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Strength Prediction of Hybrid Fiber Reinforced High Strength Concrete

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Abstract: This paper presents the prediction of experimental results of high strength concrete of Grade M60 with hooked end steel fiber and combination of steel and polyolefin straight fibers (hybrid).The high strength concrete specimens were cast and considered as control specimens, high strength concrete added with steel fibers at 0.5%, 1.0%, 1.5%, and 2.0% volume fractions, and each volume fraction, hooked ends steel and polyolefin straight fibers were added at 80%- 20% and 60% -40% combinations to get steel and hybrid fiber reinforced high strength concrete specimens. All the specimens were tested under compression, splitting and flexural strength. Test results shown that by increase in fiber volume fractions, the strength values were increased and also resist the crack formations compare with control specimen. Empirical expressions were established by using regression analysis to predict the compressive, splitting tensile strength and modulus of rupture of all types of concrete specimens. The predicted values were compared with the experimental results of all specimens.
Keywords: High strength concrete, steel fibers, Polyolefin fibers, Hybrid fibers, Strength prediction.

1.0 Introduction

Concrete is a brittle material, and the mechanical behavior of concrete is appreciably improved by addition of fibers in concrete. Fiber reinforced concrete has been successfully designed and used in engineering structures, for example tunnel linings and industrial floors [1-3], and high-strength concrete is being generally used all over the world. The engineering characteristics and economic advantages of high-strength concrete (HSC) are distinct from conventional concrete, thereby popularizing the HSC concrete in a large variety of applications in the construction industry. Due to Poor toughness and brittleness of high strength concrete can be overcome by reinforcing with short discontinuous fibers [4]. The Fibers are primarily control the propagation of cracks and limit the crack width [5, 6]. The addition of steel fibers at high dosages, have some disadvantages in terms of poor workability and increased cost. However, Steel fibres are used in the concrete to increased strength and improve the performance in seismic resistant structures [7] and where as synthetic fibres give the concrete, increased durability and toughness. Therefore, the steel and synthetic fibers were combined with various combination in concrete have been the research works for researchers and engineers [8]. The hybrid composites studied by previous researchers were focused on hybridization of steel, polypropylene, carbon fiber and other types of fibers [9, 10]. The mechanical properties of hybridization of steel and polyolefin fibers in high strength concrete at different volume fraction have been studied previously are very limited. In this study high strength concrete added with steel fibers at the volume fraction of 0.5%, 1.0%, 1.5%, and 2.0%, and each volume fraction steel – polyolefin fibers combinations were added at 80% - 20% and 60% -40%. 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 strength tests in comparison with the steel fiber reinforced high strength concrete and plain high strength concrete, the test results were predicted by using regression analysis and compare with the experimental results.

2.0 Experimental Program

2.1 Materials

The cement used in concrete mixes was ordinary Portland cement of grade 53 confirmed with IS 12269- 1987. The fine aggregate 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. Condensed silica fume obtained from Elkem Materials. It was used to improve the fresh and hardened state of concrete properties. A high – range water reducing admixture (HRWR) Gelenium B233 was used to increase the workability of concrete. The fibers used in the study was hooked end steel fiber and Polyolefin straight fiber, the properties both the fibers are as shown in Table 1.The high strength concrete mix proportions were designed based on the steps given by the code - ACI 211-4R-1993 [11].The mix proportions for $1m^3$ of concrete is as shown in Table 2.

Table 1 Property of Fibers

Fibre Properties	**Fiber Details**	
	Polyolefin	**Steel**
Length (mm)	54	35
Shape	Straight	Hooked at ends
Size / Diameter (mm)	1.38 x 0.41 mm	0.6 mm
Aspect Ratio	63.68	58.33
Density (kg / m^3)	920	7800
Specific Gravity	0.90-0.92	7.8
Young's Modulus (GPa)	10	210
Tensile strength (MPa)	550	>1100

Table 2 Mix Proportions for 1 m^3 of Concrete

Cement (kg)	**Silica Fume (kg)**	**Fine Aggregate (kg)**	**Coarse Aggregate (kg)**	**HRWR (kg)**	**Water (kg)**
468.48	43.52	594.40	1037.22	6.40	159.50

2.2 Casting and Testing of Specimens

Steel mould of size 150 x 300 mm cylinder for compressive strength, splitting tensile strength, and prisms of size 100 x 100 x 500 mm were used for flexural strength test. The specimen names and details of study parameters are shown in Table 3. Each parameter two specimens were cast. In the preparation of concrete, coarse aggregate, fine aggregate cement and silica fume were initially mixed in dry state. Next the fibers were added and maintain uniform distribution by proper dry mixing operations. Then Water, high range water reducing admixture Gelenium B233, already diluted in 50% required quantity of water was added into the dry mix. High - strength concrete, steel fiber reinforced concrete and hybrid fiber reinforced concrete specimens were cast by using above moulds with proper compaction. The specimens were demoulded after 24 hours and then placed in a curing tank for 28 days. The tests were conducted using 200 T capacity of compression testing machine. The compressive strength test was carried out as per ASTM C 39[12]. The Splitting tensile strength test was conducted as per ASTM C 496[13]. The flexural strength test was carried out as per ASTM C 78[14]. The test results are shown in Table 4.

Table 3 Specimen details

Sl. No	Specimen Name	Fiber volume fraction (%)		
		Steel	Polyolefin	Total
1	HSC	0	0	0
2	HSFRC1	0.5	0	0.5
3	HYFRC1	0.4	0.1	0.5
4	HYFRC2	0.3	0.2	0.5
5	HSFRC2	1	0	1
6	HYFRC3	0.8	0.2	1
7	HYFRC4	0.6	0.4	1
8	HSFRC3	1.5	0	1.5
9	HYFRC5	1.2	0.3	1.5
10	HYFRC6	0.9	0.6	1.5
11	HSFRC4	2	0	2
12	HYFRC7	1.6	0.4	2
13	HYFRC8	1.36	0.64	2

Table 4 Measured and Predicted values of Strengths

Specimen Name	Compressive Strength (N/mm^2)			Splitting Tensile Strength (N/mm^2)			Modulus of Rupture (N/mm^2)		
	Measured value	Predicted value	Error (%)	Measured value	Predicted value	Error (%)	Measured value	Predicted value	Error (%)
HSC	61.1	60.52	-0.94	4.97	4.86	-2.12	7.46	7.65	2.53
HSFRC1	62.5	62.48	-0.02	5.08	5.17	1.77	10.58	8.63	-18.41
HYFRC1	62	62.48	0.78	6.39	5.47	-14.26	10.68	9.52	-10.85
HYFRC2	61.5	62.48	1.60	5.54	5.78	4.51	10.02	10.32	2.94
HSFRC2	65	64.28	-1.09	6.95	6.10	-12.17	11.82	11.01	-6.81
HYFRC3	66.1	64.28	-2.74	7.13	6.41	-9.96	12.5	11.62	-7.04
HYFRC4	62.85	64.28	2.28	6.58	6.73	2.41	12.2	12.13	-0.56
HSFRC3	67.9	65.91	-2.91	7.67	7.06	-7.95	12.98	12.55	-3.33
HYFRC5	66.25	65.91	-0.50	7.98	7.38	-7.46	13.15	12.87	-2.14
HYFRC6	64.2	65.91	2.67	7.25	7.71	6.35	12.65	13.09	3.52
HSFRC4	67.8	67.38	-0.61	8.02	8.03	0.24	13	13.23	1.75
HYFRC7	67.2	67.38	0.27	9.5	8.37	-11.87	13.58	13.27	-2.31
HYFRC8	66.8	67.38	0.87	8.64	8.70	0.76	13.28	13.21	-0.53

3.0 Results and Discussions

3.1 performances of fibers in strength of concrete

The compressive strength of HSFRC specimens increased from 2.29% to 11.13% compare with HSC. And the HYFRC specimens were increased the strength 0.65 % to 9.93%. Improvement in compressive strength of hybrid fiber reinforced high strength concrete specimen was less than the steel fiber reinforced high strength concrete specimen. HSFRC specimens improve the Splitting tensile strength from 2.21 % to 61.36 %, HYFRC specimens improved the strength from 22.87% to 91.14 %. Improvement in splitting tensile strength of Hybrid fiber 80% -20% combination gave better strength compare with High strength concrete and steel fiber reinforced high strength concrete. The modulus of rupture of HSFRC specimen improvement started from 41.82 % to 76.27 %, HYFRC specimen varies from 43.56% to 82%. These strength comparisons were made with respect to HSC specimen.

3.1 Failure Pattern of Specimens

The failure pattern of compression test specimens are shown in Figure 1, the high strength concrete failure in brittle mode compare with that of fiber and hybrid fiber reinforced high strength concrete specimens, The spalling of high strength concrete was also more compare with the fibrous high strength concrete specimens. The crack pattern of splitting tensile test specimens is shown in Figure 2. In this test, the high strength concrete specimens were broken into two pieces but fiber and hybrid fiber reinforced high strength concrete specimens were resist crack formation. The flexural test specimens after failure are show in Figure 3. From the observation the high strength concrete specimens were suddenly broken into two pieces but the fiber and hybrid fiber reinforced high strength concrete specimens were bridging the crack formation even after failure, and the width of the crack also very less.

Figure 1. Failure pattern due to compression test

Figure 2. Failure pattern due to Splitting tensile test

Figure 3. Failure pattern of HSC, and HYFRC specimens due to Flexural test

3.2 Strength Prediction Analysis

In this study regression analysis was carried out and established the mathematical equation for 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 as shown in Table 4.

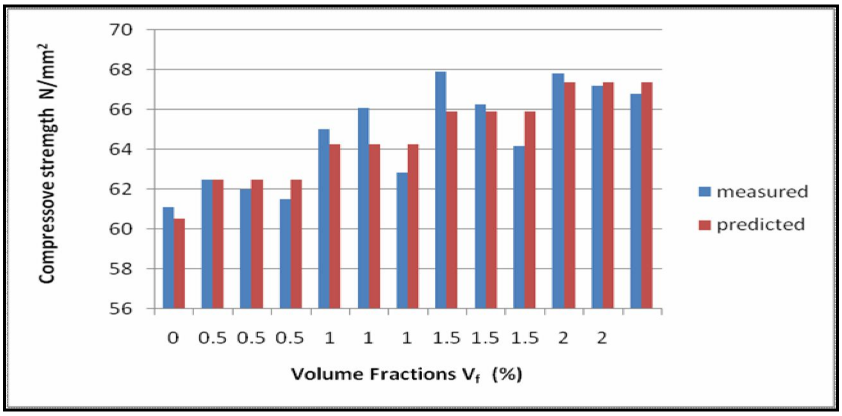

Figure 4. Measured and predicted values of compressive strength

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 volume fraction 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 experimental and predicted values were compared as shown in Figure 4.

$$Y = -0.438X^2 + 4.35X + 60.46 \quad (1)$$

R^2 = 0.798

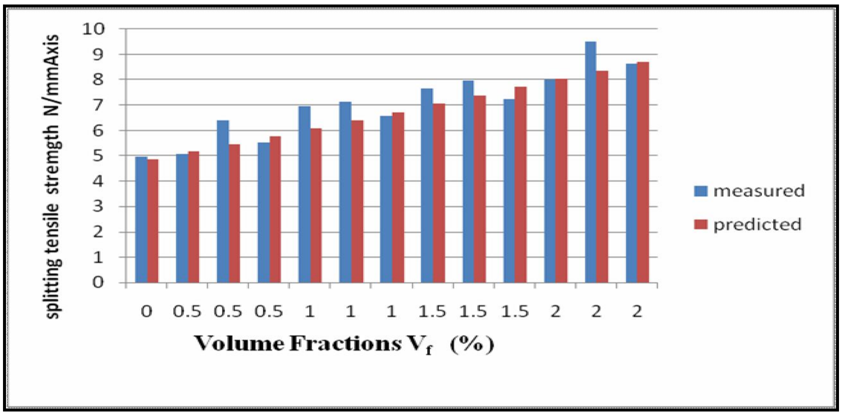

Figure 5. Measured and predicted values of splitting tensile strength

From the analysis the equation – (2) was used for predicting the splitting tensile strength (f'sp) in terms of volume fraction (V_f). 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 is 2.12 percent. Other values are also predicted and compare with experimental results the predication error was from 0.24% to 14.26% percent. The comparison chart is as shown in Figure 5.

$$Y = -0.438X^2 + 4.35X + 60.46 \quad (2)$$

R^2 = 0.0.883

The Modulus of rupture predicted using experimental values of flexural strength and fiber volume fraction (V_f) by applying the regression analysis gave equation – (3), Y = Modulus of rupture (f'_{Cr}) , 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 $0.94\sqrt{f'c}$ as per ACI 363 – 93.The predicted values of high strength, steel fiber reinforced concrete and hybrid fiber reinforced concrete are plotted as a graph shown in Figure 6.

$$Y = -1.701X^2 + 6.183X + 7.748 \qquad (3)$$

$R^2 = 0.973$

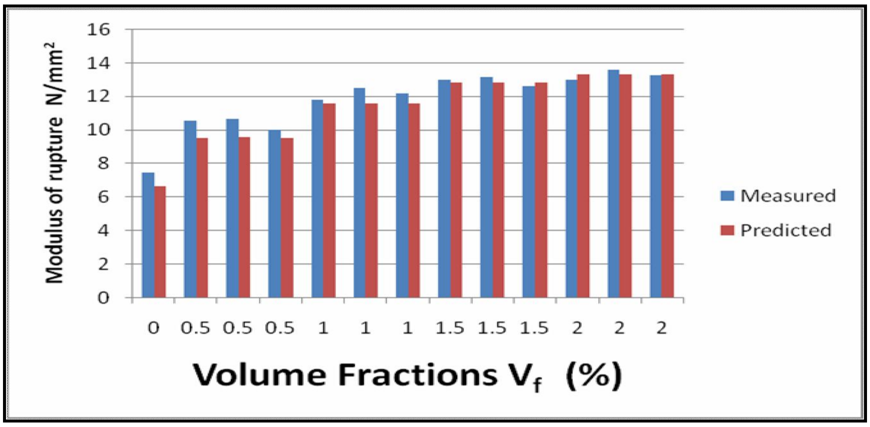

Figure 6. Measure and predicted values of Modulus of rupture

4.0 Conclusions

The following conclusions were made from the experimental and regression analysis

The compressive strength of hybrid fiber reinforced high strength concrete specimen (HYFRC), steel fiber reinforced high strength concrete (HSFRC) specimen was improved compare with that of high strength concrete specimen (HSC).

1. High strength concrete in Flexural strength, the specimens were failed suddenly and separated into two pieces. Whereas the steel fiber (HSFRC) and hybrid fiber reinforced high strength concrete (HYFRC) specimens resist the crack formation up to failure.
2. Hybrid fiber volume fraction of 2.0% with 80% - 20% steel-polyolefin combination (HYFRC7) specimens were improved the mechanical properties.
3. Regression analysis gave the prediction values of compressive strength is almost nearer to experimental results.
4. Prediction of splitting tensile strength of steel fiber and hybrid fiber reinforced high strength concrete was having error from 0.76% to 14.26% compared with the experimental results.
5. Prediction error of Modulus of rupture of hybrid fiber reinforced high strength concrete was 0.53% to 10.85% comparing with the Experimental values of specimens.
6. The regression equation estimated the strength parameters reasonably nearer to the experimental values of high strength concrete (HSC), steel fiber reinforced high strength concrete (HSFRC) and hybrid fiber reinforced high strength concrete (HYFRC) specimens.

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