Flexural behaviour of hybrid fibre reinforced concrete beams made with various packing factors and fine to total aggregate ratio

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Abstract. The objective of this study is to investigate the flexural behavior of M30 grade PSCC, GFRSCC, SFRSCC and HFRSCC beams made with PF=1.12 and s/a=0.53 and PF=1.14 and s/a=0.57 to understand the effect of copper slag as partial replacement of fine aggregate on its deflection characteristics and cracking behaviour. The yield and ultimate load taken by HFRSCC beams made with optimum PF and s/a ratios are higher than the conventional RCC beam elements. The deflections at centre at failure in HFRSCC beams made with optimum PF and s/a ratios were more than that of conventional beams. This shows improvement in ductility of HFRSCC beams. First crack formation was delayed in M30 grade HFRSCC beams due to dense micro structure with low pore fraction and reduced pore size due to which fatigue strength is increased which in turn increases the time taken for first crack occurrence and thereby increasing the load carrying capacity. The deflection at the mid span decreased in HFRSCC beams which shows that the flexural stiffness of the elements increases thereby reducing the structural member's deformability, increasing strength and hence controlling deflection.

1 Introduction

Self-Compacting concrete, originally developed in Japan has given answers to many mechanical and durability problems and enhanced the strength and durability characteristics of concrete. Introduction of fibers in SCC has further improved its characteristics like crack, resistance, plasticity, impact resistance, durability etc., The Studies on Stress-Strain behavior of concrete are essential in determining the parameters like energy absorption, toughness, plasticity index and they are very useful in design of structures using such concretes. Further modeling the stress-strain behavior helps in predicating their behavior. As only scant work is reported on the mathematical modeling of the stress strain behavior SCC and f FRSCC, an attempt is made to make M30 grade SCC, FRSCC, developed two mathematical models for stress-strain behavior after going thoroughly through different models for stress- strain behavior developed for vibrated concrete. The two models were compared for their suitability for SCC and FRSCC.

2 Methodology

The goal of this research is to look at the flexural behaviour of M30 grade PSCC, GFRSCC, SFRSCC, and HFRSCC beams with PF=1.12 and s/a=0.53 and PF=1.14 and s/a=0.57 to see how copper slag as a partial substitute for fine aggregate affects deflection and cracking behaviour. According to IS: 9399 – 1979, the beams are evaluated under symmetrical two-point flexural stress.

According to Nan Su's recommended criteria for SCC, the ideal packing factor and fine to total aggregate ratio are shown in Table 1. Different combinations of packing factors (PF) (ranging from 1.12 to 1.18) and fine to total aggregate ratios (s/a) (ranging from 0.50 to 0.57) were tested, and it was discovered that the PF & s/a combinations of 1.12 & 0.53 and 1.14 & 0.57 were the most effective, resulting in the highest

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compressive strengths, which can be attributed to high particle packing densities in SCC mixes.

Table 1. Optimum PF and s/a ratio combinations for M30 grade PSCC mixes

Mix Type	PF	s/a ratio	Compressive Strength (MPa) at 28 days
M30PSCC1	1.12	0.53	40.35
M30PSCC2	1.14	0.57	41.03

Table 2. Dosage of percentage of glass fibre for M30 grade SCC mixes made with optimum combinations of PF and s/a ratios

Type	Percentage of Glass fibre by volume of Concrete	Glass fibre (kg/m^3)	Compressive Strength (MPa)
M30GFRSCC PF=1.12 and s/a=0.53	0.05	1.33	44.16
M30GFRSCC PF=1.14 and s/a=0.57	0.05	1.33	45.05

Table 3. Dosage of percentage of steel fibre for M30 grade SCC mixes made with optimum combinations of PF and s/a ratios

Type	Percentage of Glass fibre by volume of Concrete	Glass fibre (kg/m^3)	Compressive Strength (MPa)
M30GFRSCC PF=1.12 and s/a=0.53	1.0	78.50	43.40
M30GFRSCC PF=1.14 and s/a=0.57	1.0	78.50	44.27

Table 4. Fresh properties for M30 PSCC, SFRSCC, GFRSCC and HFRSCC mixes

	Optimum PFs and s/a ratios	Fly Ash %	Paste volume	Fresh properties					
				Slump (650-800 mm)	J-Ring (0-10mm)	V-Funnel time	V-T5 (6-15 sec)	U-Box (0-30 mm)	L-Box (0.8-
M30PSCC	PF=1.12 and s/a=0.53	40.47	28.67	752	5	7	9	21	0.93
M30SFRSCC		40.47	28.67	670	9	10.24	12.27	29	0.82
M30GFRSCC		40.47	28.67	714	7	9.41	10.93	26	0.90
M30HFRSCC		40.47	28.67	708	8	9.81	11.44	28	0.87
M30PSCC	PF=1.14 and s/a=0.57	38.33	27.59	752	7	8	12	21	0.92
M30SFRSCC		38.33	27.59	682	11	9.30	13.81	29	0.83
M30GFRSCC		38.33	27.59	742	9	8.73	11.68	24	0.88
M30HFRSCC		38.33	27.59	727	10	8.90	12.55	28	0.86

Addition of fibre reduces workability in SCC mixes. Workability is reduced drastically in SFRSCC when compared to GFRSCC. In HFRSCC mixes, due to addition of steel and glass fibres workability is affected which can be improved using fly ash and super plasticizers

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Table 5. Beam types and designations

Designation of beam	Mix type
Beam 1	M30PSCC PF=1.12 and s/a=0.53
Beam 2	M30SFRSCC PF=1.12 and s/a=0.53
Beam 3	M30GFRSCC PF=1.12 and s/a=0.53
Beam 4	M30HFRSCC PF=1.12 and s/a=0.53
Beam 5	M30PSCC PF=1.14 and s/a=0.57
Beam 6	M30SFRSCC PF=1.14 and s/a=0.57
Beam 7	M30GFRSCC PF=1.14 and s/a=0.57
Beam 8	M30HFRSCC PF=1.14 and s/a=0.57
Under reinforced M30 beams of size 1200 mm x 100 mm x 150 mm Grade of Steel -Fe 415 Tensile Reinforcement -2 No - 10mmφ Tor steel bars Nominal Compression Reinforcement -2 No - 10mm φ MS bars Shear Reinforcement -2 legged - 8mm φ @200mm c/c	

Experimental research revealed that 0.05 percent glass fibre by volume of concrete and 1.0 percent steel fibre by volume of concrete are the best doses of glass and steel fibres to utilise in M30 SCC mixtures. 0.05 percent glass fibre and 1.0 percent steel fibre by volume of concrete are utilised in hybrid fibre reinforced SCC mixtures.

3 Load – deflection relations

The goal of this research is to look at the flexural behaviour of M30 grade PSCC, GFRSCC, SFRSCC, and HFRSCC beams with PF=1.12 and s/a=0.53 and PF=1.14 and s/a=0.57 to see how copper slag as a partial substitute for fine aggregate affects deflection and cracking behaviour.

Table 6. Load deflections of M30 grade PSCC, GFRSCC, SFRSCC and HFRSCC beams made with PF=1.12 and s/a=0.53

Beam 1		Beam 2		Beam 3		Beam 4	
Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
5	0.22	5	0.18	5	0.16	5	0.15
10	0.52	10	0.37	10	0.35	10	0.34
15	0.78	15	0.69	15	0.62	15	0.58
20	1.26	20	1.01	20	0.99	20	0.97
25	1.68	25	1.50	25	1.43	25	1.35
30	2.16	30	2.06	30	1.94	30	1.81
35	2.67	35	2.50	35	2.22	35	2.07
40	3.19	40	2.86	40	2.69	40	2.49
45	3.78	45	3.60	45	3.47	45	2.98
50	4.62	50	4.39	50	3.75	50	3.65
54	6.81	55	5.76	55	4.93	55	4.39
		60	5.93	60	5.28	60	5.10
		61	7.95	65	6.53	65	6.40
				68	10.27	70	6.57
						74	11

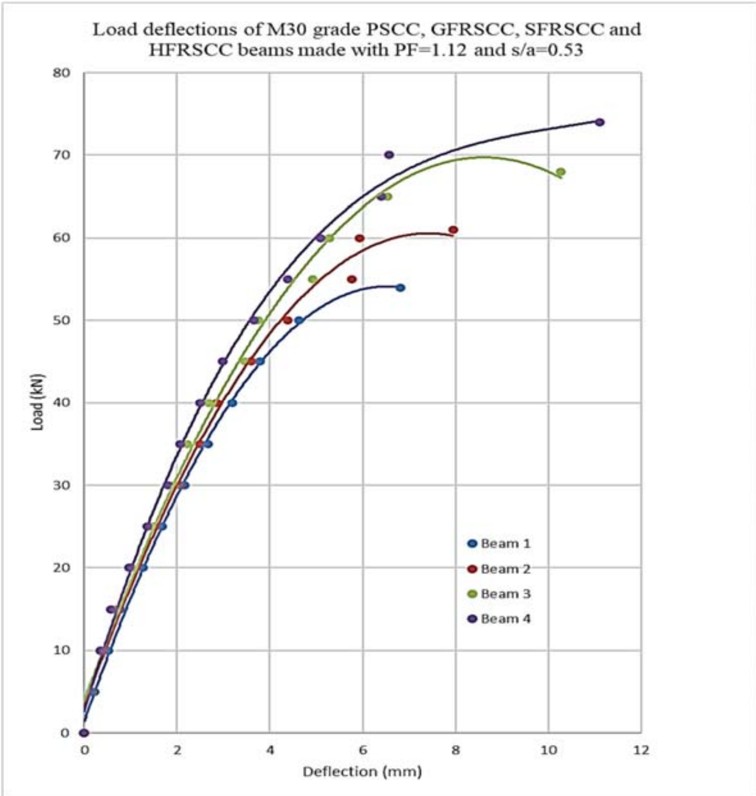

Fig.1. Load deflections curves of M30 grade PSCC, GFRSCC, SFRSCC and HFRSCC beams made with PF=1.12 and s/a=0.53

Table 7. Load deflections of M30 grade PSCC, GFRSCC, SFRSCC and HFRSCC beams made with PF=1.14 and s/a=0.57

Beam 5		Beam 6		Beam 7		Beam 8	
Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
5	0.21	5	0.17	5	0.15	5	0.14
10	0.49	10	0.35	10	0.33	10	0.32
15	0.74	15	0.66	15	0.59	15	0.55
20	1.20	20	0.96	20	0.94	20	0.92
25	1.60	25	1.43	25	1.36	25	1.28
30	2.05	30	1.96	30	1.84	30	1.72
35	2.54	35	2.38	35	2.11	35	1.97
40	3.03	40	2.72	40	2.56	40	2.37
45	3.59	45	3.42	45	3.30	45	2.83
50	4.39	50	4.17	50	3.56	50	3.47
55	6.47	55	5.47	55	4.68	55	4.17
57	6.93	60	5.63	60	5.02	60	4.85
		65	7.55	65	6.20	65	6.08
		66	8.24	70	9.76	70	6.24
				73	10.89	75	10.55
						78	11.46

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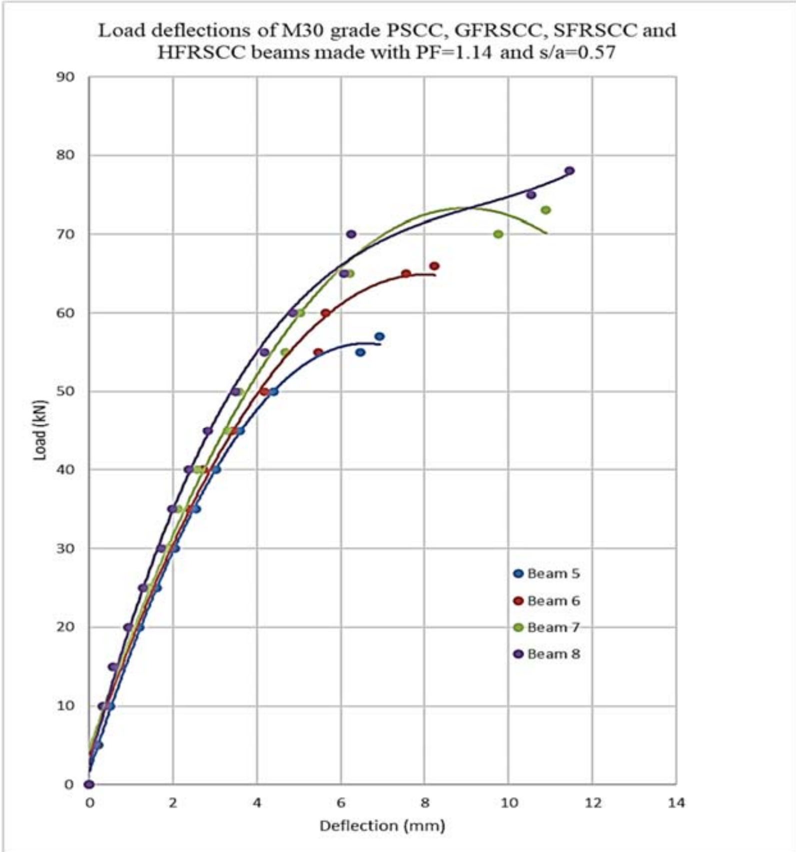

Fig.2. Load deflections curves of M30 grade PSCC, GFRSCC, SFRSCC and HFRSCC beams made with PF=1.14 and s/a=0.57

Table 8. Flexural Characteristics of M30 grade PSCC, GFRSCC, SFRSCC and HFRSCC beams made with various PF and s/a ratios

Beam Designation	M30 Grade Reference Concrete			
	Load at first crack occurrence (kN)	Load at Failure (kN)	Mid-deflection (mm)	Width of crack at failure (mm)
Beam 1	24	55	6.81	0.98
Beam 2	32	62	7.95	0.90
Beam 3	37	69	10.27	0.80
Beam 4	44	75	11.10	0.80
Beam 5	32	58	6.93	0.98
Beam 6	33	67	8.94	0.90
Beam 7	39	74	10.89	0.79
Beam 8	48	79	11.46	0.75

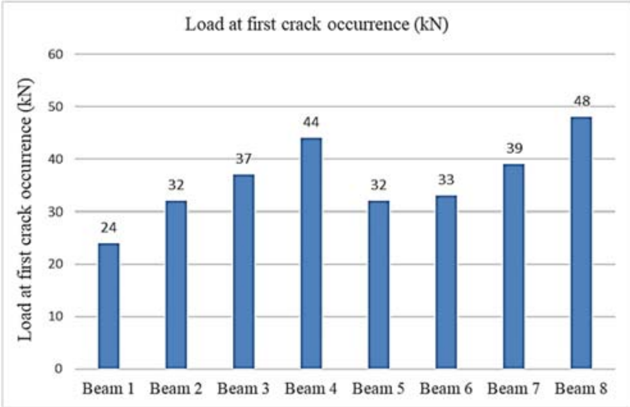

Fig.3. Load at first crack of M30 grade PSCC, GFRSCC, SFRSCC and HFRSCC beams made with various PF and s/a ratios

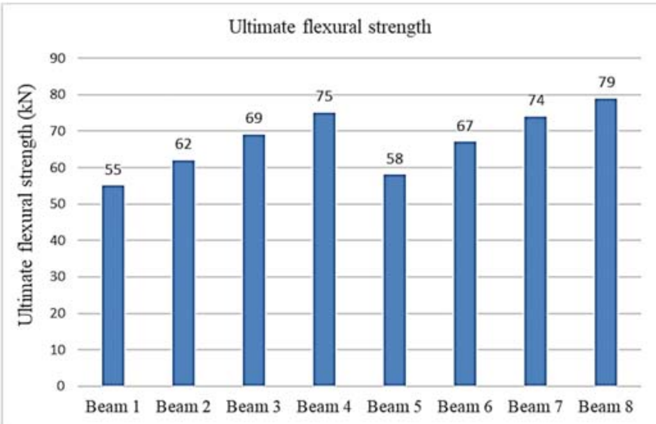

Fig.4. Ultimate flexural strength of M30 grade PSCC, GFRSCC, SFRSCC and HFRSCC beams made with various PF and s/a ratios

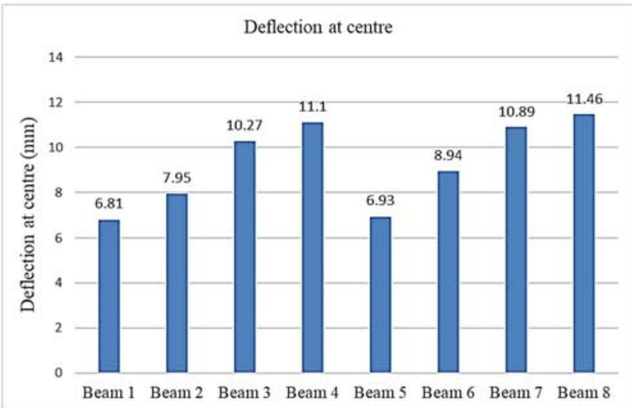

Fig.5. Deflection at centre of M30 grade PSCC, GFRSCC, SFRSCC and HFRSCC beams made with various PF and s/a ratios

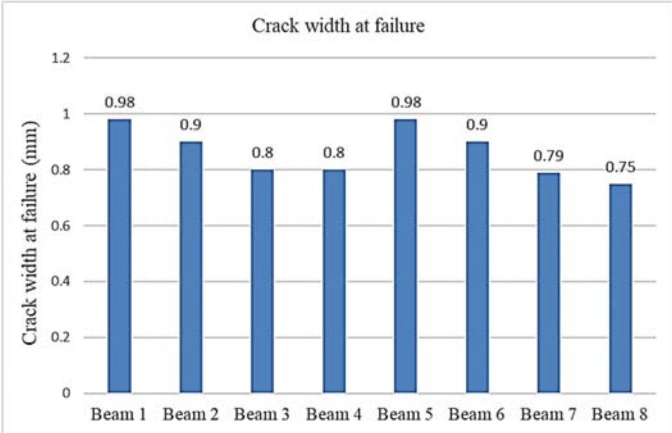

Fig.6. Crack width at failure of M30 grade PSCC, GFRSCC, SFRSCC and HFRSCC beams made with various PF and s/a ratios

4 Conclusions

Flexural parameters such as load at first crack, ultimate flexural strength, deflection at the centre, and crack width at failure are assessed using load–deflection plots. From these obtained results the following observations are made:

1. The yield and ultimate load taken by HFRSCC beams made with optimum PF and s/a ratios are higher than the conventional RCC beam elements.
2. The deflections at centre at failure in HFRSCC beams made with optimum PF and s/a ratios were more than that of conventional beams. This shows improvement in ductility of HFRSCC beams
3. In HFRSCC beams, using hybrid fibres enhances the load at first crack, ultimate flexural strength, and deflection at the centre of failure, while also reducing crack width.
4. The occurrence of the first crack was delayed in M30 grade HFRSCC beams due to a dense microstructure with low pore fraction and reduced pore size, resulting in increased fatigue strength, which in turn increases the time taken for the occurrence of the first crack and thus increases the load carrying capacity.
5. The mid-span deflection of HFRSCC beams reduced, indicating that the components' flexural stiffness increased, lowering the structural member's deformability, improving strength, and therefore regulating deflection.

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