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Flexural Performance and Toughness Evaluation of Hybrid Steel-Polypropylene Fibre Reinforced Self Compacting Concrete

*S. Bawa, S.P. Singh **

Department of Civil Engineering, Dr B R Ambedkar National Institute of Technology, Jalandhar, India

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ABSTRACT

The paper presents the results of an investigation conducted to study the influence of fiber hybridization on the compressive strength, flexural strength, flexural fatigue and flexural toughness of the Hybrid Fiber Reinforced Self Compacting Concrete (HyFRSCC). The Steel Fibers (SF) and Polypropylene Fibers (PPF) at 1% by volume of concrete have been used. The PPF and SF proportions used are 100% PPF, 75% PPF + 25% SF, 50% PPF + 50% SF, 25% PPF + 75% SF and 100% SF. The flexural toughness parameters were calculated using procedure laid down in JCI Method, ASTM C-1018 C and ASTM 1609/C 1609 M. The flexural fatigue tests were conducted at stress levels of 0.65, 0.7, 0.75, 0.8, 0.85 and 0.9. The Weibull parameters have been calculated using the graphical method and the method of moments. The results indicate that the mix with a fiber combination of 25% PPF + 75% SF can be adjudged as the optimum combination for HyFRSCC in terms of compressive strength, flexural strength and flexural toughness. Gradual replacement of steel fibers with polypropylene fibers has been found to reduce the variability in fatigue life data of HyFRSCC.

1 Introduction

The improvement in mechanical properties of normally vibrated concrete using hybrid fibers is well known. Different combinations of fibers such as metallic - metallic and metallic - non-metallic fibers have been employed. The different types of fibers used are steel, glass, polyester, carbon and polypropylene fibers [1-6]. There is a positive interaction between the fibers in a well designed composite and the resulting hybrid performance exceeds the individual fiber performances [7]. Generally one metallic and one nonmetallic type of fibers are used. The metallic fiber is stronger and provides reasonable first crack strength and ultimate strength, while the non-metallic fiber is relatively flexible and imparts improved toughness and strain capacity in the post-crack zone. The Steel – Polypropylene fiber combination is such one promising combination which can be used for better performance [4].

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* *Corresponding author. Tel.: +91 98140 88475.*
E-mail address: spsingh@nitj.ac.in

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Self Compacting Concrete (SCC) offers many benefits to the construction practice - the elimination of the compaction work results in reduced costs of placement, shortening of the construction time, reduction in noise during casting thus leading to better working conditions. Other advantages of SCC are - improved homogeneity of the concrete and the excellent surface quality without blowholes or other surface defects. The basic components of SCC are the same as used in Normally Vibrated Concrete (NVC). However, to obtain the required rheological properties of fresh SCC, a higher proportion of fine materials and the incorporation of chemical admixture, a super-plasticizer is necessary. Sometimes, a viscosity modifying agent may also be used for the stability of the mix [8-10].The need for high powder content in SCC is usually met by using pozzolanic fillers like fly ash, silica fume, blast furnace slag and non pozzolanic fillers like limestone powder, chalk powder, dolomite fines and quartzite powder.

Many researchers, in the last decade have started using fibers in SCC and as a result, Fiber Reinforced Self Compacting Concrete (FRSCC) is now being used in structures such as airport pavements, highway overlays, bridge decks and machine foundations. The fresh, mechanical properties under statically applied loads and durability characteristics of FRSCC have been investigated [11-15]. It has been observed that the performance of FRSCC was much better than that of Normally Vibrated Fiber Reinforced Concrete (NVFRC). Information on the mix proportioning methods of SCC and FRSCC is also available [16-18].

The fresh and hardened state properties of Hybrid Fiber Reinforced Self Compacting Concrete (HyFRSCC) have been tested by various researchers [5, 19-21]. The positive results show that in a well-designed hybrid composites, there is a positive interaction between the fibers and the resulting hybrid performance may exceed that of mono fiber composites.

The objective of this study is to evaluate the mechanical properties of the SCC containing steel, polypropylene and hybrid fiber combinations. The total volume fraction is kept constant at 1%. The proportions used are 100% polypropylene fibers (PPF), 100% Steel Fibers (SF), 25% PPF + 75% SF, 50% PPF + 50% SF and 25% SF + 75% PPF. The comparative evaluation of various HyFRSCC is made based on the hardened properties i.e. Compressive Strength, Flexural Strength, Flexural Fatigue and Flexural Toughness. The JCI, ASTM C1018 and ASTM C 1609/C 1609M have been employed to evaluate the toughness parameters of HyFRSCC. Probabilistic analysis of HyFRSCC mixes has been carried out using two-parameter Weibull distribution.

2 Experimental Programme

In the present study, Ordinary Portland Cement of 43 grade conforming to requirements of IS 8112-1989 has been used. Crushed stone aggregates (below 12.5 mm) of specific gravity 2.78 were used as coarse aggregates and locally available coarse sand of specific gravity 2.75 conforming to Zone II grain size distribution was used as fine aggregates. The water absorption of coarse aggregates was 0.28% and that of fine aggregates was 0.25%. The Class F fly ash was used with grading as shown in Figure 1.

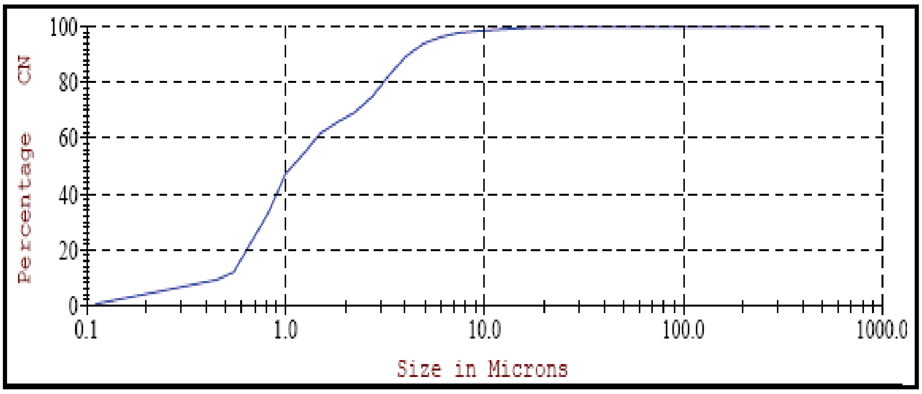

Fig. 1 - Grading of Fly Ash used in this Investigation.

Glenium 51, a polycarboxylic ether based super-plasticizer as admixture was used in suitable dosages to obtain the required HyFRSCC mixes with different volume fractions of fibers. Glenium Stream II was used as Viscosity Modifying Agent (VMA).The following type of fibers in different combinations such as 100-0%, 75%-25%, 50%-50%, 25%-75% and 0-100% by volume were used at 1% volume fraction.

Figure 2, shows Corrugated Steel Fibers (SF) of 1mm diameter, 30mm length and specific gravity of 7.8 and Polypropylene Fibers (PPF) of 1mm diameter, 10mm length and specific gravity of 0.91.

Fig. 2 - Steel Fibers and Polypropylene Fibers used in HyFRSCC.

Suitable SCC mixes with different proportions of steel and polypropylene fibers were obtained through trials as per EFNARC guidelines. The Proportions of the SCC mix are shown in Table 1.

Table – 1 Mix Proportions of the SCC (kg/cum)

Cement	Fly ash	Fine Aggregates	Coarse Aggregates	Water
410	205	846	602	277

Water/Binder ratio	Sand/Binder ratio	Coarse Aggregate/ Binder Ratio
0.45	1.37	0.98

The dosage of Super-plasticizer (SP) was kept in a range of 0.6–1.2% by weight of cement content for various HyFRSCC mixes and the dosage for Viscosity Modifying Agent (VMA) was kept between 0.35-0.5 percent of the cement content in order to meet required EFNARC limits for SCC. For compressive strength tests, the specimens used were 150 x 150 x 150 mm cubes whereas standard prisms of size 100 x 100 x 500 mm were used for the static flexural strength tests.

The schematic diagram for flexural test is shown in Figure 3.

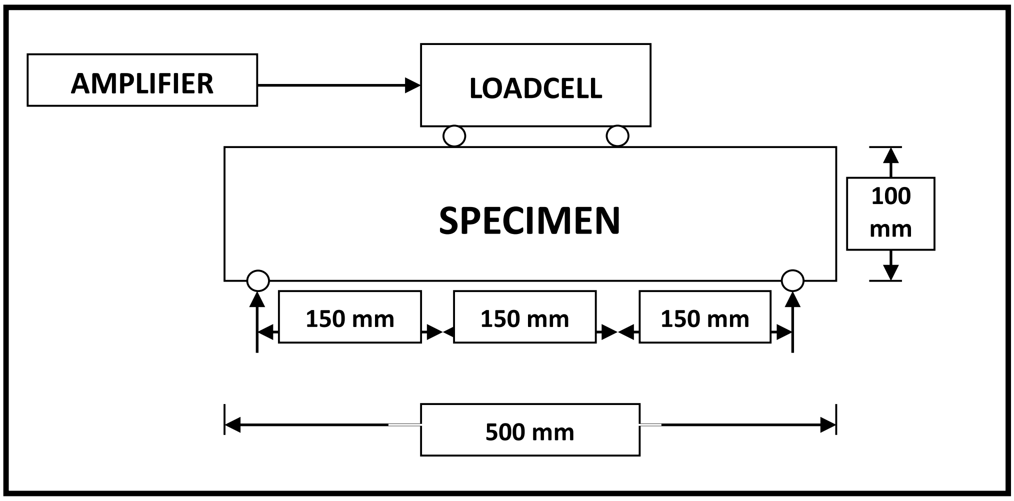

Fig. 3- Schematic Diagram for Flexural Tests

The specimens were cast in the different batches. Each batch had fourteen flexural test specimen and six cubes for testing the 28-day compressive strength of each mix. The specimen for compressive strength tests were cured for 28 days, whereas, the specimens for flexural strength tests were cured for 90 days.

The compressive strength tests were conducted on concrete cubes in a 200 tons Universal Testing Machine. The flexural strength and flexural fatigue of HyFRSCC was obtained by testing prism specimens under four-point bending test.

All the flexural strength tests were done on a 100 kN servo-controlled actuator. The fatigue tests were performed at different stress levels of 0.65, 0.7, 0.75, 0.8, 0.85 and 0.95 for all the mixes with different fiber combinations.

3 Results And Discussion

3.1 Compressive Strength Results

The average of three batches has been taken as the compressive strength of a particular mix. The compressive strength results have been tabulated in Table 2 along with standard deviation.

Table – 2 Compressive Strength Test Results for HyFRSCC

Fiber Mix Proportion by Volume (%)		Fiber Volume Fraction	28 Days Compressive Strength (MPa)	
SF	PPF		Average*	Percentage Increase
--	--	0.0	28.90 ± 3.28	---
0	100	1.0	29.45 ± 3.41	1.9
25	75	1.0	34.98 ± 2.23	21
50	50	1.0	37.70 ± 3.31	30.4
75	25	1.0	44.32 ± 1.89	53.3
100	0	1.0	41.23 ± 2.28	42.6

** Average compressive strength along with standard deviation*

It may be noted that the coefficient of variation of the compressive strength values of all the mixes was in the range of 4% - 11%, which is acceptable. The Self Compacted Concrete (SCC) is taken as a reference mix. The compressive strength of SCC is 28.9 MPa. With the addition of 100% PPF, there was a slight increase of 1.9% in compressive strength (29.45 MPa). It has also been concluded that polypropylene fibers have little or no effect on the compressive strength of the SCC [22]. The PPF have a low modulus and a weak bond with the matrix in comparison with metal fibers.

By replacing 25% PPF with SF, the compressive strength observed was 34.98 MPa with an increase of 21% as compared to reference mix. Further addition of SF demonstrated the increase of 30.4% in the compressive strength for the mix having 50% SF and 50% PPF giving the compressive strength of the order of 37 MPa.

The optimum fiber combination is 75% SF + 25% PPF for which the remarkable increase in compressive strength of 53.3% over SCC was observed. Further, it can also be seen that the compressive strength of concrete mix containing 100% SF is 41.23 MPa, which is 42.6% higher than the reference mix but lesser than the mix having 25% PPF and 75% SF. This shows the positive interaction of hybridization of given type of fibers.

The results of the fiber-reinforced specimens show that the use of fibers in any form and volume fraction resulted in an increase in the compressive strength compared to that of concrete without fibers [23].

The compressive strength results are shown in Figure 4 as bar chart along with error bars based on standard deviation.

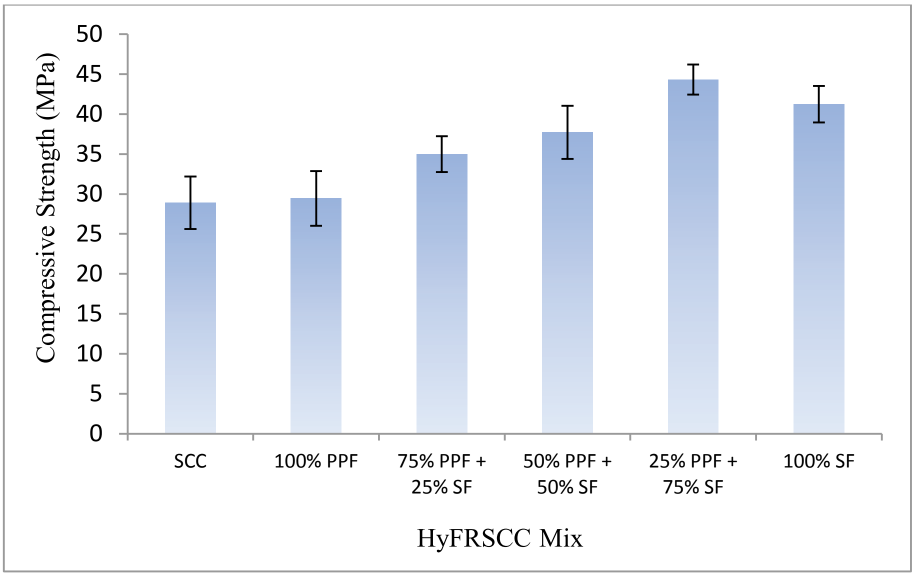

Fig. 4- Compressive Strength of HyFRSCC for Different Fiber Combinations

3.2 Flexural Strength Results

The flexural strength results of HyFRSCC mixes with different combinations of steel and polypropylene fibers are presented in Table 3 along with standard deviation.

Table – 3 Flexural Strength Test Results for HyFRSCC

Fiber Mix Proportion by Volume		Fiber Volume Fraction	Flexural Strength (MPa)	
SF	PPF		Average*	% Increase
---	---	0.0	4.63 ± 0.38	--
0	100	1.0	5.44 ± 0.16	17.4
25	75	1.0	6.28 ± 0.36	35.6
50	50	1.0	6.90 ± 0.17	42.2
75	25	1.0	8.12 ± 0.24	49.0
100	0	1.0	7.34 ± 0.29	58.5

** Average flexural strength along with standard deviation*

It may be noted that the coefficient of variation of the flexural strength values of all the mixes was in the range of 2% - 8%, which is acceptable. The flexural strength of SCC has been listed for reference and comparison. There is an increase of approximately 17% in the flexural strength of SCC containing 100% PPF as compared to that of SCC. With the gradual replacement of PPF with SF, an increase in the flexural strength is observed up to a fiber combination of 75% SF + 25% PPF. With further replacement of polypropylene fibers with steel fibers i.e. for concrete containing 100% steel fibers, a decrease in flexural strength is observed. The increase in flexural strength of fibrous SCC containing different combinations of SF and PPF varied from 35% to 58% thus showing an increase of the order of 35% for HyFRSCC with 25% SF + 75% PPF; 42% for 50% SF + 50% PPF; 49% for SCC containing 75% SF + 25% PPF and 58% for concrete containing 100% SF. Thus the optimum fiber combination for maximum flexural strength is 75% SF + 25% PPF as obtained in this investigation. The similar improvement in flexural strength for NVFRC has been reported by various researchers [24-26].

The flexural strength results are shown in Figure 5 as bar chart along with error bars based on standard deviation.

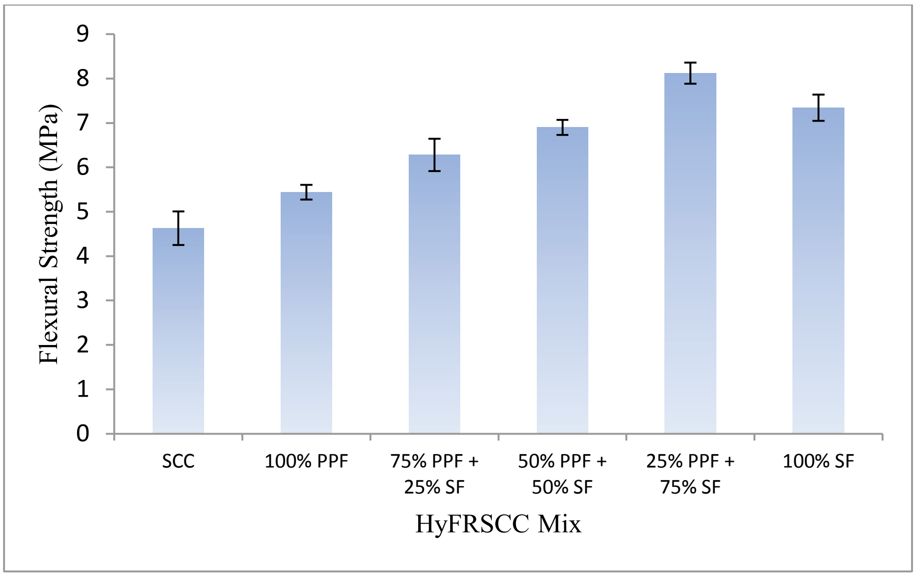

Fig. 5- Flexural Strength of HyFRSCC for Different Fiber Combinations

Typical load-deflection curves obtained in this investigation for concrete containing different combinations of fibers are presented in Figure 6. It is clear from the load deflection curves that mix containing 25% PPF+ 75% SF is giving the maximum peak load. There is a steep fall in load for the mix containing 100% polypropylene fibers as compared to other mixes.

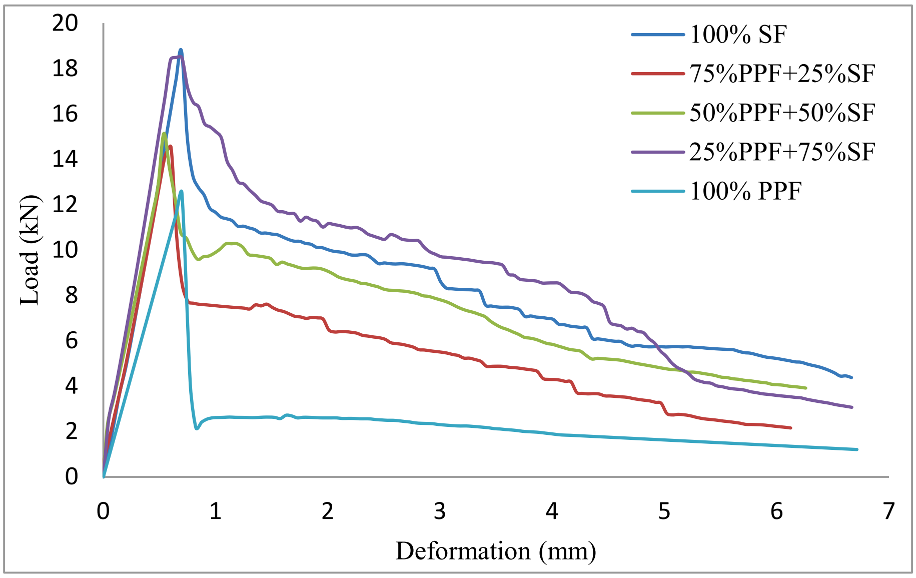

Fig. 6 - Load Deflection Curves under Static Flexural Loading for all Mixes.

3.3 Toughness Indices

The toughness of fiber reinforced concrete in terms of indices can be expressed as the ratio between the energy absorbed up to a predetermined deformation level and the energy needed for the onset of cracking [27]. The load-displacement curves generated under four-point loading were analyzed for the evaluation of toughness parameters for different concrete mixes used in the investigation. Different methods like JCI, ASTM C1018 and ASTM C 1609/C 1609M have been used to evaluate the toughness parameters of HyFRSCC using the load-deflection curves as given in Figure 6.

3.3.1 JCI method

The JCI method provides a single value of toughness. In this method, the toughness value T_{JCI} has been defined as the area under the load-deflection curve up to the deflection of 1/150 of span (δ_{150}). By taking into account the beam size and span, the flexural toughness factor (σ_b) (equivalent to the average residual strength) is determined as:

$$\sigma_b = \frac{T_{JCI} \text{ X } L}{\delta_{150} \text{ X } b\, h^2} \tag{1}$$

where T_{JCI} is the energy absorbed (flexural toughness), δ_{150} is the deflection of 1/150 of span L, b and h are the width and depth of the specimen section respectively [28]. The toughness and flexural toughness factor values calculated as per JCI specifications for all HyFRSCC's are given in Table 4, and are represented in graph in Figure 7.

Table – 4 Flexural Toughness Indices using JCI Method

Fiber Mix Proportion by Volume (%)		Fiber Volume Fraction	Toughness Indices JCI METHOD		
SF	PPF		T_{JCI}	σ_{JCI} (MPa)	$T_{F.C.}$
0	100	1.0	10.77	1.62	4.38
25	75	1.0	21.40	3.21	4.63
50	50	1.0	27.47	4.12	4.08
75	25	1.0	35.35	5.30	6.54
100	0	1.0	30.67	4.60	6.33

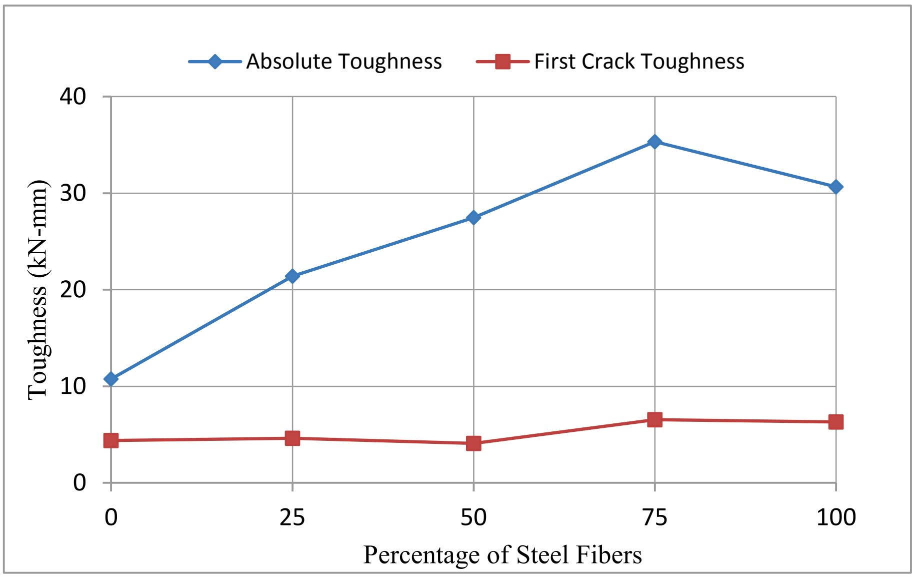

Fig. 7 - Absolute Toughness and First Crack Toughness vs Steel Fiber Content

The trends observed in Figure 7 indicate that amongst all the mixes, the mix having 75% steel fibers and 25% polypropylene fibers yields a higher flexural toughness of 35.35 kN-mm with flexural toughness factor of 5.30 MPa. The mix with 100% PPF have the steep decrease in load after the peak load and hence have the lowest amount of energy absorbed as 10.77 kN-mm with σ_{JCI} as 1.62 MPa. Even for the mix with 100% SF the values of flexural toughness and flexural toughness factor were 30.67 kN-mm and 4.60 MPa respectively, which are lesser than the maximum values. It is clear from Figure 7 that the fiber type has not much effect on the first crack toughness; however the absolute toughness varies considerably.

3.3.2 ASTM C1018 method

In ASTM C 1018 method, the toughness is expressed as a ratio of the amount of energy required to deflect the beam to a specified deflection, expressed as multiples of the first crack deflection [28]. The evaluation of toughness is made on the basis of dimensionless parameters i.e. toughness indices and residual strength factors [29]. The Residual Strength Factor (RSF) can be obtained directly from toughness indices and represents the level of strength retained after first crack [30]. The toughness indices I_5, I_{10} and I_{20} are calculated by taking the ratios of the energy absorbed to a certain multiple of first-crack deflection and residual strength factors $R_{5,10}$, and $R_{10,20}$ are calculated directly from toughness indices. The toughness calculated at the deflection (δ) is considered the elastic or pre-peak toughness (first-crack toughness), while the other three (at 3δ, 5.5δ and 10.5δ) are considered the post-peak toughness [31]. The residual strength represented by the average post-cracking load that the specimen may carry over a specific deflection interval, are determined as follows:

$$R_{5,10} = 20\left(I_{10} - I_5\right) \tag{2}$$

$$R_{10,20} = 10\left(I_{20} - I_{10}\right) \tag{3}$$

Toughness indices and RSFs for all the mixes using ASTM C-1018 method are given in Table 5.

Table – 5 Flexural Toughness Indices using ASTM C-1018

Fiber Mix Proportion by Volume (%)		Fiber Volume Fraction	ASTM C-1018						
			Toughness Indices			Toughness Index		Residual	
SF	PPF		I_5	I_{10}	I_{20}	I_{10} / I_5	I_{20} / I_{10}	$R_{5,10}$	$R_{10,20}$
0	100	1.0	1.95	2.88	4.09	1.47	1.42	18.5	12.10
25	75	1.0	3.02	5.02	7.17	1.66	1.43	40.08	21.47
50	50	1.0	3.66	5.96	8.56	1.63	1.44	46.06	26.01
75	25	1.0	3.69	6.28	8.93	1.70	1.42	51.65	26.55
100	0	1.0	3.50	5.89	8.84	1.69	1.50	47.98	29.50

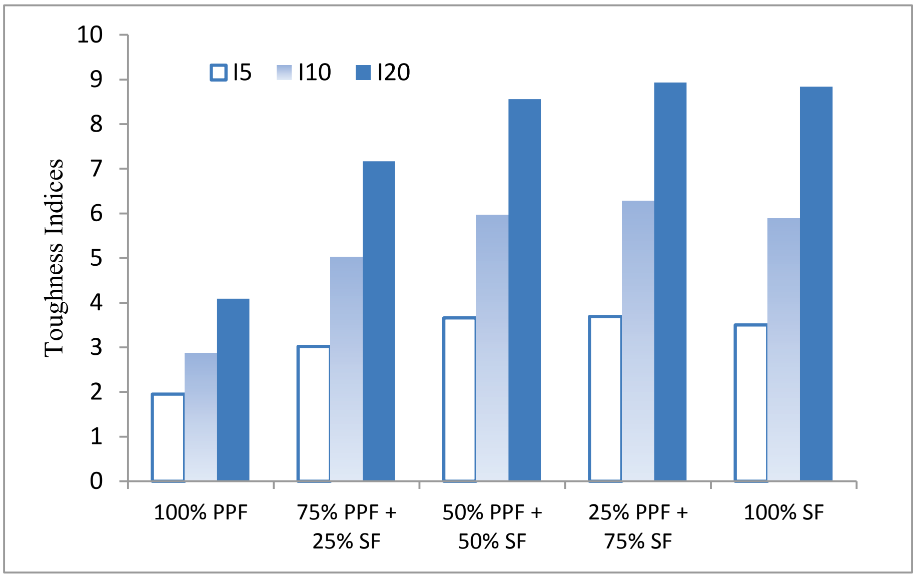

Fig. 8 - Comparison of Toughness Indices of all Mixes as per ASTM C 1018 Method

The increased toughness of the mix in the case of HyFRSCC with 25% PPF and 25% SF can be expressed by the increased value of the toughness indices. The highest values of the toughness indices (I_5, I_{10}, and I_{20}), and the residual strengths ($R_{5,\,10}$

and $R_{10,20}$) for this mix are 3.69, 6.28, 8.93 and 51.65, 26.55 respectively. The lowest values of the toughness indices (I_5, I_{10}, and I_{20}), and the residual strengths ($R_{5,10}$ and $R_{10,20}$) obtained by mix with 100% PPF are 1.95, 2.88, 4.09 and 18.50, 12.10 respectively. The comparison of the toughness indices and the residual strengths for all mixes has been shown in Figure 8 and 9 respectively. The Figure 10 represents the variation of toughness indices with the percentage of steel fibers in the mix.

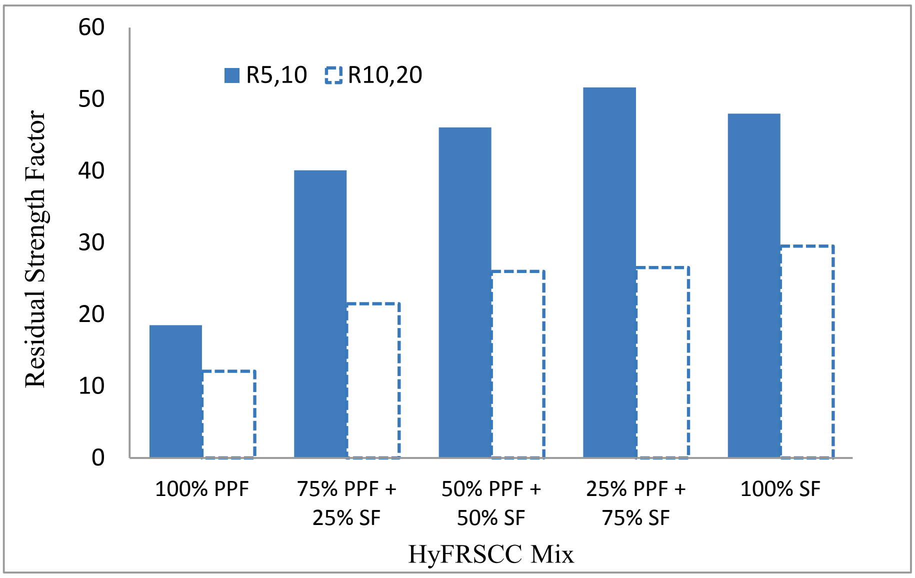

Fig. 9 - Comparison of Residual Strengths of Different Mixes as per ASTM C 1018 Method

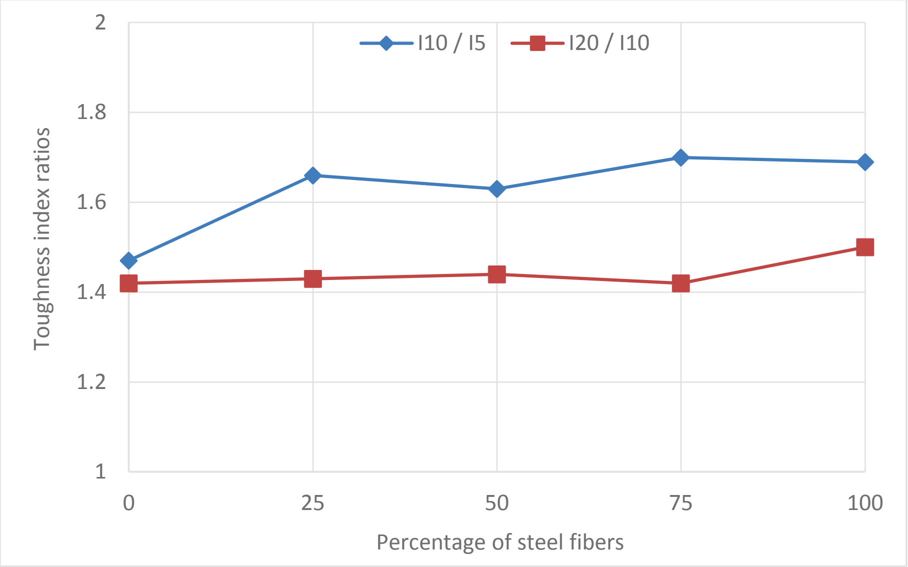

Fig. 10 - Variation of Toughness Index Ratios with the percentage of Steel Fibers

3.3.3 ASTM C 1609/C 1609 M method

This test method determines the first peak, the peak load and the corresponding stresses for the toughness evaluation. The parameters derived from the load deflection curve to evaluate the flexural performance of HyFRSCC mixes are as follows: P_{600}=Residual load at net defection of L/600, P_{150}= Residual load at net defection of L/150, f_{600}= Residual strength at net defection of L/600, f_{150}= Residual strength at net defection of L/150, T_{150}=Area under the load deflection curve from 0 to 1/150 of L, T_{600}=Area under the load deflection curve 0 to 1/600 of L where L=Span length or distance between the supports. The flexural performance parameters P_{600}, P_{150}, f_{600}, f_{150}, T_{600} and T_{150} for all the concrete mixes have been presented in Table 6.

Table – 6 Flexural Toughness Indices using ASTM C-1609

Fiber Mix Proportion by Volume (%)		Fiber Volume Fraction	ASTM C-1609					
			Toughness Indices					
SF	PPF		P_{150} (kN)	P_{600} (kN)	f_{150} (MPa)	f_{600} (MPa)	T_{150} (Joules)	T_{600} (Joules)
0	100	1.0	2.29	6.50	1.03	2.91	10.77	4.78
25	75	1.0	5.87	8.83	2.63	3.96	21.40	6.14
50	50	1.0	7.73	10.50	3.47	4.71	27.47	6.57
75	25	1.0	9.70	17.16	4.35	7.70	35.35	8.37
100	0	1.0	8.60	14.98	3.86	6.72	30.67	7.28

The mix with 25% PPF and 75% SF has performed better than the other mixes with toughness values (T_{150} and T_{600}) as 35.35 and 8.37 Joules, residual strength values (f_{150} and f_{600}) as 4.35 and 7.70 MPa and residual load values (P_{150} and P_{600}) as 9.70 and 17.16 kN respectively. The mix having 100% PPF with toughness i.e. T_{150} and T_{600} values as 10.77 and 4.78 Joules; residual strength i.e. f_{150} and f_{600} values as 1.03 and 2.91 MPa; load values i.e. P_{150} and P_{600} as 2.29 and 6.50 kN, respectively has shown poor performance.

3.4 Flexural Fatigue Studies

The results of HyFRSCC for compressive strength, flexural strength and flexural toughness are part of an ongoing investigation to study the flexural fatigue performance of hybrid fibrous SCC containing steel and polypropylene fibers in different combinations. The influence of these hybrid fiber additions on the probability distributions for the fatigue life of HyFRSCC, development of stress level (S) - fatigue life (N) - probability of failure (P_f) diagrams, study of the available fatigue strength models and fatigue performance by determining fatigue design life or two-million endurance limits are being taken up.

Since the fatigue data of HyFRSCC exhibits considerable scatter due to the material heterogeneity, it is required to employ probability concept in estimating the fatigue life of concrete. So to develop the fatigue equations with survival probability, a statistical analysis was carried out at each stress level. Probabilistic analysis of fatigue data has been modelled by two-parameter Weibull distribution. The two-parameter Weibull distribution has increasing hazard function, easy to use, well defined statistical procedure and thus is the most fit in fatigue studies. The distribution of fatigue life of plain concrete, SFRC and SFRSCC has been shown to approximately follow the two-parameter Weibull distribution [32-34]. The parameters of the Weibull distribution have been calculated by two methods, the graphical method and the method of moments.

3.4.1 Graphical Method

The survivorship function $L_N(n)$ of the two-parameter Weibull distribution may be written as follows [35-36]:

$$L_N = \exp\left[-\left(\frac{n}{u}\right)^{\alpha}\right] \tag{4}$$

where n is the specific value of N which is the number of cycles to failure or fatigue life; α is the shape parameter at stress level S and u is the scale parameter at stress level S.

Taking the logarithm twice on both sides of Eq. (4)

$$\ln\left[\ln\left(\frac{1}{L_N}\right)\right] = \alpha\ln(n) - \alpha\ln(u) \tag{5}$$

Equation (5) represents a linear relationship between $ln\left[ln\left(1/L_N\right)\right]$ and $ln\left(n\right)$ and is used to verify the two-parameter Weibull distribution for analysis of the fatigue life of concrete. To obtain a plot between $ln\left[ln\left(1/L_N\right)\right]$ and $ln\left(n\right)$, the fatigue test results for a given stress level S, are firstly arranged in ascending order of N, the number of cycles to failure and the empirical survivorship function L_N is then obtained from the following expression [35-36]:

$$L_N = 1 - \frac{i}{k+1} \tag{6}$$

Where i is a failure order number, and k is a number of fatigue data points at a given stress level S. If at a particular stress level, the test result data follows approximately a linear trend on the graph, then it can be concluded that the Weibull distribution is a reasonable assumption for the statistical analysis of fatigue life data at that particular stress level. The shape parameter α and the scale parameter u can be obtained directly from the regression analysis or graph. The parameters α and u calculated directly from the regression analysis for the fatigue life of HyFRSCC corresponding to all the proportions of steel and polypropylene fibers are listed in Table 7. The maximum value of shape parameter α as per graphical method is 2.7239 for mix having 100% polypropylene fibers at 0.85 stress level and the least value of α is 1.2711 as observed in mix having 100% steel fibers at 0.7 stress level.

3.4.2 Method of Moments

In this method, the parameters are obtained by calculating the appropriate sample moments, such as sample mean and sample variance. The following expressions may be used to obtain the values of shape parameter α and scale parameter u [36]:

$$\alpha = \left(CV\right)^{-1.08} \tag{7}$$

$$u = \frac{\mu}{T\left(\frac{1}{\alpha}+1\right)} \tag{8}$$

in which CV = $\frac{\sigma}{\mu}$ is the coefficient of variation of the fatigue data sample at a particular stress level S, σ is the standard deviation and μ is the mean of the test data at particular stress level S.

Γ( ) is gamma function.

The parameters of the Weibull distribution for the fatigue life data of HyFRSCC containing different mix proportions of steel and polypropylene fibers were obtained by the method of moments using Eqs. (7) and (8) and are listed in Table 7.

The preliminary results on HyFRSCC mixes indicate that the probability distribution of fatigue life at a given stress level S, can be approximately represented by the two-parameter Weibull distribution. The parameters of the Weibull distribution have been obtained by both the methods of analysis.

The average values of parameters for different fiber combinations at stress levels of 0.65, 0.7, 0.75, 0.8, 0.85 and 0.9 are given in Table 7. It has been observed that for a particular HyFRSCC mix, the shape parameter increases with the increase of fatigue stress level, which means that the variability in the distribution of fatigue life becomes lesser as one move towards higher fatigue stress levels.

The average values of the shape parameter of the Weibull distribution for the fatigue life of HyFRSCC ranges from 3.0668 to 1.6141 for mix containing 100% polypropylene fibers, from 2.6286 to 1.4853 for mix having 75% PPF + 25% SF, from 2.8786 to 1.5404 for mix having 50% PPF + 50% SF, from 2.4714 to 1.4636 for mix having 25% PPF + 100% SF and from 2.1943 to 2.4147 for mix with 100% SF. It can be seen that as the proportion of polypropylene fibers increases, the value of shape parameter also increases.

The gradual replacement of steel fibers by the polypropylene fibers in the HyFRSCC concrete mix has been proved to significantly reduce the variability in the distribution of fatigue life of HyFRSCC at different stress levels.

Table – 7 Values of Weibull Parameters for Fatigue Life of HyFRSCC at Different Stress Levels

	Stress Level 'S'	Parameter	Fiber Mix Proportion				
			100% PPF	75% PPF + 25% SF	50% PPF + 50% SF	25%PPF + 75%SF	100%SF
Graphical Method	0.9	α	-	-	2.4759	2.117	1.8618
		u	-	-	3095	12320	6376
Method of Moment		α	-	-	3.2813	2.8259	2.5268
		u	-	-	3011	11677	6114
Average		α	2.7239	2.4112	2.8786	2.4714	2.1943
		u	3996	8728	3053	11998	6245
Graphical Method	0.85	α	3.4097	2.8460	2.1563	1.9043	1.7152
		u	3918	8585	19497	98227	55271
Method of Moment		α	3.0668	2.6286	2.5516	2.3253	2.0618
		u	3957	8657	19077	95585	53459
Average		α	2.1977	1.9075	2.3540	2.1148	1.8885
		u	32471	60743	19287	96906	54365
Graphical Method	0.80	α	2.6585	2.3213	1.6747	1.6091	1.5682
		u	31658	59149	153650	483140	232842
Method of Moment		α	2.4281	2.1144	2.2167	1.9963	1.8174
		u	32064	59946	147871	467437	226194
Average		α	1.7987	1.6031	1.9457	1.8027	1.6928
		u	155294	291231	150760	475289	229518
Graphical Method	0.75	α	2.2603	1.9721	1.5465	1.3803	1.3557
		u	150160	281682	586309	1190296	1100893
Method of Moment		α	2.0295	1.7876	1.8212	1.7859	1.649922
		u	152727	286456	564938	970320	1055765
Average		α	1.6533	1.5098	1.6839	1.5831	1.5028
		u	370585	690719	575624	1080308	1078329
Graphical Method	0.70	α	1.9154	1.7592	1.3736	1.1985	1.2711
		u	359375	667498	987710	1558900	1206964
Method of Moment		α	1.7844	1.6345	1.7073	1.7287	1.5582
		u	364980	679109	943292	1200066	1143998
Average		α	1.4640	1.3706	1.5404	1.4636	1.4147
		u	969129	1195256	965501	1379483	1175481
Graphical Method	0.65	α	1.7643	1.5999	-	-	-
		u	936029	1135801	-	-	-
Method of Moment		α	1.6141	1.4853	-	-	-
		u	952579	1165528	-	-	-
Average		α	2.7239	2.4112	-	-	-
		u	3996	8728	-	-	-

4 Conclusion

It has been observed from the results of this investigation that hybridization of PPF and SF has positive influence on the compressive strength, flexural strength and flexural toughness of the HyFRSCC. There is a remarkable increase in compressive strength and flexural strength of the mix containing 25% PPF + 75% SF as compared to SCC. It has also been seen that the fiber addition has not much influence on the first crack toughness but the absolute toughness is highly influenced by the percentage of different types of fibers. The mix containing 25% PPF + 75% SF has been observed to give best performance in terms of flexural toughness of HyFRSCC. Increase of fiber availability in hybrid fiber system due to the low density non-metallic PPF could be the reason for enhanced flexural toughness. The preliminary results on the flexural fatigue studies on HyFRSCC show that the gradual replacement of SF with PPF results in higher values of the shape parameters of Weibull distribution, which indicates lower variability in test results.

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