Flexural Behavior of SCC with Copper Slag as Partial Replacement of Fine Aggregate.

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***Abstract:** Natural fine aggregates are becoming more limited, and their production and consignment are turning out hard day by day. Therefore, the production of concrete needs to turn into eco-friendly construction practice. Self-Compacting Concrete (SCC) self-consolidates itself without any external vibration, and subsequently it quickens the concrete placement process and decreases the labor demands. In this study, the Flexural behavior of the SCC was studied. Reinforced SCC beam specimens were cast and tested in laboratories. The flexural behavior of SCC with copper slag as replacement for sand is delimited with the flexural test on beam specimens by examining the factors like deflection, flexural strength, crack pattern and strain pattern.*

***Keywords:** SCC, Copper slag, Flexural behaviour, Durability*

I. INTRODUCTION

SCC can be produced with the help of water reducing admixture like superplasticizer which helps in achieving a high value of slump. On the other hand, usage of superplasticizer may lead to segregation of concrete. To beat this condition, the content of the finer particles in the concrete may be enhanced and simultaneously the coarse aggregates which tend to block the flow of concrete through mass reinforcements may be minimized to achieve a better SCC. So, to produce a better SCC without segregation, the content of cement may be increased, but it may lead to excessive cost. Hence, the mineral admixtures such as silica fume or fly ash may be used to restrict the segregation.

Hwang and Laiw (et al.,1989) assessed the compressive strength effects of concrete with copper slag substituted for fine aggregate with various water-cement ratios. The research study clearly showed that when copper slag is adopted as an alternate for sand at 20 to 80%, concrete shows better performance than that of the control specimens. SCC is a pioneering throughout the world since it compacts by itself without introducing any vibratory compaction. The SCC can flow under its weight, entirely accommodate the formwork and it attains complete compaction even in overcrowded reinforcement. The use of Viscosity Modifying Agents gives better homogeneity, and it also restricts the concrete against segregation. SCC shows good fluidity and segregation resistance in its fresh state which results in a highly compacted concrete without any honey comb. Therefore, with these better qualities, the SCC can enhance the reliability and durability of reinforced concrete structures.

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This study proposes the behaviour of the SCC and RCC beams with M30 and M40 mixes by adding copper slag. The same study can be extended to higher grades of SCC mixes. Copper slag can be utilized in the manufacturing of bricks, hollow blocks and pavement blocks. Since copper slag has higher shear strength, it can also be utilized for soil stabilization. Along with mineral admixtures like fly ash and granulated blast furnace slag if copper slag is added in SCC, and its behaviour can be assessed for the strength and durability properties.

II. MATERIALS AND METHOD

The most extensively used material for construction in India, as well as the world, is concrete. Due to its versatility to mold to any shape and its strength and durability properties. The principal elements of Concrete are binding material (cement), fine aggregate (river sand) and coarse aggregate (stone chips) with water. Therefore, it is necessary to know the properties of the elements of concrete, since they are liable for the strength and durability aspects of concrete. Copper slag obtained from Sterlite Industries Limited, Tuticorin, Tamilnadu was employed in this study. The copper slag has a particle size distribution of that of the natural river sand. However, it was observed that copper slag has limited fine content than the natural river sand. At all proportions of copper slag replacement, the fine aggregate confines to Zone II as per IS: 383-1970.

Specimen Notations: The specimens were categorised in two ways; first, according to its grade of concrete and its percentage of copper slag replacement for sand. In this way, each specimen was categorised into five unique such as M30CS0, M30CS20, M30CS40, M30CS60, M30CS80 respectively for M30 grade SCC. Likewise, for M40 grade SCC the specimens were categorised as M40CS0, M40CS20, M40CS40, M40CS60, M30CS80 Thus actual notations provided for the specimens are as given in example below:

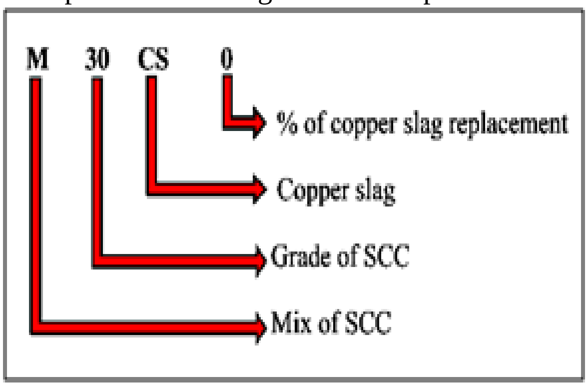

Fig:1: Specimen notation

Fig:2: Experimental setup

III. METHODOLOGY

Five SCC mixes including one control mix with several percentages of fine aggregate partly replaced by copper slag were made according to the condition specified in the EFNARC guidelines and reviewed whether it matches the standards for SCC. The flowchart (Fig:3) below represents the methodology of our project.

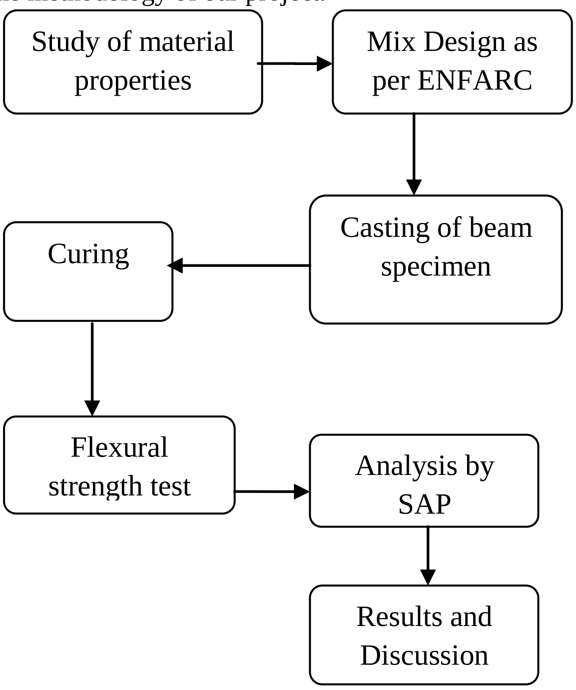

Fig: 3: Flowchart representation for the methodology

IV. TESTS CONDUCTED

The beams used in this study were 125mm x 200mm in cross section and 1800mm in length. Two 16 mm diameter bars were used for flexural reinforcement at the bottom, and two 12 mm rods were provided for top reinforcement. For the shear reinforcement of the beams, 8 mm diameter mild steel bars are adopted as stirrups at 150 mm centre to centre spacing. Beams were centred on a platform and levelled in both directions by adjusting the bearing plates. The load was applied gradually up to the failure of the specimen. The load was applied as two-point loads symmetrically placed from the mid-span. Three LVDT connected to a displacement sensor indicator were used to note the deflection at the three different points. Strains were calculated at Demec target points from 1 to 15 in both M30 and M40 beams for various loading conditions until failure. Readings of strain and deflection were taken at precise load interval. Crack generations were outlined with the help of a marker, and their ends were named corresponding to the load value. The crack was named as A, B, C and D etc. as per order of formation during testing.`

Flexural behaviour of RCC SCC beams cast with copper slag as a partial substitute for fine aggregate in concrete has been considered for this investigation. Simply supported RCC SCC beams were constrained to flexural failure by subjecting them with two-line loads.

The influence of copper slag replacement as a fine aggregate on the flexural strength of M30 and M40 grade SCC is presented in Table 1 and 2, which presents the average 7, 14 and 28-day flexural strength of SCC prism specimens. A total number of 45 SCC prism specimens were cast and examined. The flexural strength values of SCC mix with several proportions of copper slag examined are sketched in Figure 3 and 4 respectively.

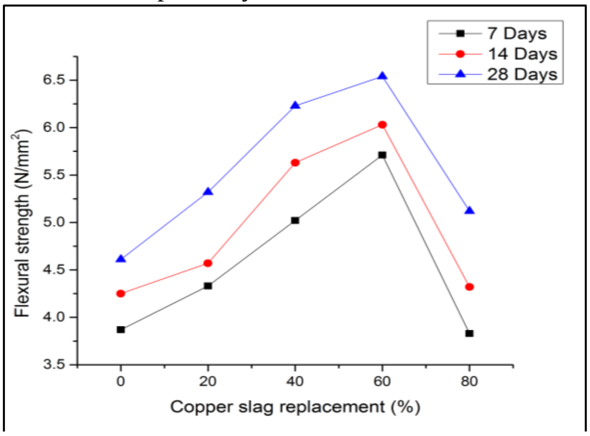

Figure 4 Flexural strength of SCC for M30

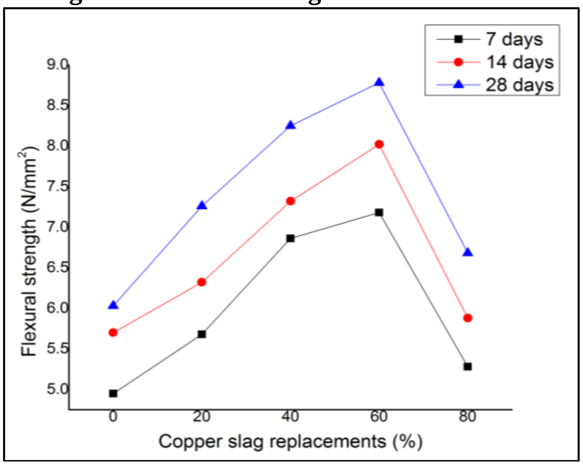

Figure 5 Flexural strength of SCC for M40

Table 1 Flexural strength of SCC for M30

Specimen	Flexural strength (N/mm^2)		
	7 days	14 days	28 days
M30CS0	3.87	4.25	4.61
M30CS20	4.33	4.57	5.32
M30CS40	5.02	5.63	6.23
M30CS60	5.71	6.03	6.54
M30CS80	3.83	4.32	5.12

Table 2 Flexural strength of SCC for M40

Specimen	Flexural strength (N/mm^2)		
	7 days	14 days	28 days
M40CS0	4.95	5.70	6.03
M40CS20	5.68	6.32	7.26
M40CS40	6.86	7.32	8.25
M40CS60	7.18	8.02	8.78
M40CS80	5.28	5.88	6.68

V. RESULTS AND DISCUSSION

The results revealed that the average flexural strength of copper slag replaced SCC specimens grew up to 60% replacement. However, for SCC mix with 80% replacement of copper slag for sand, the flexural strength reduced rapidly. The SCC Mix M30CS60 and M40CS60 produced the largest 28-day flexural strength of 6.54 N/mm2 and 8.78 N/mm2 respectively compared with 4.61 N/mm2 and 6.03 N/mm2 for the control mixture. However, the least flexural strength of 5.12 N/mm2 and 6.68 N/mm2 were obtained for the SCC mix M30CS80 and M40CS80. The reason for the reduction in flexural strength at a higher percentage of copper slag is because of the glassy surface texture of copper slag particles which has an adverse effect on the cohesion. This causes the development of internal voids and capillary channels within the SCC, resulting a decline in its quality. Hence, the flexural strength of SCC with lesser copper slag volume can be enhanced by the positive influence of copper slag, whereas if copper slag content exceeds 80%, the flexural strength of SCC reduces considerably with a reduction in cohesion governed by copper slag.

The table 3 and 4 gives the flexural behaviour of the specimen tested. The results of the deflection behaviour of the SCC beam samples are presented in Table 5 to 8.

Table 3 Flexural Behavior test results for M30 grade SCC

Specimen	Load at First Crack in kN	Deflection at First Crack in mm			Ultimate Load in kN	Deflection at Ultimate Load in mm			Mode of Failure
		L/3	L/2	L/3		L/3	L/2	L/3	
M30CS0	22	1.25	1.53	1.35	68	10.01	11.64	10.27	Flexure
M30CS20	23	1.51	1.73	1.58	76	11.77	13.68	11.23	Flexure
M30CS40	24	1.79	1.836	1.78	83	12.32	14.12	11.94	Flexure
M30CS60	26	2.46	2.73	2.52	88	15.13	17.74	15.65	Flexure
M30CS80	30	2.66	2.96	2.64	94	16.32	18.15	16.5	Flexure

Table 4 Flexural Behaviour test results for M40 grade SCC

Specimen	Load at First Crack in kN	Deflection at First Crack in mm			Ultimate Load in kN	Deflection at Ultimate Load in mm			Mode of Failure
		L/3	L/2	L/3		L/3	L/2	L/3	
M30CS0	24	2.13	2.19	2.19	84	12.30	13.78	12.48	Flexure
M30CS20	30	2.55	2.94	2.65	94	14.29	15.74	14.19	Flexure
M30CS40	33	2.71	2.95	2.68	105	15.51	19.92	19.57	Flexure
M30CS60	41	2.99	3.85	2.67	113	18.2	20.34	18.2	Flexure
M30CS80	48	3.46	4.05	3.68	125	19.54	21.8	19.34	Flexure

Crack patterns and crack width profile is drawn as per actual observations during formation of cracks in beam. Several data concerning the number of cracks, the width of cracks, zone in which cracks are developed, the length of cracks and angle of cracks with horizontal, etc., are recorded for various CS SCC beams. Each above data is necessary for analysis and study of cracks behaviour of self-compacting concrete beams. During current investigations, determination of the width of micro cracks was regularly done using a hand microscope. Hand microscope allows the image to be focused by turning the knob at a site of the microscope with eyepiece graticule rotated through 360° to align with the direction of the cracks under examinations. Similarly, Table 9 show the crack patterns and crack width profile.

From the analyses, the load-deflection relationships until failure are obtained and compared with the experimental results. Validation of experimental results was also done using SAP 2000. The experimental results when compared to analysis using SAP 2000 found to vary between 4.55% and 6.67% for load at first crack and between 7.35% and 9.57% for ultimate load. Table 10,11 show the comparison of the first crack load and ultimate loads obtained from the experimental and analytical results.

VI. . CONCLUSION

From the flexural behaviour test results, it was observed that the slag replaced SCC RCC Beams took higher load to attain the first crack than that of the control SCC. Ultimate load of the RCC SCC beam with higher percentage replacement of copper slag is higher than the control RCC SCC beam. All the beam specimens failed due to flexure. Therefore, it can be concluded that, when higher copper slag is replaced for sand in SCC the RCC flexural strength has increased. From the crack pattern and crack width profile behaviour of RCC SCC beam test results, following observations may be made. The control SCC and CS20 specimens failed due to flexure only whereas the CS40, CS60 and CS80 of M30 grade SCC specimens failed due to the combined effect of flexure and shear.

In the case of M40 grade, SCC all the RCC beams including the control SCC and copper slag replaced specimens failed due to flexure only which indicates that for M40 grade SCC beams have better stiffness and hence lesser number of shear cracks are formed. The maximum crack width in the control SCC for M30 grade was 3.11mm, which is higher compared to the other Copper slag replaced specimens where the maximum crack width for CS20, CS40, CS60 and CS80 for M30 grade SCC was 1.32mm, 1.21mm, 1.91mm and 1.51mm.

The maximum crack width in the M40CS20 SCC was 2.61mm, which is higher compared to the other Copper slag replaced specimens where the maximum crack width for CS0, CS40, CS60 and CS80 for M40 grade SCC was 1.12mm, 1.41mm, 0.715mm and 0.915mm. Maximum crack width at 40% replacement of copper slag is found to be least (1.21mm) in the M30 grade SCC beam specimens whereas for M40 grade SCC beams the least maximum crack width was 0.715mm at 60% replacement of copper slag.

Therefore, it is concluded that addition of copper slag in SCC RCC beams has better crack pattern and crack width than that of a control SCC beams. The results obtained from finite element models developed by SAP2000 software indicated a difference between 7.35 and 9.57% for the ultimate load and a difference between 7.56 and 11.18% for the mid span deflection at ultimate load when compared with the experimental results.

Table 5 Deflection behaviour of M30CS0

S.No	Load (kN)	Deflection(mm)		
		L/3 Left	L/2	L/3 Right
1	0	0	0	0
2	1	0.26	0.287	0.28
3	6	1.41	1.554	1.49
4	9	2.03	2.236	2.09
5	22	2.55	2.831	2.65
6	26	3.53	3.908	3.63
7	31	4.37	4.822	4.47
8	37	5.09	5.63	5.24
9	43	5.44	6.019	5.61
10	47	5.69	6.319	5.9
11	51	5.74	6.373	5.92
12	55	6.39	7.188	6.61
13	59	7.09	8.126	7.41
14	61	7.93	9.029	8.14
15	64	8.75	10.069	8.99
16	66	9.47	10.929	9.68
17	68	10.01	11.639	10.27

Table 6 Deflection behaviour of M30CS80

S.No	Load (kN)	Deflection (mm)		
		L/3 Left	L/2	L/3 Right
1	0	0	0	0
2	5	0.16	0.19	0.19
3	8	0.45	0.52	0.5
4	18	0.96	1.13	1.05
5	24	1.47	1.73	1.62
6	28	1.62	1.89	1.75
7	30	1.66	1.96	1.84
8	32	1.71	2.01	1.86
9	33	1.73	2.05	1.91
10	37	2.35	2.5	1.952
11	55	3.46	3.87	3.56
12	65	4.04	4.47	4.1
13	74	4.58	5.14	4.73
14	78	5.34	6.13	5.52
15	85	7.15	8.52	8.12
16	89	9.57	11.07	10.26
17	93	11.6	13.52	12.75

Table 7 Deflection behaviour of M40CS0

S.No	Load (kN)	Deflection (mm)		
		L/3 Left	L/2	L/3 Right
1	1	0.1144	0.09	0.1
2	3	0.208	0.19	0.14
3	4	0.2704	0.27	0.3
4	5	0.3744	0.36	0.43
5	7	0.5408	0.5	0.58
6	8	0.6864	0.64	0.74
7	10	0.9152	0.85	0.93
8	14	0.9048	0.87	0.98
9	24	2.132	2.19	2.19
10	37	3.5048	3.09	2.89
11	46	4.2848	4.47	4.32
12	53	4.9608	5.12	4.85
13	58	6.448	6.82	6.33
14	67	8.9752	9.84	8.85
15	73	10.3896	11.58	10.62
16	80	11.2944	12.208	11.5
17	84	12.3032	13.78	12.48

Table 8 Deflection behaviour of M40CS

S.No	Load (kN)	Deflection (mm)		
		L/3 Left	L/2	L/3 Right
1	0	0	0	0
2	0	0.0336	0.04	0.02224
3	1	0.056	0.11	0.01112
4	2	0.1008	0.14	0.12232
5	3	0.1568	0.2	0.18904
6	3	0.2016	0.29	0.2224
7	5	0.28	0.34	0.31136
8	9	0.4928	0.54	0.52264
9	16	0.8064	0.85	0.85624
10	26	1.3552	1.44	1.4456
11	36	2.016	2.14	2.14616
12	48	2.8672	3.05	3.98096
13	61	3.7072	3.79	3.892
14	73	4.536	3.92	4.73712
15	83	5.4208	4.78	5.60448
16	88	7.7952	5.68	7.71728

17	93	11.6592	8.24	12.30984

Table 9 Crack patterns and crack width profile for M30CS0

Crack Name	Load	Zone	Distance From		Crack Length (mm)	Crack Width (mm)	Angle (°)	Max Width (mm)	Type of failure
	kN		LHS mm	RHS mm					
A	58	Flexure	540	960	20	3.11	68.19	3.11	F
A1	66	Flexure	576	924	95	2.60	106.6		
A2	68	Flexure	555	945	82	2.10	53.13		
A3	68	Flexure	545	955	63	1.18	41		
B	37	Flexure	620	880	20	1.424	90	1.424	F
B1	58	Flexure	630	870	81	0.615	88		
B2	66	Flexure	640	860	38	0.015	81.25		
C	22	Flexure	750	750	20	2.7	90	2.7	F
C1	37	Flexure	723	777	88	0.7	119		
C2	51	Flexure	705	795	60	0.015	154		
D	37	Flexure	832	668	20	1.20	46	1.20	F
D1	51	Flexure	857	643	81	0.6	45		
D2	58	Flexure	890	610	49	0.011	39.28		
D3	68	Flexure	855	645	42	0.015	130		
F	58	Flexure	1050	450	20	1.23	68.19	1.5	F
F1	66	Flexure	1150	350	66	1.5	89		
F2	68	Flexure	995	505	56	1.1	130		

Table 10 Comparison of Load at first crack-SAP Vs Experimental results.

Specimen	Load at First Crack kN		
	SAP	Experimental	% Difference
M30CS0	21	22	4.55
M30CS20	22	23	4.35
M30CS40	23	24	4.17
M30CS60	25	26	3.85
M30CS80	28	30	6.67

Table 11 Comparison of Ultimate load: SAP Vs Experimental results.

Specimen	Ultimate Load (kN)		
	SAP	Experimental	% Difference
M30CS0	63	68	7.35
M30CS20	70	76	7.89
M30CS40	75	83	9.64
M30CS60	80	88	9.09
M30CS80	85	94	9.57

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