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Investigations on Mechanical Properties of Hybrid Fibre Reinforced High Strength Concrete

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Abstract

Concrete with a single type of fiber may improve the desired properties to a limited level. A composite is termed as hybrid, if two or more types of fibers are rationally combined to produce a composite that derives benefits from each of the individual fibers. This paper focuses on the experimental investigation of high strength concrete with steel fibers and combination of steel and polyolefin fibers (hybrid) by testing of compressive strength, splitting tensile strength of cylinders and flexural strength of prisms. For this ACI 211-4R-93 guide line was followed to design the high strength concrete of grade M60. Each test the high strength concrete specimens were cast and treated as control specimens, other specimens were cast high strength concrete added with steel fibers at the volume fraction of 0.5%, 1.0%, 1.5%, and 2.0%. At each volume fraction Steel – polyolefin fibers were added at 80% - 20% and 60% - 40% combinations. Test results showed that the compressive strength, splitting tensile strength and modulus of rupture improved with increasing volume fraction. Regression analyses were done to predict the values of compressive strength, splitting tensile strength and modulus of rupture of all parameters. The prediction values were matching with the experimental results.

Keywords: High strength concrete, steel fibers, polyolefin fibers, hybrid fibers, Regression analysis.

1. Introduction

High-strength and High-performance concrete are being widely used throughout the world and to produce them it is necessary to reduce the water/binder ratio and increase the binder content. High-strength concrete means good abrasion, impact and cavitations resistance. Using High strength concrete in structures today would result in economical advantages. Most applications of high strength concrete to date have been in high-rise buildings, long span bridges and some special structures. Major application of high strength concrete in tall structures have been in columns and shear walls, which resulted in decreased dead weight of the structures and increase in the amount of the rental floor space in the lower stories. (V. Bhikshma 2009) Fiber - reinforced cement-based composites which possess the unique ability to flex and self-strengthen before fracturing. This particular class of concrete was developed with the goal of solving the structural problems inherent with today's typical concrete, such as its tendency to fail in a brittle manner under excessive loading and its lack of long-term durability. To improve the ductility of High strength concrete, a strategy is to introduce steel or polymeric fibers in high strength which results in development of near isotropic material with reasonable tensile strength and greater toughness which prevents the limitation and propagation of cracks. It has also been shown recently that by using the concept of hybridization with two different fibers incorporated in a cement matrix, the hybrid composite can offer more attractive engineering properties because the presence of one fiber enables the more efficient utilization of the potential properties of the other fiber. However, the hybrid composites studied by previous researchers were focused on hybridization of steel, polypropylene and carbon fibers. The mechanical properties of hybridization of steel and polyolefin fibers in high strength concrete at different volume fraction have been studied previously are available limited. Therefore the objective of this paper is to determine the basic properties of hybrid fiber reinforced high strength concrete in terms of compressive, splitting tensile and flexural tests in comparison with the steel fiber reinforced high strength concrete and plain high strength concrete**.**

2 Experimental Programs
2.1 Materials

The cement used in concrete mixes was ordinary Portland cement 53 grade as per IS 12269- 1987. The fine aggregate used was local river sand with specific gravity of 2.40. The coarse aggregate was crushed stone with size of 10 mm and specific gravity of 2.74 Silica fume obtained from Elkem Materials which improved concrete properties in fresh and hardened states. To improve the workability of concrete, a high – range water reducing admixture Gelenium B233 was used. The fibers used in the study were Hooked end steel as shown in Fig. 1, Polyolefin straight as shown in Fig. 2, the properties were given by the manufacturers as shown in Table 1.The high strength concrete mix proportions were designed by using ACI 211-4R-1993 guide lines as shown in Table 2, the material proportions are same for all test, the volume fraction of fibers only vary and consider as study parameter.

Fig. 1 Hooked end steel fiber

Fig. 2 Polyolefin straight fiber

Table 1. Properties of Fiber

Fibre Properties	Fiber Details	
	Polyolefin	Steel
Length (mm)	54	35
Shape	Straight	Hooked at ends
Size / Diameter (mm)	1.22 x 0.732 mm	0.6 mm
Aspect Ratio	44.26	58.33
Density (kg / m^3)	920	7850
Specific Gravity	0.90-0.92	7.8 g/cc
Young's Modulus (GPa)	6	210
Tensile strength (MPa)	550	>1100 Mpa

Table 2. Concrete Mix Proportions for 1m^3 Concrete

Materials	Quantity in kg
Cement	468.48
Silica Fume	43.52
Fine Aggregate	594.40
Coarse Aggregate	1037.22
HRWR	6.40
Water	159.50

2.2 Preparation of test specimens:

For compressive strength, splitting tensile strength 100 x 300 mm cylinders, prisms of size 100 x 100 x 500 mm were used for flexural strength. In the preparation of concrete, coarse aggregate, fine aggregate cement and silica fume were initially mixed in dry state .Next the fibers were added manually and maintain uniform distribution by proper dry mixing operations. Then Water, the high range water reducing admixture Gelenium B 233 already mixed with 50% of required quantity water was added into the dry mix. The well prepared mix of High strength concrete, Steel fiber reinforced concrete and Hybrid fiber reinforced concrete specimens were cast with above moulds with proper compaction. The specimens were remolded after 24 hours and then placed in a curing tank for 28 days.

2.3 Testing Procedure

The compressive strength test was carried out as per ASTM C 39. The cylinders were loaded at the rate of 0.3N/mm^2/s until failure. The Splitting tensile strength test was conducted as per ASTM C 496. The rate of loading for the test was 0.9 N/mm^2 /s. The flexural strength test was carried out as per ASTM C 78. All tests were conducted using 200 T capacity of compression testing machine. Table 3 Shows the designation of the specimens and its strength test results on high strength concrete (HSC) and the steel fibers high strength concrete (HS0.5 -S100/P0 to HS 2.0 -S100/P0) and Hybrid fiber high strength concrete (HS0.5- S80 P20, HS0.5 -S60 P40 to HS2.0-S80/P20, HS2.0 -S60/P40 .).

3 Test Results and Discussion

The effect of fiber volume on compressive strength of High strength concrete, steel fiber reinforced high strength concrete and hybrid fiber reinforced high strength concrete at each volume fraction as shown in (Fig. 3). The compressive strength effectiveness ranged from2.29% to 11.13% at the volume fraction of 0.5% to 2.0% and no significant improvement at 2.0% volume fraction of steel fibers compared to 1.5% volume fraction. Strength effectiveness of hybrid fiber combination S80- P20 ranged from 1.47 %.to 9.98 %., fiber combination S60 –P40 ranged from 0.65 % to 9.93%. Improvement in compressive strength of hybrid fiber high strength concrete was less than the steel fiber high strength concrete.

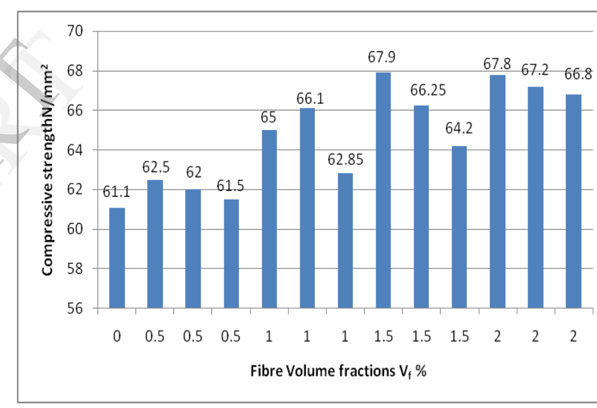

Figure 3 Effects fiber volume on Compressive strength

The splitting tensile strength of all the fibrous concrete in this investigation was significantly higher than that of plain concrete even at volume fraction as low as 0.5%. The development of splitting tensile strength of Steel fiber reinforced high strength concrete and hybrid fiber reinforced high strength concrete at various volume fractions is shown in (Fig. 4).

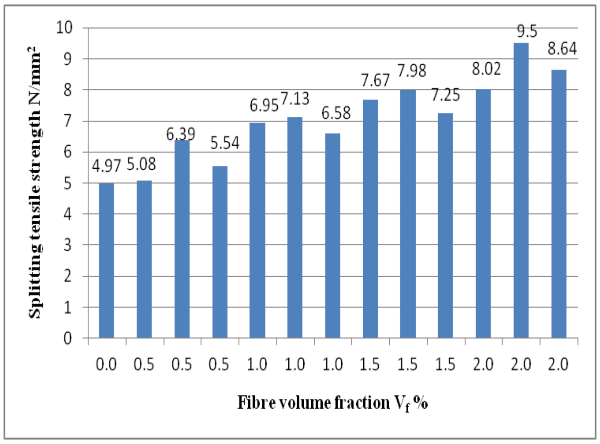

Figure 4 Effect of fiber volume on Splitting tensile strength

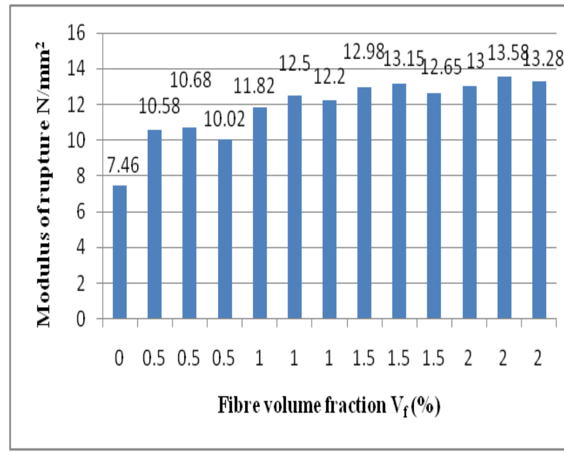

Figure 5 Effects of fiber volume fraction on Modulus of rupture

Compared to High strength concrete, the strength improved with increasing the volume fraction. From the strength effectiveness in Table 3, the improvement started from 2.21 % to 61.36 % at the volume fraction of 0.5% to 2.0% in case of steel fiber reinforced high strength concrete., 22.87 to 91.14 % in case of Hybrid fiber S80 –P20 composition 11.46% to 73.84% in case of S60 – p40 composition. Improvement in splitting tensile strength of Hybrid fiber HS2.0 S80 – P20 combination gave better strength compare with High strength concrete and steel fiber reinforced high strength concrete.

The Modulus of rupture for high strength concrete steel fiber reinforced high strength concrete and hybrid fiber reinforced high strength concrete is shown in Fig.5.

strength effectiveness in Table 3 indicates that modulus of rupture values of all fibrous concrete were significantly higher than that of high strength control concrete. The strength improved with increasing the volume fraction.

From the strength effectiveness in Table 3, the improvement started from 41.82 % to 76.27 % at the volume fraction of 0.5 % to 2.0 % in case of Steel fiber reinforced high strength concrete , 43.56 to 82% in case of S80 – P20 composition and 34.32% to 78 % in case of S60 % to 40% composition. The composition HS2.0 -S 80 / P20 strength was more than the other fibrous composition of high strength concrete.

Table 3. Test Results

Specimen Name	Volume Fraction V_f (%)	compressive strength N/mm²		Splitting tensile strength N/mm²		Modulus of rupture N/mm²	
		Measured value	Strength effectiveness (%)	Measured value	Strength Effectiveness (%)	Measured Value	Strength effectiveness (%)
HSC	0	61.1	0	4.97	0	7.46	0
HS0.5 S100/P0	0.5	62.5	2.29	5.08	2.21	10.58	41.82
HS0.5 S80 P20	0.5	62	1.47	6.39	8.57	10.68	43.16
HS0.5 S60 P40	0.5	61.5	0.65	5.54	11.46	10.02	34.32
HS1.0 S100 P0	1	65	6.38	6.95	39.83	11.82	58.44
HS1.0 S80/P20	1	66.1	8.18	7.13	45.47	12.5	67.56
HS1.0 S60/P40	1	62.85	2.86	6.58	32.39	12.2	63.75
HS1.5 S100/P0	1.5	67.9	11.13	7.67	54.32	12.98	73.99
HS1.5 S80/P20	1.5	66.25	8.43	7.98	60.56	13.15	76.27
HS1.5 S60/P40	1.5	64.2	5.07	7.25	45.87	12.65	69.57
HS2.0 S100/P0	2	67.8	10.97	8.02	61.36	13	76.27
HS2.0 S80/P20	2	67.2	9.98	9.5	91.14	13.58	82
HS2.0 S60/P40	2	66.8	9.33	8.64	73.84	13.28	78

Table 4. Comparison of measured and Predicted values of strengths

V_f (%)	Compressive Strength N/mm^2			Splitting Tensile Strength N/mm^2			Modulus of Rupture N/mm^2		
	Measured	Predicted	Error (%)	Measured	Predicted	Error (%)	Measured	Predicted	Error (%)
0.0	61.1	60.52	-0.94	4.97	4.86	-2.12	7.46	7.65	2.53
0.5	62.5	62.48	-0.02	5.08	5.17	1.77	10.58	8.63	-18.41
0.5	62	62.48	0.78	6.39	5.47	-14.26	10.68	9.52	-10.85
0.5	61.5	62.48	1.60	5.54	5.78	4.51	10.02	10.32	2.94
1.0	65	64.28	-1.09	6.95	6.10	-12.17	11.82	11.01	-6.81
1.0	66.1	64.28	-2.74	7.13	6.41	-9.96	12.5	11.62	-7.04
1.0	62.85	64.28	2.28	6.58	6.73	2.41	12.2	12.13	-0.56
1.5	67.9	65.91	-2.91	7.67	7.06	-7.95	12.98	12.55	-3.33
1.5	66.25	65.91	-0.50	7.98	7.38	-7.46	13.15	12.87	-2.14
1.5	64.2	65.91	2.67	7.25	7.71	6.35	12.65	13.09	3.52
2.0	67.8	67.38	-0.61	8.02	8.03	0.24	13	13.23	1.75
2.0	67.2	67.38	0.27	9.5	8.37	-11.87	13.58	13.27	-2.31
2.0	66.8	67.38	0.87	8.64	8.70	0.76	13.28	13.21	-0.53

4 Regression Analyses

In this study regression analysis was carried out by using Data analysis software Origin 9.0. From the regression analysis compressive strength, Splitting tensile strength and Modulus of rupture of High strength concrete, steel fiber reinforced high strength concrete and hybrid fiber reinforced high strength concrete values were predicted in terms of fiber volume fraction (V_f) The values are almost matching the experimental results with minimum percentage of errors which was calculated and tabulated as shown in Table 4. The compressive strength predictions were obtained from the regression analysis which yields the equation – (1) in this equation (Y = Compressive strength of concrete (f'c)), (X = Volume fraction V_f), at the volume fraction V_f is 0.0 the compressive strength of the high strength concrete is 60.52 N/mm^2, this value is very nearer to experimental value with error of 0.94 percent similarly we can predict the other values. The error of steel fiber reinforced concrete was from 0.02 to 2.91 percent, the error of hybrid fiber reinforcement high strength concrete S80 -P20 combinations was 0.78 to 2.91% and S 60 % – P40% combination was 0.87 to 2.67.The prediction curve for compressive strength as shown in Fig. 6

$$Y = -0.438X^2 + 4.35X + 60.46 \text{ ------------- (1)}$$
$$R^2 = 0.798$$

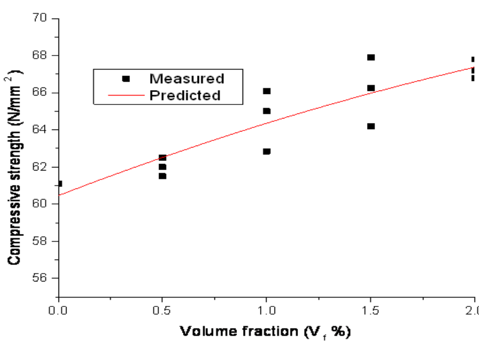

Figure 6 Prediction curve for Compressive strength

Regression analysis gave the equation – (2) for predicting the splitting tensile strength (f'sp) in terms of volume fraction (V_f). In this equation (Y = Splitting tensile strength (f'sp)), (X =Volume fraction (V_f)). At V_f = 0.0 for high strength concrete , the splitting tensile strength predicted was 4.86 N/mm^2 , it is very nearer to experimental value and 0.59√f'c as per ACI 363 R – 93.The prediction error was 2.12 percent. Other values are also predicted and compare with experimental results the prediction error was from 0.24 to 14.26 percent.

The prediction curve for splitting tensile strength as shown in Fig. 7

$$Y = -0.438X^2 + 4.35X + 60.46 \text{ ----- ------- (2)}$$
$$R^2 = 0.883$$

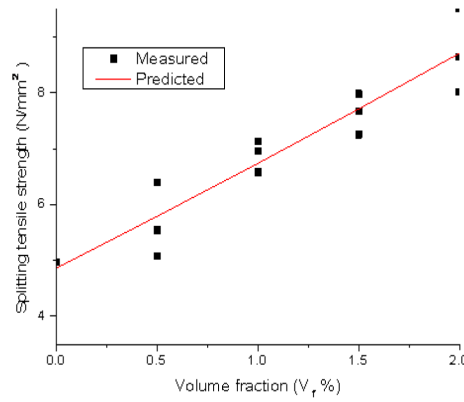

Figure 7 Prediction curve for Splitting tensile strength

The Modulus of rupture predicted using measured values of flexural strength and fiber volume fraction (V_f) by applying the regression analysis gave equation – (3), (Y = Modulus of rupture (f'r)) , (X= Volume fraction (V_f)). In this equation modulus of rupture of high strength concrete was predicated as 7.65 at V_f = 0.0. It is very nearer to the experimental results and 0.94√f'c as per ACI 363 – 93.The predicted values of steel fiber reinforced concrete and hybrid fiber reinforced concrete were shown in Table . 4 and the prediction were shown in Fig. 8.

$$Y = -1.701X^2 + 6.183X + 7.748 \text{ ----------- (3)}$$
$$R^2 = 0.973$$

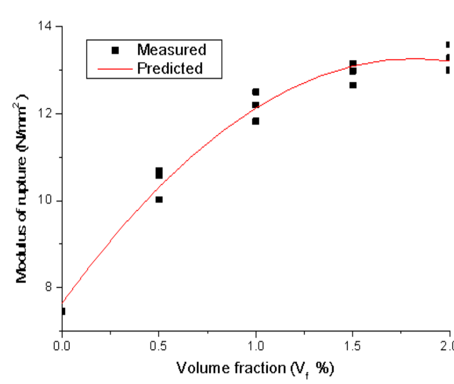

Figure 8 Prediction curve for Modulus of rupture

5 Conclusions

The compressive strength of hybrid fiber reinforced high strength concrete, steel fiber reinforced high strength concrete was slightly improved compare with the high strength concrete. But its values were very less.

The strength effectiveness showed at each volume fraction a maximum for splitting tensile strength, followed by modulus of rupture and compressive Strength.

It is concluded from this investigation that the use of 80 % steel fibers and 20 % Polyolefin fibers at each volume fraction gave optimum mechanical properties. At hybrid fiber volume fraction of 2.0% with 80% - 20% steel-polyolefin Combination has more significant effect on mechanical properties.

Regression analysis gave the prediction values of compressive strength is almost nearer to experimental results, 5. Prediction of splitting tensile strength of steel fiber and hybrid fiber reinforced high strength concrete was having error percentage from **0**.76 to 14.26 compare with the measured value.

Prediction error of Modulus of rupture of hybrid fiber reinforced high strength concrete was 0.53% to 10.85 comparing with the measured value.

The regression equation estimated the strength parameters reasonably nearer to the measured values of high strength concrete, steel fiber reinforced high strength concrete and hybrid fiber reinforced high strength concrete.

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