VOL. 10, NO 20, NOVEMBER, 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

AN EXPERIMENTAL INVESTIGATION ON STRENGTH PROPERTIES OF COPPER SLAG FIBRE REINFORCED CONCRETE

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ABSTRACT

This paper presents a study of the mechanical properties of copper slag fibre reinforced concrete considering the effect of fibre content (0%, 0.5%, 1%, and 1.5%). Also an attempt has been made to establish the relationship between different mechanical and non-destructive test properties of concrete. Furthermore a mathematical model was proposed to determine different strength properties of copper slag concrete with variation of fibre content in it. The suggested model successfully epitomizes the rise of tensile and flexure strength properties of copper slag concrete with increase in fibre content, however a different pattern has been observed in case of compressive strength. In the present experimental investigation, concretes of grade M20 and M30 were used with crimped steel fibres having an Aspect Ratio of 60.

Keywords: copper slag, crimped steel fibre, compressive strength, tensile strength, flexural strength, ultrasonic pulse velocity, rebound hammer.

INTRODUCTION

Alternative to river sand, which is a common form of fine aggregate in preparation of concrete have been in demand due to large scale depletion of river bed and increasing cost of river sand. Many non-conventional resources such as Stone Dust, Carbonate Sand, Fly Ash, Copper Slag etc. with larger percentage of Silica (SiO_2) have been tried out as an alternative to river sand as fine aggregate in preparation of concrete. Several studies have shown promising result in terms of strength properties of concrete by using copper slag as a partial replacement of river sand, also the optimum percentage of copper slag as a partial replacement of sand has been established to 40%. The deficiencies of a Plain Cement Concrete are low strain at fracture and low tensile strength. The micro cracks present in mortar-aggregate interface are responsible for the inherent weakness and can be removed by inclusion of crimped steel fibres in it.

OBJECTIVE

The objective of this study is to use Crimped Steel Fibres in preparation of copper slag concrete and normal concrete and study various strength properties such as Compressive Strength, Split Tensile Strength, Flexural Strength, Ultrasonic Pulse Velocity, and Rebound Hammer. Further a mathematical model was established between the mechanical properties of concrete.

LITERATURE REVIEW

Al-Jabri *et al*. [1] used copper slag and cement by-Pass dust (CBPD) in cement mortar preparation. The optimum strength was achieved at 95% cement +5% CBPD mix and 1.5% CBPD + 13.5 CS + 85% cement mix. Ishimaru *et al.* [2] used copper Slag and class II fly ash as fine aggregates in concrete production. The results showed that the best results are achieved in terms of compressive strength by substituting copper slag or class II fly ash up to 20% (in volume) as fine aggregates. Washington Almeida, Moura *et al*. [3] studied various strength properties of concrete (compressive and split tensile strength) by using copper slag as partial replacement of sand. The results showed that the strength properties increase when compared to normal concrete. The results also showed a decreased carbonation which signifies a good concrete from durability perspective. Brindha *et al.* [4] studied compressive strength behavior of copper slag concrete (M20 Grade) by partially replacing sand with copper slag. The strength was found to maximum at 40% of copper slag replacement with sand. It was also observed that for increased partial replacement of copper slag beyond 40%, the strength of copper slag concrete decreases. A. M. Shende *et al.* [5] studied the effect of steel fibres on M40 grade concrete and found that the compressive strength, tensile strength and flexural strength increases with increase in the percentage of steel content up-to 3 %. Mazen Musmar [6] studied the effect of addition of steel fibres in concrete and found improved mechanical properties of concrete such as Tensile strength, impact strength and toughness. It was also concluded that Compressive strength, fibre content and the fibre aspect ratio has greater impact on the tensile strength of fibre concrete. Binaya *et al*. [7] studied the strength and durability properties of M20 and M30 grade copper slag concrete. The results showed that addition of copper slag increases the density of concrete there by increasing the self-weight. The optimum % of copper slag for both the mixes (M20 and M30) was found to be 40%. The durability results showed the copper slag concrete has a low resistance to H_2SO_4 and HCL compared to controlled

concrete. Binaya *et al.* [8] reported that when copper slag is partially replaced with sand in M30 Grade concrete, the coefficient of determination for 28 days and 90 days compressive strength found to be 0.9753 and 0.9748 which indicates that the model has a good fit.

EXPERIMENT DETAILS

Materials used and properties

Cement

53 grade Ordinary Portland Cement having specific gravity of 3.094; fineness modulus of 4.62% and normal consistency of 32% was used. The quality of the cement was confirmed as per IS 4031-1988 and all the quality tests were conducted confirming to specifications of 12269-1987. The basic components of cement are mentioned in Table-1.

Table-1. Composition of cement.

Composition	Percentage
Calcium -CaO	61-63 %
Silica - SiO_2	17-25 %
Aluminum - Al_2O_3	4-8%
Iron - Fe_2O_3	0.5-0.6 %
Magnesium– MgO	0.1-4.0 %
Sodium - SO_3	1.3-3.0 %
Sodium and Potassium Na_2 + K_2O	0.4-1.3 %
Chemical Ionization -Cl	0.01-0.1%
IR	0.6-1.75 %

Aggregate

- **Coarse aggregate**

Angular crushed granite metal of 20mm size having specific gravity of 2.6 and fineness modulus of 7.1 was used. Bulk Density in loose state was found to be 1414 Kg/m^3 and on compacted state 1550 kg/m^3. The water absorption was 1.1%.

- **Fine aggregate**

River sand having specific gravity of 2.6 and fineness modulus 2.4 was used. The Bulk Density in loose state was found to be 1597 kg/m^3 and on compacted state 1700kg/m^3 respectively. The water absorption was 1.20%. The combined grading is presented in the Figure-1.

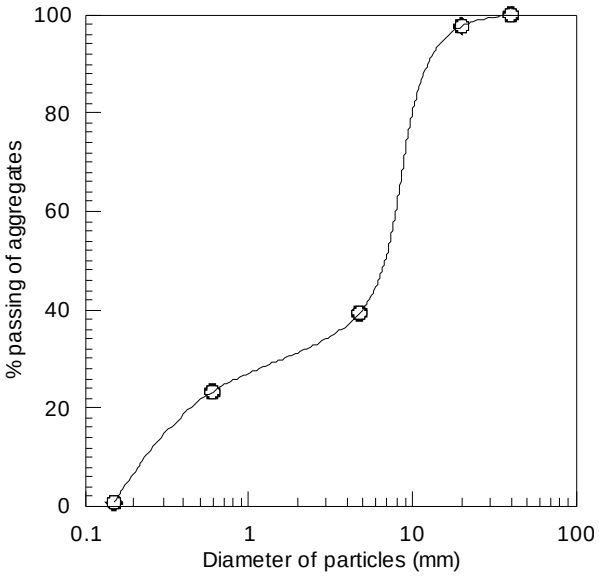

Figure-1. Combined grading of aggregates.

- **Copper slag**

Irregular, air cooled, glassy black copper slag with sp.gravity 3.47 and fineness modulus 3.3 was used. Bulk Density in loose state was found to be 1898 kg/m^3 and in compacted stage 2024 kg/m^3. The water absorption was 0.24%. Table-2 shows the chemical properties of copper slag. The grading of copper slag has been presented in Figure-2.

Table-2. Chemical composition of copper slag.

Composition	Percentage
Silica - $SiO2$	33.52
Iron - Fe_2O_3	55.8
Aluminum - Al_2O_3	3.8
calcium – CaO	3.14
Magnesium – MgO	0.72
Sodium - Na_2O	0.4
Potassium - K_2O	0.76
Titanium - TiO_2	0.5
Copper – Cu	0.99

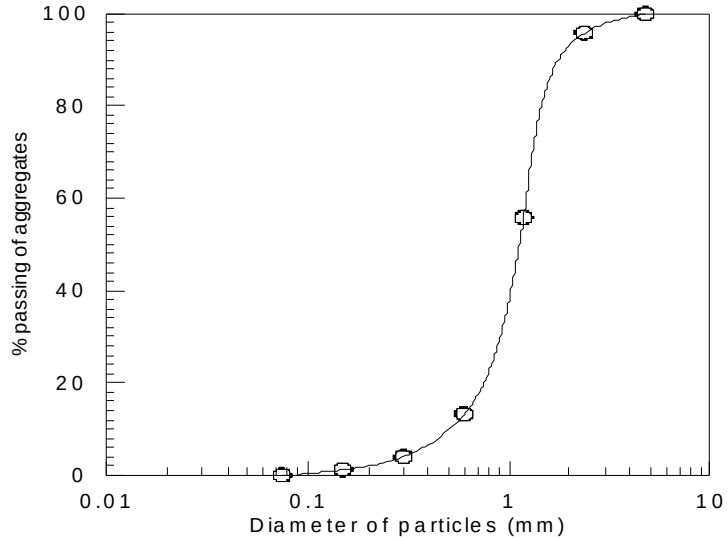

Figure-2. Grading of copper slag.

Crimped steel fibre

Rounded crimped steel fibres of length 30 mm X diameter 0.5 mm (Aspect ratio = 60) with different volume fraction of 0, 0.5, 1 and 1.5 have been used for this study. The Ultimate Tensile Strength of the fibres was found to be 1020 MPa.

Mix design

A per the code book IS: 10262 -1979, the mix design was done for M20 and M30 grade mix and the amount of materials were calculated. Table 3 gives the quantities required for M20 and M30 grade of concrete Mixes.

Table-3. Mix design and proportion of M20 and M30 grade concrete.

Grade	Cement (Kg/m^3)	Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)	Water (Kg/m^3)	W/C Ratio	Mix proportion
M-20	320	712	1178	176	0.55	1:2.225:3.68
M-30	350	703.6	1164	175	0.5	1:2.01:3.326

Mixes

The optimum percentage of copper slag has been established as 40% for partially replacing sand in preparation M20 and M30 grade concrete. In this study, various mixes were prepared by adding crimped steel fibres of different volume fraction (0%, 0.5%, 1% and1.5%) to this optimized copper slag concrete and plain cement concrete. Here 'C' and 'S' represents copper slag and crimped steel fibre respectively whereas the suffix represents the percentage of material replaced and used. Table-4 gives the quantity required for various mixes.

Table-4. Concrete mix details.

Mix	Type of mix	Cement (Kg/m^3)	Copper slag (Kg/m^3)	Water (Kg/m^3)	Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)	Crimped steel fibre (Kg/m^3)
M20	C_0S_0	320	0	176	712	1178	0
	$C_0S_{0.5}$	320	0	176	712	1178	39.25
	C_0S_1	320	0	176	712	1178	78.5
	$C_0S_{1.5}$	320	0	176	712	1178	117.75
	$C_{40}S_0$	320	284.8	176	427.2	1178	0
	$C_{40}S_{0.5}$	320	284.8	176	427.2	1178	39.25
	$C_{40}S_1$	320	284.8	176	427.2	1178	78.5
	$C_{40}S_{1.5}$	320	284.8	176	427.2	1178	117.75
M30	C_0S_0	350	281.44	175	422.16	1164	0
	$C_0S_{0.5}$	350	281.44	175	422.16	1164	39.25
	C_0S_1	350	281.44	175	422.16	1164	78.5
	$C_0S_{1.5}$	350	281.44	175	422.16	1164	117.75
	$C_{40}S_0$	350	281.44	175	422.16	1164	0
	$C_{40}S_{0.5}$	350	281.44	175	422.16	1164	39.25
	$C_{40}S_1$	350	281.44	175	422.16	1164	78.5
	$C_{40}S_{1.5}$	350	281.44	175	422.16	1164	117.75

DISCUSSION OF RESULT

Compressive strength test results

The results in Table-5 shows the compressive strength of M20 and M30 grade concretes with varying copper slag and fibre content at different ages. Along with compressive strength, the percentage change in strength with respect to normal concrete and age is also presented to have a better understanding. It can be observed from Table-5 that the compressive strength of concrete increases with the increase of crimped steel fibres for normal concrete but in case of copper slag concrete the maximum is perceived at one percentage of crimped steel fibre. The same pattern is observed for concretes of grades M20 and M30. The results also show that the compressive strength of all the copper slag mixes is more when compared to its respective normal concrete.

Table-5. Compressive strength of M20 and M30 mix copper slag fibre reinforced concrete.

Mix	Type of mix	Density (Kg/m^3)	Compressive strength (MPa)			Percentage increase in compressive strength with respect to normal concrete			Percentage increase in compressive strength with respect to age		
			28 days	90 days	180 days	28 days	90 days	180 days	28 days	90 days	180 days
M20	C_0S_0	2259	36.8	44.34	46.2	-	-	-	-	20.49	25.54
	$C_0S_{0.5}$	2350	43.3	48.06	51.23	17.66	8.39	10.89	-	10.99	18.31
	C_0S_1	2455	47.6	51.1	52.8	29.35	15.25	14.29	-	7.35	10.92
	$C_0S_{1.5}$	2467	50.73	57.2	59.2	37.85	29	28.14	-	12.75	16.7
	$C_{40}S_0$	2539	41.05	55.17	59.1	11.55	24.42	27.92	-	34.4	43.97
	$C_{40}S_{0.5}$	2554	53.8	56.9	59.38	46.2	28.33	28.53	-	5.76	10.37
	$C_{40}S_1$	2587	57.53	63.83	65.92	56.33	43.96	42.68	-	10.95	14.58
	$C_{40}S_{1.5}$	2597	55.36	58.08	61.69	50.43	30.99	33.53	-	4.91	11.43
M30	C_0S_0	2434	41.16	51.28	53.45	-	-	-	-	24.59	29.86
	$C_0S_{0.5}$	2471	55.8	56.34	57.19	35.57	9.87	7	-	0.97	2.49
	C_0S_1	2451	59.53	63.76	65.63	44.63	24.34	22.79	-	7.11	10.25
	$C_0S_{1.5}$	2459	61.5	67.6	69.78	49.42	31.83	30.55	-	9.92	13.46
	$C_{40}S_0$	2544	47.41	57.24	60.23	15.18	11.62	12.68	-	20.73	27.04
	$C_{40}S_{0.5}$	2546	65.77	68.96	71.2	59.79	34.48	33.21	-	4.85	8.26
	$C_{40}S_1$	2571	67.16	73.86	74.3	63.17	44.03	39.01	-	9.98	10.63
	$C_{40}S_{1.5}$	2575	60.26	69	72.67	46.4	34.56	35.96	-	14.5	20.59

Split tensile strength test results

The results in Table-6 shows the split tensile strength of M20 and M30 grade concretes with varying copper slag and fibre content at different ages. Along with split tensile strength, the percentage change in split tensile strength with respect to normal concrete and age is also presented to have a better understanding. It can be observed from Table-6 that the split tensile strength of concrete increases with the increase of crimped steel fibres for both normal and copper slag concrete and the maximum is attainted at 1.5 percentage of crimped steel fibre. The same pattern is observed for concretes of grade M20 and M30. The results also show that the split tensile strength of all the copper slag mixes is more when compared to its respective normal concrete.

Table-6. Split tensile strength of M20 and M30 mix copper slag fibre reinforced concrete.

Mix	Type of mix	Density (Kg/m^3)	Split tensile strength (MPa)			Percentage increase in split tensile strength with respect to normal concrete			Percentage increase in split tensile strength with respect to age		
			28 days	90 days	180 days	28 days	90 days	180 days	28 days	90 days	180 days
M20	C_0S_0	2259	2.171	2.39	2.47	-	-	-	-	10.09	13.77
	$C_0S_{0.5}$	2350	3.14	3.24	3.37	44.63	35.56	36.44	-	3.18	7.32
	C_0S_1	2455	3.307	3.529	3.71	52.33	47.66	50.2	-	6.71	12.19
	$C_0S_{1.5}$	2467	4.77	4.93	5.12	119.7	106.3	107.29	-	3.35	7.34
	$C_{40}S_0$	2539	2.204	2.59	2.63	1.52	8.37	6.48	-	17.51	19.33
	$C_{40}S_{0.5}$	2554	3.41	3.741	3.89	57.07	56.53	57.49	-	9.71	14.08
	$C_{40}S_1$	2587	3.633	3.818	3.96	67.34	59.75	60.32	-	5.09	9
	$C_{40}S_{1.5}$	2597	4.874	5.278	5.51	124.5	120.8	123.08	-	8.29	13.05
M30	C_0S_0	2434	2.924	3.34	3.58	-	-	-	-	14.23	22.44
	$C_0S_{0.5}$	2471	3.421	3.65	3.78	17	9.28	5.59	-	6.69	10.49
	C_0S_1	2451	4.125	4.91	5.13	41.07	47.01	43.3	-	19.03	24.36
	$C_0S_{1.5}$	2459	5.227	5.42	5.63	78.76	62.28	57.26	-	3.69	7.71
	$C_{40}S_0$	2544	2.982	3.67	3.87	1.98	9.88	8.1	-	23.07	29.78
	$C_{40}S_{0.5}$	2546	3.83	3.886	4.1	30.98	16.35	14.53	-	1.46	7.05
	$C_{40}S_1$	2571	3.93	4.15	4.32	34.4	24.25	20.67	-	5.6	9.92
	$C_{40}S_{1.5}$	2575	5.38	5.71	5.73	83.99	70.96	60.06	-	6.13	6.50

Relationship between Compressive Strength (CS)and Split Tensile Strength (TS)

Mathematical equations were obtained for expressing compressive strength and split tensile strength for concrete with and without copper slag for different percentage of crimped steel fibres. Figure-3 shows the relationship between compressive strength and split tensile strength at 28 days. The equations obtained as below:

For up-to 1 percentage of crimped steel fibre, TS=0.4+0.055*CS and 'R^2'=0.806.

For up-to 1.5 percentage of crimped steel fibre, TS=2.0+0.0538*CS and 'R^2'=0.846.

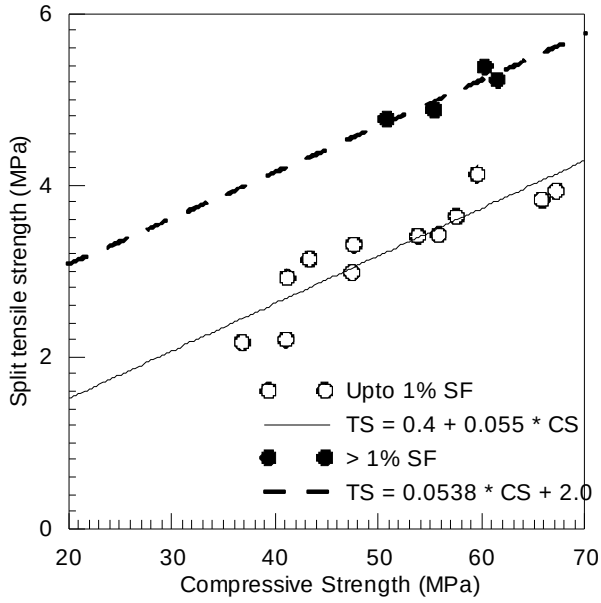

Figure-3. Variation of compressive strength with respect to split tensile strength.

Relationship between Split Tensile Strength (TS) and percentage of steel fibre (SF)

Mathematical equations were obtained for expressing split tensile strength and percentage of crimped steel fibre for concrete with and without copper slag for different percentage of crimped steel fibres. Figure-4 shows the relationship between split tensile strength and percentage of crimped steel fibre at 28 days. The equations obtained as below:

For WO-CS-M20, TS=2.15+1.592*SF and 'R^2'=0.918
For CS-M20, TS=2.29+1.646*SF and 'R^2'=0.944
For WO-CS-M30, TS=2.78+0.968*SF and 'R^2'=0.968
For CS-M30, TS=2.93+1.458*SF and 'R^2'=0.895

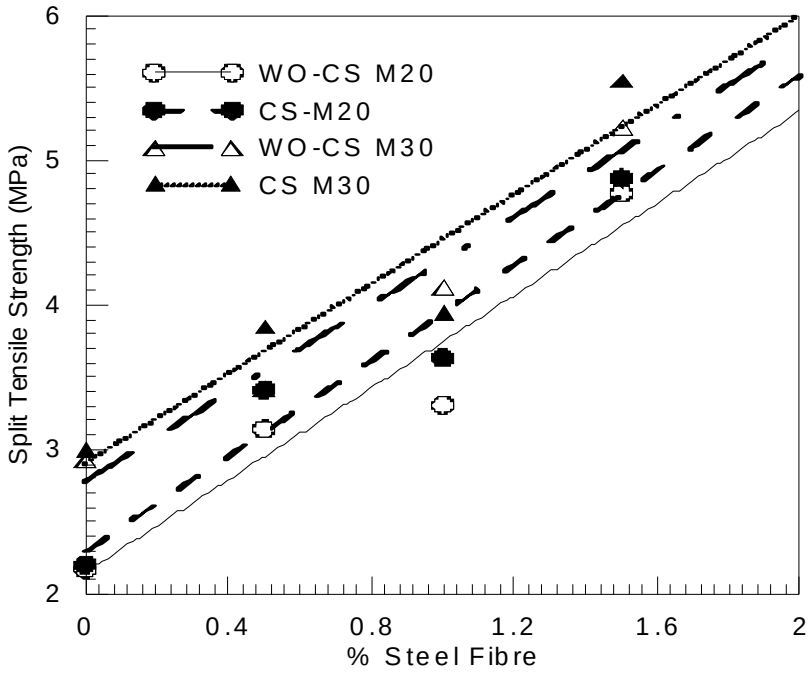

Figure-4. Variation of split tensile strength with respect to percentage of steel fibres.

Flexural strength test results

The results in Table-7 shows the flexural strength of M20 and M30 grade concretes with varying copper slag and fibre content at different ages. Along with flexural strength, the percentage change in flexural strength with respect to normal concrete and age is also presented to have a better understanding. It can be observed from Table-7 that the flexural strength of concrete will increase with the increase of crimped steel fibres for both normal and copper slag concrete and the maximum is attainted at 1.5 percentage of crimped steel fibre. The same pattern is observed for concretes of grade M20 and M30. The results also show that the flexural strength of all the copper slag mixes is more when compared to its respective normal concrete.

Table-7. Flexural strength of M20 and M30 mix copper slag fibre reinforced concrete.

Mix	Type of Mix	Density (Kg/m^3)	Flexural Strength (MPa)			Percentage increase in flexural strength with respect to normal concrete			Percentage increase in flexural strength with respect to age		
			28 days	90 days	180 days	28 days	90 days	180 days	28 days	90 days	180 days
M20	C_0S_0	2259	4.44	4.8	4.96	-	-	-	-	8.11	11.71
	$C_0S_{0.5}$	2350	4.62	5.42	5.54	4.05	12.92	11.69	-	17.32	19.91
	C_0S_1	2455	4.93	5.57	5.75	11.04	16.04	15.93	-	12.98	16.63
	$C_0S_{1.5}$	2467	5.26	5.7	5.8	18.47	18.75	16.94	-	8.37	10.27
	$C_{40}S_0$	2539	4.51	5.74	5.98	1.58	19.58	20.56	-	27.27	32.59
	$C_{40}S_{0.5}$	2554	5.23	5.81	6.18	17.79	21.04	24.6	-	11.09	18.16
	$C_{40}S_1$	2587	5.41	5.94	6.23	21.85	23.75	25.6	-	9.8	15.16
	$C_{40}S_{1.5}$	2597	5.46	6.1	6.4	22.97	27.08	29.03	-	11.72	17.22
M30	C_0S_0	2434	4.87	5.16	5.3	-	-	-	-	5.95	8.83
	$C_0S_{0.5}$	2471	5.23	5.86	5.89	7.39	13.57	11.13s	-	12.05	12.62
	C_0S_1	2451	5.48	5.9	6.15	12.53	14.34	16.04	-	7.66	12.23
	$C_0S_{1.5}$	2459	5.51	6.26	6.32	13.14	21.32	19.25	-	13.61	14.7
	$C_{40}S_0$	2544	5.28	6.41	6.62	8.42	24.22	24.91	-	21.4	25.38
	$C_{40}S_{0.5}$	2546	5.69	6.44	6.65	16.84	24.81	25.47	-	13.18	16.87
	$C_{40}S_1$	2571	5.81	6.5	6.69	19.3	25.97	26.23	-	11.88	15.15
	$C_{40}S_{1.5}$	2575	5.96	6.63	6.72	22.38	28.49	26.79	-	11.24	12.75

Relationship between Compressive Strength (CS) and Flexural Strength (FS)

A mathematical equation is obtained for expressing compressive strength and flexural strength for concrete with and without copper slag for different percentage of crimped steel fibres. Figure-5 shows the relationship between compressive strength and flexural strength at 28 days. The equation obtained is FS = 2.84+0.045*CS and 'R^2'=0.86.

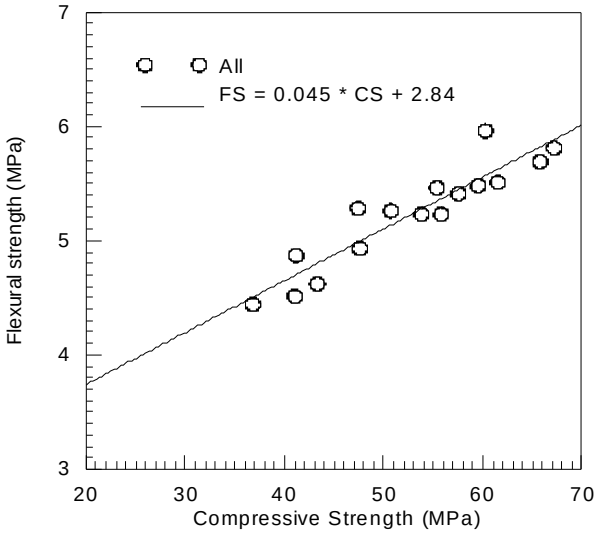

Figure-5. Variation of compressive strength with respect to flexural strength.

Relationship between Flexural Strength (FS) and percentage of steel fibre (SF)

Mathematical equations were obtained for expressing flexural strength and percentage of crimped steel fibre for concrete with and without copper slag for different percentage of crimped steel fibres. Figure-6 shows the relationship between flexural strength and percentage of crimped steel fibre at 28 days. The equations obtained as below:

For WO-CS-M20, FS=4.397+0.554*SF and 'R^2'=0.984
For CS-M20, FS=4.698+0.6065*SF and 'R^2'=0.80
For WO-CS-M30, FS=4.947+0.434*SF and 'R^2'=0.894
For CS-M30, FS=5.361+0.432*SF and 'R^2'=0.913

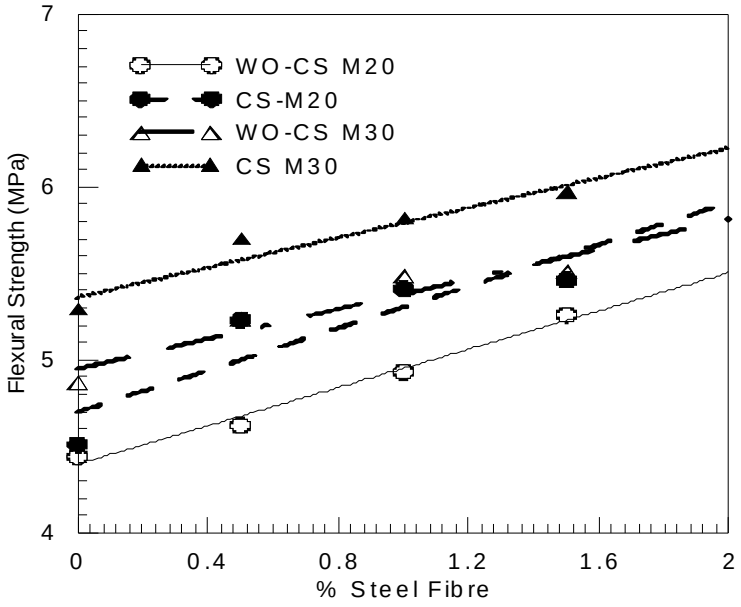

Figure-6. Variation of flexural strength with respect to percentage of Steel Fibres.

UPV Test results

The results in Table-8 shows the ultrasonic pulse velocity of M20 and M30 grade concretes with varying copper slag and fibre content at different ages. Along with UPV, the percentage change in UPV with respect to normal concrete and age is also presented to have a better understanding. It can be observed from Table 8 that the UPV of concrete increases with the increase of crimped steel fibres for normal concrete but in case of copper slag concrete the maximum is perceived at 1 percentage of crimped steel fibre. The same pattern is observed for concretes of grades M20 and M30. The results also show that the UPV of all the copper slag mixes is more when compared to its respective normal concrete.

Table-8. Ultrasonic pulse velocity of M20 and M30 mix copper slag fibre reinforced concrete.

Mix	Type of mix	Density (Kg/m^3)	Ultrasonic Pulse Velocity (Km/S)			Percentage increase in ultrasonic pulse velocity with respect to normal concrete			Percentage increase in ultrasonic pulse velocity with respect to age		
			28 days	90 days	180 days	28 days	90 days	180 days	28 days	90 days	180 days
M20	C_0S_0	2259	4.37	4.45	4.6	-	-	-	-	1.83	5.26
	$C_0S_{0.5}$	2350	4.562	4.6	4.64	4.39	3.37	0.87	-	0.83	1.71
	C_0S_1	2455	4.64	4.68	4.7	6.18	5.17	2.17	-	0.86	1.29
	$C_0S_{1.5}$	2467	4.68	4.75	4.76	7.09	6.74	3.48	-	1.5	1.71
	$C_{40}S_0$	2539	4.47	4.56	4.78	2.29	2.47	3.91	-	2.01	6.94
	$C_{40}S_{0.5}$	2554	4.708	4.73	4.81	7.73	6.29	4.57	-	0.47	2.17
	$C_{40}S_1$	2587	4.767	4.78	4.9	9.08	7.42	6.52	-	0.27	2.79
	$C_{40}S_{1.5}$	2597	4.687	4.72	4.84	7.25	6.07	5.22	-	0.7	3.26
M30	C_0S_0	2434	4.42	4.65	4.74	-	-	-	-	5.2	4.24
	$C_0S_{0.5}$	2471	4.58	4.72	4.78	3.62	1.51	0.84	-	3.06	4.37
	C_0S_1	2451	4.64	4.8	4.85	4.98	3.23	2.32	-	3.45	4.53
	$C_0S_{1.5}$	2459	4.73	4.84	4.94	7.01	4.09	4.22	-	2.33	4.44
	$C_{40}S_0$	2544	4.49	4.7	4.82	1.58	1.08	1.69	-	4.68	7.35
	$C_{40}S_{0.5}$	2546	4.681	4.8	4.93	5.9	3.23	4.01	-	2.54	5.32
	$C_{40}S_1$	2571	4.783	4.9	4.99	8.21	5.38	5.27	-	2.45	4.33
	$C_{40}S_{1.5}$	2575	4.735	4.76	4.86	7.13	2.37	2.53	-	0.53	2.64

Relationship between Compressive Strength (CS)and UPV

A mathematical equation is obtained for expressing compressive strength and ultrasonic pulse velocity for concrete with and without copper slag for different percentage of crimped steel fibres. Figure-7 shows the relationship between compressive strength and UPV at 28 days. The equation obtained is

UPV= 4+0.0118* CS and 'R^2' = 0.74.

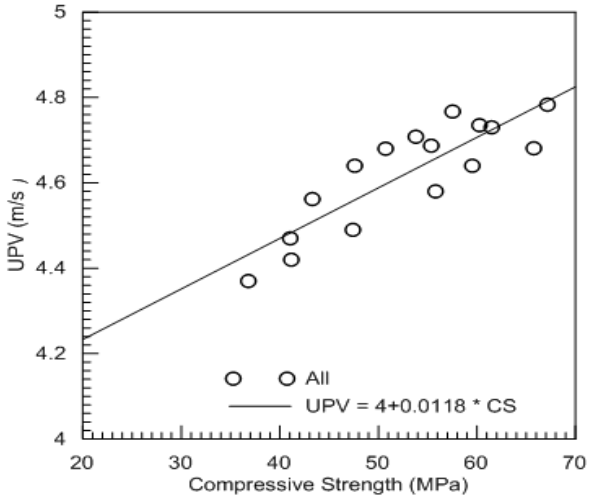

Figure-7. Variation of compressive strength with respect to UPV.

Rebound hammer test results

The results in Table-9 shows the rebound hammer number of M20 and M30 grade concretes with varying copper slag and fibre content at different ages.

Along with rebound hammer number, the percentage change in rebound hammer number with respect to normal concrete and age is also presented to have a better understanding. It can be observed from Table-9 that the rebound hammer number of concrete will increase with the increase of crimped steel fibres for both normal and copper slag concrete and the maximum is attainted at 1.5 percentage of crimped steel fibre. The same pattern is observed for concretes of grade M20 and M30. The results also show that the rebound hammer number of all the copper slag mixes is more when compared to its respective normal concrete.

Table-9. Rebound hammer number of M20 and M30 mix copper slag fibre reinforced concrete.

Mix	Type of mix	Density (Kg/m^3)	Rebound hammer number			Percentage increase in rebound hammer number with respect to normal concrete			Percentage increase in rebound hammer number with respect to age		
			28 days	90 days	180 days	28 days	90 days	180 days	28 days	90 days	180 days
M20	C_0S_0	2259	41.3	43.2	43.8	-	-	-	-	4.6	6.05
	$C_0S_{0.5}$	2350	41.7	43.4	44	0.97	0.46	0.46	-	4.08	5.52
	C_0S_1	2455	42.5	43.6	44.5	2.91	0.93	1.6	-	2.59	4.71
	$C_0S_{1.5}$	2467	43.8	44.5	44.5	6.05	3.01	1.6	-	1.6	1.6
	$C_{40}S_0$	2539	42.7	43.8	44.1	3.39	1.39	0.68	-	2.58	3.28
	$C_{40}S_{0.5}$	2554	43	44.2	44.5	4.12	2.31	1.6	-	2.79	3.49
	$C_{40}S_1$	2587	44.6	44.8	44.9	7.99	3.7	2.51	-	0.45	0.67
	$C_{40}S_{1.5}$	2597	44.8	45	45	8.47	4.17	2.74	-	0.45	0.45
M30	C_0S_0	2434	42.1	43.5	44.5	-	-	-	-	3.33	5.7
	$C_0S_{0.5}$	2471	43.25	44	44.6	2.73	1.15	0.22	-	1.73	3.12
	C_0S_1	2451	44.6	44.8	44.8	5.94	2.99	0.67	-	0.45	0.45
	$C_0S_{1.5}$	2459	44.8	45.1	45	6.41	3.68	1.12	-	0.67	0.45
	$C_{40}S_0$	2544	43.8	44	44.8	4.04	1.15	0.67	-	0.46	2.28
	$C_{40}S_{0.5}$	2546	44.25	44.5	45	5.11	2.3	1.12	-	0.56	1.69
	$C_{40}S_1$	2571	44.9	45	45.2	6.65	3.45	1.57	-	0.22	0.67
	$C_{40}S_{1.5}$	2575	45.3	45.5	45.6	7.6	4.6	2.47	-	0.44	0.66

Relationship between Compressive Strength (CS) and Rebound Hammer (RH)

A mathematical equation is obtained for expressing compressive strength and rebound hammer number of concrete with and without copper slag for different percentage of crimped steel fibres. Figure-8 shows the relationship between compressive strength and rebound hammer number at 28 days. The equation obtained is, RH=37.34+0.118*CS and 'R^2' =0.76.

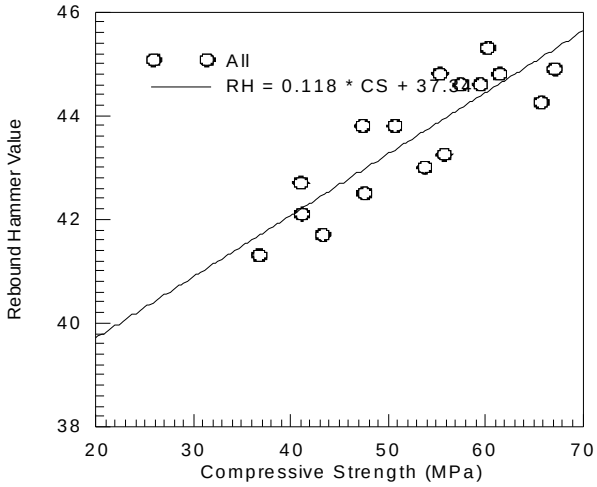

Figure-8. Variation of compressive strength with respect to rebound hammer number.

CONCLUSIONS

- The compressive strength of normal concrete increases linearly with addition of crimped steel fibres. However for concretes containing copper slag, the maximum compressive strength is observed at 1 percentage crimped steel fibre addition by volume and further addition of crimped steel fibres leads to decrease in compressive strength. Interestingly, the same pattern was observed for different grades of concrete (M20 and M30).
- The split tensile strength of normal concrete and concrete containing copper slag increases with percentage increase of crimped steel fibre content.
- The flexural strength of normal concrete and concrete containing copper slag increases with percentage increase of crimped steel fibre content.
- The compressive strength of the concrete at 28 days increased by 11.5percentage for M20 grade and 15.18 percentage for M30 grade, when 40% of fine aggregate is replaced with copper slag.
- The split tensile strength of copper slag concrete with 1.5 percentage crimped steel fibre at 28 days increases by 124.5 and 81.94 percentages respectively for M20 and M30 grade concrete, when compared to normal concrete.
- The flexural strength of copper slag concrete at 1.5 percentage crimped steel fibre increases by 22.97 and 22.38 percentages respectively for M20 and M30 grade concrete, when compared to normal concrete at 28 days.
- The relation between compressive strength and split tensile strength of copper slag fibre reinforced concrete at 28 days is obtained as TS=0.4+0.055*CS with 'R^2' = 0.806 for concrete up-to one percentage of crimped steel fibre. For concrete up-to 1.5 percentage of crimped steel fibre, the relation obtained as TS=2.0+0.0538*CS with 'R^2'=0.846.
- The relation between compressive strength and flexural strength of copper slag fibre reinforced concrete at 28 days is obtained as FS = 2.84+0.045*CS with 'R^2'=0.86.
- The relation between compressive strength and UPV of copper slag fibre reinforced concrete at 28 days is obtained as UPV = 4+0.0118* CS with equal to 'R^2' = 0.74.
- The relation between compressive strength and rebound hammer number of copper slag fibre reinforced concrete at 28 days is obtained as RH=37.34+0.118*CS with 'R^2' equal to 0.76.

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