorption of copper slag was less compared to sand. Therefore, the workability of concrete increases with the increase of copper slag content in concrete mixes.

Increasing in percentage replacement of fine aggregate by copper slag causes the increase of the unit weight of concrete. From the results of Compressive, Split tensile strength and Flexure strength test we found out that the strength of concrete increases with respect to the percentage of copper slag added by the weight of fine aggregate up to 30% as shown in the above graphs. Further addition of copper slag caused reduction in compressive strength due to an increase of free water content in the mix.

For Cube compressive strength, Split tensile strength and Flexural strength, the highest percentage increase in the strength of concrete was observed to be 43.24, 33.98 and 48.08% respectively.

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