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Research Paper

STRENGTH DEVELOPMENT OF HYBRID STEEL FIBRE REINFORCED CONCRETE

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The paper presents results of an investigation conducted to study the compressive strength, split tensile strength and flexural strength of Hybrid Steel Fibre Reinforced Concrete (HySFRC). Steel fibres of different lengths, i.e., 12.5 mm, 25 mm and 50 mm having constant diameter of 0.6 mm were systematically combined in different mix proportions to obtain binary and ternary combinations. Mixes with no fibres and containing mono, binary, ternary steel fibres were also cast for comparison purpose. Three fibre volume fractions were used 0.5%, 1.0% and 1.5%. A total number of 132 cube specimens of size 100 x 100 x 100 mm and 63 prisms specimens of size 100 x 100 x 500 mm were tested for compressive strength, split tensile strength and flexural strength respectively. It has been observed that a fibre combination of 33% 12.5 mm + 33% 25 mm + 33% 50 mm, long fibres can be adjudged as the most appropriate combination to be employed in HySFRC for compressive strength, split tensile strength and flexural strength.

Keywords: Fibre reinforced concrete, Steel fibre reinforced concrete, HySFRC, Flexural strength

INTRODUCTION

It is known that concrete is relatively a brittle material and has short-coming of poor toughness. The addition of fibres in concrete inhibits cracking and considerably enhances its structural properties, viz., compressive strength, tensile strength and static flexural strength. Fibres provide well defined post-cracking behavior.

However, the improvement mainly depends on the size, shape, type of fibre used, its aspect ratio and the volume fraction of fibres. Therefore proper knowledge of the influence of these factors in the structural properties of concrete is essential.

Recent years have been considerable interest in the hybridization—particularly combination of metallic and non-metallic fibres. Different fibres have been tried in cement and concrete, but steel fibres are the one which have found extensive in-situ and precast engineering application.

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The mechanical properties such as compressive strength, tensile strength and static flexural strength, etc., of mono Steel Fibre Reinforced Concert (SFRC) have been particularly combination of metallic and non-metallic fibres. Different fibres have been tried in cement and concrete, but steel fibres are the one which have found extensive in-situ and precast engineering application. The mechanical properties such as compressive strength, tensile strength and static flexural strength, etc., of mono SFRC have been investigated by different investigators.

It has been reported that the effect of addition of mono steel fibres on compressive strength ranges from negligible to marginal and sometimes up to 25% (Balaguru and Shah, 1991; Gao *et al.,* 1997). It was reported that the steel fibres were effectively increasing compressive strength up to 1.0% fibre content, beyond which the increase is not much effective (Saluja *et al.,* 1992). Effect of fibre shape was investigated that the addition of 1.5 percentages by volume of hooked-end steel fibres results in a small increase about 4.6 percentages in the compressive strength (Faisal *et al.,* 1992; Song and Hwang, 2004; Altun *et al.,* 2007; Yazici *et al.*, 2007), it was also reported by many authors that the use of Crimped steel fibres increased the compressive strength of the concrete mix (Mohammadi and Kaushik, 1995; Nataraja *et al.,* 1998; Nataraja *et al.*, 1999; Singh and Singhal, 2000; Singh *et al.,* 2002; Sivakumar and Santhanam, 2007 Mohammadi *et al.,* 2008).

Addition of mono steel fibres to concrete significantly improves the tensile strength. Yazici *et al.* (2006) was reported that the increase was from 11 to 54 percentages due to addition of hooked end and corrugated steel fibres, increase in tensile strength was reports by other authors (Mangat, 1975; Soroushian and Lee, 1990; Shah, 1991; Gao *et al.,* 1997; Nataraja *et al.*, 2001; Mohammadi and Kaushik, 2003; Song and Hwang, 2004; Altun *et al.,* 2007; Mohammadi *et al.,* 2008).

Many investigations support that the flexural strength and toughness is increased with addition of steel fibres (Dwarakath and Nagaraj, 1991; Saluja *et al.,* 1992; Balaguru *et al.*, 1992; Gao *et al.*, 1997; Mohammadi and Kaushik, 1995; Song and Hwang, 2004; Banthia and Soleimani, 2005; Banthia and Sappakittipakorn, 2006; Yazici *et al.*, 2007; Altun *et al*,. 2007; Mohammadi *et al.*, 2008).

RESEARCH SIGNIFICANCE

In the recent past, investigators attempted to enhance the mechanical properties of fibre reinforce concrete using mono steel fibres or hybrid steel fibres. Different types of steel fibres in different combinations and volume fractions used to enhance the mechanical properties of concrete. Mostly, mono and binary combination of steel fibres used in the previous investigations, but there exists little understanding was planned to study the mechanical properties hybrid fibres with ternary combination. Tests such as compressive, tensile and flexural strength have been conducted on concrete specimens containing different volume fractions and aspect.

EXPERIMENTAL PROGRAM

The basic concrete mix proportions used in this investigation for casting of the test specimens is shown in Table 1. Pozzololanic Portland Cement, crushed stone coarse aggregates having maximum size of 12 mm and locally available river sand were used. The materials conformed to the Bureau of Indian Standard specifications. Corrugated steel fibres 12.5 mm, 25 mm and 50 mm long, each with constant diameter of 0.6 mm were used in different combinations by weight as shown in Table 2. The total fibres volume fraction was 0.5%, 1.0 % and 1.5 %. In all, there were 22 concrete mixes containing different combinations of fibres. The specimen used for compressive strength and split tensile strength tests were cubes of 100 x 100 x 100 mm size, for flexural strength 100 x 100 x 500 mm prisms. The specimens were cast in different batches, each batch consisting of 6 cubes and 3 prisms for compressive strength, split tensile strength and flexural strength, respectively. The compressive strength, split tensile strength and flexural strength tests were conducted after 28 days of curing. In all 132 cube and 66 prisms specimens were tested in this investigation. The compressive strength and split tensile tests were conducted on concrete cubes in a 2000 KN Universal Testing Machine, the flexural strength tests were conducted on a 100 kN servo-controlled actuator.

RESULTS AND DISCUSSION

Compressive Strength Test Results

The results of the compressive strength tests conducted on HySFRC specimens containing

Table 1: Concrete Mix Proportion

Water/Cement Ratio	Sand/Cement Ratio	Coarse Aggregate/Cement Ratio
0.46	1.52	1.88

Table 2: Fibre Concrete Mixes

Mix ID	Fibre Mix Proportions (by Weight)		
	S1*12.5 mm	S2*25 mm	S3*50 mm
Plain (No Fibres)	0	0	0
100 % 12.5mm L	100	0	0
50% 12.5mm L + 50% 25mm L	50	50	0
100 % 25mm L	0	100	0
50% 12.5mm L + 50% 50mm L	50	0	50
100 % 50mm L	0	100	0
50% 25mm L + 50% 50mm L	0	50	50
33% 12.5mm L + 33% 25mm L + 33% 50mm L	33	33	33

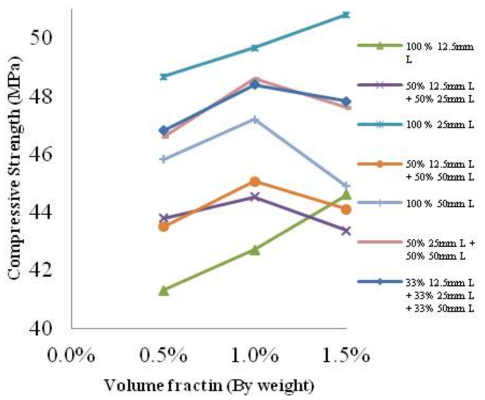
different volume fractions (i.e., 0.5%, 1.0% and 1.5%) and different combinations of steel fibres which were cured for 28 days are presented in Table 3. The compressive strength results for mixes containing mono, binary, ternary combination steel fibres of 12.5 mm, 25 mm and 50 mm length are presented in Figure 1 along with the results for plain concrete.

Figure 1 presents the results of 100% 12.5 mm mono steel fibres mix combination for three different volume fractions 0.5%, 1.0% and 1.5%. The trend of compressive strength is increasing with increase the volume fraction as compared to plain concrete mix. It was 5.28%, 8.85% and 13.69%, respectively. The results for 100% 25 mm long mono steel fibres were increased for 0.5% and 1.0%, but strength dropped for 1.5% volume fraction. It was 24.06%, 26.61% and 24.45%,

Table 3: Compressive Strength Results of Different Mixes

Mix ID	Compressive Strength (MPa)		
	$V_f = 0.5\%$	$V_f = 1.0\%$	$V_f = 1.5\%$
Plain (No Fibres)	39.25	39.25	39.25
100 % 12.5mm L	41.30	42.70	44.60
50% 12.5mm L + 50% 25mm L	43.80	44.55	43.35
100 % 25mm L	48.65	49.65	50.80
50% 12.5mm L + 50% 50mm L	43.50	45.05	44.10
100 % 50mm L	45.85	47.20	44.90
50% 25mm L + 50% 50mm L	46.60	48.60	47.60
33% 12.5mm L + 33% 25mm L + 33% 50mm L	46.80	48.40	47.85

Figure 1: Compressive Strength Vs. Volume Fraction at 28th Day of Curing



respectively for three volume fractions. The drop in compressive strength at 1.5% volume fraction was due to the balling effect of the steel fibres. 100% 50 mm long steel fibres were presents the good compressive strength for 0.5% and 1.0% volume fraction but compressive strength dropped tremendously for volume fraction 1.5%. It was 16.82%, 20.32% and 9.36%, respectively for three volume fractions as compared to plain mix combination. Compressive strength was dropped due to high concentration and the balling effect of the steel fibres.

In the binary mix combination, 50% 12.5 mm + 50% 25 mm long steel fibres for all volume fraction at 28 day of curing presented in Figure 1 .For volume fraction 0.5% and 1.0% the compressive strength increased but at 1.5% volume fraction the fall in compressive strength was noticed. It was 11.65%, 13.51% and 8.0%, respectively for all volume fractions. The mix combination which was containing 50% 12.5 mm + 50% 50 mm long steel fibres. Compressive strength was increased for 0.5% and 1.0% volume fractions but decreased for 1.5% volume fraction. It was 10.88%, 14.89% and 7.32% respectively for all volume fractions as compared to plain concrete mix combination. Similar trends were observed in mix 50% 25 mm + 50% 50 mm, it was 18.79%, 23.88 % and 6.04%, respectively for all volume fractions.

In the ternary mix combination 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres the compressive strength was highest for 1.0% followed by 1.5% and 0.5 % volume fraction mix combination. It was 23.37%, 21.92% and 19.63% as discussed above.

Amongst all the mixes containing mono, binary and ternary steel fibres mix combinations, as shown in Figure 1. It is very clear from the results that the compressive strength was high among all mixes at 1.0% volume fraction. The common things come that at the volume fraction 1.5% there as balling of steel fibres. In addition to it, when the aspect ratio is increased the chances of balling of steel fibres increased. The same effect is seen here, which the major cause is of dressed the compressive strength at 1.5% volume fraction.

The best mix combinations identified were 100% 12.5 mm, 100% 25 mm long steel fibres and 33% 12.5 mm + 33% 25mm + 33% 50 mm .

Split Tensile Strength Test Results

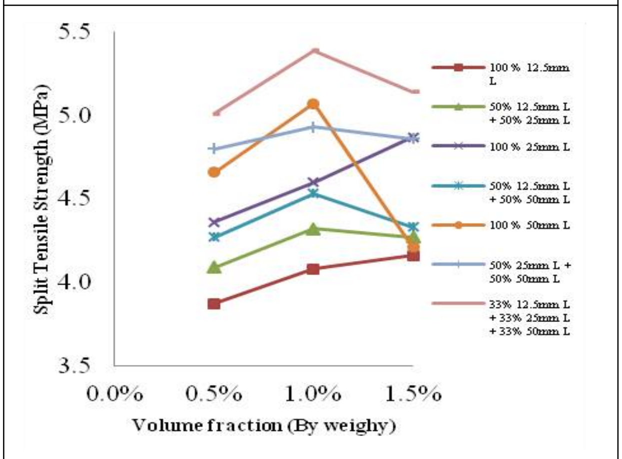
Table 4 shows the results of the split tensile strength tests conducted on mixes containing different combinations of volume fractions (i.e., 0.5%, 1.0% and 1.5%) and different combinations of steel fibres and curried 28 days. Split tensile strength results for SFRC mixes containing mono, binary, ternary combination steel fibres of 12.5 mm, 25 mm and 50 mm length are presented in Figure 2 along with the results for plain concrete.

Figure 2 presents the results of 100% 12.5 mm mono steel fibres mix combination for three different volume fractions 0.5%, 1.0% and 1.5%. The trend of split tensile strength is increasing, with increase in the volume fraction as compared to plain concrete mix. It was 4.88 %, 10.57% and 12.74%, respectively. The results for 100% 25 mm long mono steel fibres were increased for 0.5%,1.0% and 1.5% strength. It was 18.16%, 24.66% and 23.85%, respectively for three volume fractions. The slight drop in split tensile strength at 1.5% volume fraction was due to the balling effect of the steel fibres. 100% 50 mm long steel fibres were presents the split tensile strength for 0.5% and 1.0% volume fraction but split tensile strength dropped tremendously for volume fraction 1.5%. It was 26.49%, 37.40% and 14.09%, respectively for three volume fractions as compared to plain mix combination. Split tensile strength was dropped due to high concentration and the balling effect of the steel fibres. In the binary

Table 4: Split Tensile Strength Results of Different Mixes

Mix ID	Split Tensile Strength (MPa)		
	$V_f = 0.5\%$	$V_f = 1.0\%$	$V_f = 1.5\%$
Plain (No Fibres)	3.69	3.69	3.69
100 % 12.5mm L	3.87	4.08	4.16
50% 12.5mm L + 50% 25mm L	4.09	4.32	4.27
100 % 25mm L	4.36	4.6	4.87
50% 12.5mm L + 50% 50mm L	4.27	4.53	4.33
100 % 50mm L	4.66	5.07	4.21
50% 25mm L + 50% 50mm L	4.8	4.93	4.86
33% 12.5mm L + 33% 25mm L + 33% 50mm L	5.01	5.39	5.14

Figure 2: Split Tensile Vs. Volume Fraction at 28th Day of Curing



mix combination, 50% 12.5 mm + 50% 25 mm long steel fibres for all volume fractions at 28 day of curing presented in Figure 1. For volume fraction 0.5%, 1.0% and 1.5% the split tensile strength increased. It was increased for all volume fractions 10.84%, 17.07% and 17.89%, respectively for all volume fractions. The mix combination which was containing 50% 12.5 mm + 50% 50 mm long steel fibres. Split tensile strength was increased for 0.5% and 1.0% volume fractions but decreased for 1.5% volume fraction. It was 15.72%, 22.76% and 17.34%, respectively for all volume fractions as compared to plain concrete mix combination. Similar trends were observed in mix 50% 25 mm + 50% 50 mm, it was 30.08%, 33.60% and 15.18%, respectively for all volume fractions.

In the ternary mix combination 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres the split tensile strength was highest for 1.0% followed by 1.5% and 0.5 % volume fraction mix combination. It was 46.07%, 39.30% and 35.77% as discussed above.

Amongst all the mixes containing mono, binary and ternary steel fibres mix combinations, as shown in Figure 2. It is very clear from the results that the split tensile strength was high among all mixes at 1.0% volume fraction. The common things come that at the volume fraction 1.5% there as balling of steel fibres. In addition to it when the aspect ratio is increased the chances of balling of steel fibres increased. The same effect is seen here, which the major cause is of dressed the split tensile strength at 1.5% volume fraction.

The best mix identified was 33% 12.5 mm + 33% 25mm + 33% 50 mm for split tensile strength.

Flexural Strength Test Results

Table 5 shows the results of the flexural strength tests conducted on mixes containing different combinations of volume fractions (i.e., 0.5%, 1.0% and 1.5%) and different combinations of steel fibres and curried 28 days. Flexural strength results for SFRC mixes containing mono, binary, ternary combination steel fibres of 12.5 mm, 25 mm and 50 mm length are presented in Figure 3 along with the results for plain concrete.

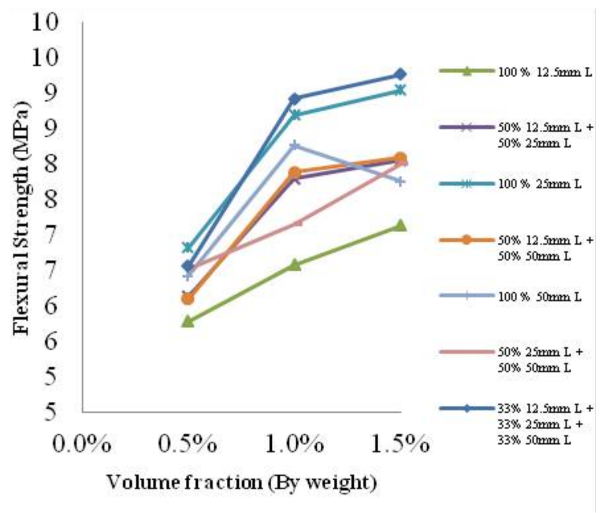
Figure 3 presents the results of 100% 12.5 mm mono steel fibres mix combination for three different volume fractions 0.5%, 1.0% and 1.5%. The flexural strength is increasing from 0.5% to 1.0% but it decreases at 1.5% volume fraction as compared to plain concrete mix. It was 22.82%, 58.73% and 51.58%, respectively. The results for 100% 25 mm long mono steel fibres were increased for 0.5% , 1.0% and 1.5% volume fraction. It was 44.74%, 84.64% and 101.70%, respectively for three volume fractions. 100% 50 mm long steel fibres were presents the flexural strength in increasing order for 0.5%, 1.0% and 1.5% volume fraction. It was 37.40%, 75.46% and 86.21%, respectively for three volume fractions as compared to plain mix combination.

In the binary mix combination, 50% 12.5 mm + 50% 25 mm long steel fibres for all volume fraction at 28 day of curing presented in Figure 3. For volume fraction 0.5%, 1.0% and 1.5%, for all volume fractions flexural strength increased. It was 30.26%, 65.54% and 72.68%, respectively for all volume fractions. The mix combination which was containing 50% 12.5 mm + 50% 50 mm long

Table 5: Flexural Strength Results of Different Mixes

Mix ID	Flexural Strength (MPa)		
	$V_f = 0.5\%$	$V_f = 1.0\%$	$V_f = 1.5\%$
Plain (No Fibres)	4.7	4.7	4.7
100 % 12.5mm L	5.78	6.57	7.13
50% 12.5mm L + 50% 25mm L	6.13	7.79	8.05
100 % 25mm L	6.81	8.69	9.04
50% 12.5mm L + 50% 50mm L	6.09	7.88	8.08
100 % 50mm L	6.41	8.26	7.75
50% 25mm L + 50% 50mm L	6.52	7.155	8.0
33% 12.5mm L + 33% 25mm L + 33% 50mm L	6.55	8.92	9.26

Figure 3: Flexual Strength Vs. Volume Fraction at 28th Day of Curing



steel fibres. Flexural strength was increased for all volume fractions 0.5%, 1.0% and 1.5%. It was 29.37%, 67.54% and 71.76%, respectively for all volume fractions as compared to plain concrete mix combination. Similar trends were observed in mix 50% 25 mm + 50% 50 mm, it was 38.58%, 51.99% and 70.07%, respectively for all volume fractions.

In the ternary mix combination 33% 12.5 mm + 33% 25 mm + 33% 50 mm long steel fibres the flexural strength in increasing trend for all volume fraction. It was 39.24%, 79.92% and 96.72%.

Amongst all the mixes containing mono, binary and ternary steel fibres mix combinations, as shown in Figure 1. It is very clear from the results that the flexural strength was in increasing order with increased the volume fraction 0.5%, 1.0% and 1.5% respectively.

The best mix combinations identified were 100% 25 mm, and 33% 12.5 mm + 33% 25mm + 33% 50 mm.

CONCLUSION

Mechanical properties of plain concrete as well as mono, binary and tertiary mixed steel fibres have been investigated. Tests such as compressive strength, split tensile strength and flexural strength were conducted on concrete mixes containing different mix proportions of steel fibres of different lengths/aspect ratios. At 28 days of curing, maximum increase in compressive strength of the order of 26.61% over plain concrete was observed in case of mono mix containing 100% 25 mm long fibres and 1.0% volume fraction. Similarly at 28 days of curing, a 46.07% increase in split tensile strength of tertiary was observed with respect to plain concrete with a fibre mix ratio of 33% 12.5 mm + 33% 25 mm + 33% 50 mm long fibres at 1.0% volume fraction. The maximum increasing trend in flexural strength of the order of 101.70% in mono mix combination over plain concrete at 28 days of curing was observed for concrete mix containing 100% 25 mm long fibres at 1.5% volume fraction. A careful examination of the results indicates that a fibre combination 33% 12.5 mm + 33% 25 mm + 33% 50 mm long fibres can be taken as the most appropriate combination for compressive strength, split tensile strength and flexural strength of HySFRC.

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