ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC) VOL. 17, NO. 4(2016)
PAGES 487-494

EXPERIMENTAL EVALUATION OF STRENGTH PROPERTIES OF STEEL FIBRE REINFORCED CONCRETE

N. Srinivasa Rao[1*], P. Rama Mohan Rao[2] and P. Jagadeesh[1]
[1]School of Mechanical and Building Sciences, VIT University, Vellore, India
[2]Centre for Disaster Mitigation and Management, VIT University, Vellore, India

Received: 12 August 2015; **Accepted:** 29 October 2015

ABSTRACT

As concrete is weak in tension, addition of extraneous materials has become an obvious choice to enhance the tensile strength properties of concrete. Steel fibres are added to enhance the strength properties of control mix. Change in either aspect ratio or geometric shape of the fibre has significant influence on the strength properties of fibre reinforced concrete. An experimental investigation was conducted to understand the influence of hooked end steel fibres on compressive, split and flexural strength properties of M30 grade concrete mix with fibre dosages of 0.50%, 1.00%, 1.25% and 1.50% of volume of concrete for the ages of 7, 28 and 90 days. It was found that though steel fibres did not influence the compressive strength to a great extent, it did influence split and flexural strength properties substantially. Increase in fibre dosage increased the compressive strength. Increase to an extent of 30% was found in split and flexural strength properties. Additionally, linear regression analysis was carried out among strength properties and R- squared value was found to be between 0.81 and 0.98.

Keywords: Steel fibre reinforced concrete; compressive strength; tensile strength.

1. INTRODUCTION

Concrete has little ability to resist tensile stresses and strains due to its brittle behavior. Fibres are randomly added to conventional to enhance its desired engineering properties. Fibre Reinforced Concrete (FRC) has become a buzzword in the concrete world today due its enhanced engineering properties. When high elastic modulus steel fibres are dispersed to enhance the tensile properties of concrete, it is known as Steel Fibre Reinforced Concrete (SFRC). Steel fibres will come into play in bridging the propagating cracks.

---

[*]E-mail address of the corresponding author: srininara123@gmail.com (N. Srinivasa Rao)

Researchers have tried to understand the influence of addition of different types of steel fibres on engineering properties of concrete. Addition of steel fibres increased the compressive and flexural strength of SFRC [1]. It was also reported that addition of fibres enhanced the load carrying capacity of columns when fibres are added [2]. Hooked end steel fibres with different aspect ratio and copper coated crimped round steel fibres were used to study their influence on compressive and split tensile strength properties and it was found that all these three fibres affected both the properties at different levels for the same mix [3]. Influence of aspect ratio in two different mixes was studied and found that addition of steel fibres enhances the compressive strength properties of concrete [4]. Compressive and Split tensile strength properties increased when steel fibres are added irrespective of aspect ratio and w/c ratio of control mix [5,6]. Higher fibre dosage caused decrease in compressive strength [7,8]. It was found that adding more fibre dosage beyond a limit would have adverse affect on strength parameters. Moreover, decrease in compressive and flexural strength properties was observed when the fibre dosage was 2% [9]. Optimum fibre content for compressive and split tensile strength was found for dosage of 1-1.5% [10]. Empirical relations established among compressive strength, split tensile strength and flexural strength for normal concrete are inapplicable to SFRC [11]. Smooth steel fibres such as those used originally are rarely seen, as they do not develop sufficient bond with the matrix [12]. Hence, it was decided to use steel fibres with hooked end.

2. RESEARCH SIGNIFICANE

Strength properties of concrete can be modified by randomly dispersing steel fibres in normal concrete. For the same fibre dosage, change in length or thickness or type of steel fibre will affect the engineering properties of SFRC differently. Moreover, the correlation or empirical formulas established for normal concrete are inapplicable to SFRC. In order to evaluate compressive and tensile strength properties of concrete, same type of steel fibre needs to be used in preparing the specimens. Moreover, high fibre dosage does not yield higher strength. It was reported that optimum fibre content was found to be between 1.00 – 1.50%. This experimental investigation was planned to understand the affect of various fibre dosages on compressive strength, split tensile strength and flexural strength properties and establish correlation among strength properties of SFRC.

3. EXPERIMENTAL PROGRAMME

3.1 Materials

The experimental investigation was aimed at studying the effect of various steel fibre dosages on compressive, split tensile strength and flexural strength properties of SFRC.

Mix proportion was designed using IS 10262-2009 [12] and IS 456-2000 [13] with mean target strength of 38.25 MPa (M30) for control mix.

Ordinary Portland cement of 43 Grade having initial and final setting time of 180 min and 230 min respectively and specific gravity of 3.15 was used as a binding material, conforming to IS 8112- 1989 [14]. Aggregates conforming to IS 383-1970 [15] were used.

Good quality river sand was used as a fine aggregate having specific gravity of 2.30 and water absorption of 1%. Coarse aggregate obtained from crushed stone with maximum size 20 mm, specific gravity 2.70 and fineness modulus 7.10 was used.

Aspect ratio of fibre is defined as ratio of length to diameter of the fibre. It plays important role in influencing the engineering properties of FRC. It has been reported that increase in aspect ratio up to 75 increases strength properties linearly. However, strength properties are reduced when the aspect ratio exceeds 75. This experimental investigation used hooked end steel fibres of length 30 mm, thickness 0.5 mm and aspect ratio 60. Steel fibres were supplied by Stewols Pvt. Ltd. Nagpur, Maharashtra, India. These steel fibres have density of 7.85 g/cm^3 and minimum tensile strength of 345 MPa. Steel fibre dosages of 0.50%, 1.00%, 1.25% and 1.50% by volume of concrete were randomly dispersed into concrete. Required workability was maintained by using superplasticizer.

3.2 Mix proportions for FRC

Computed quantities of cement, fine aggregate and coarse aggregate were mixed thoroughly in a drum type mixer for 2 min. 50% of calculated water was added, mixed thoroughly and rest 50% of water along with appropriate dosages of super plasticizer was added to maintain the workability. Steel fibres were manually dispersed into concrete for uniform distribution of fibres and continued mixing for 5 min. Balling effect was observed for fibre dosages of 1.25% and 1.50% in the absence of superplasticizer.

3.3 Details of specimen preparation

Cubes of size 150 mm were used to evaluate the compressive strength. Cylindrical moulds of 100 mm dia and 300 mm length were used to determine split tensile strength. Beams of size 100 mm x 100 mm x 500 mm were cast to ascertain the flexural strength. Steel moulds were used for casting the specimens. Concrete was poured in mould in 3 layers and each layer was vibrated for 15 s after placing it on the vibrating table for proper compaction. Smooth surface was ensured by properly leveling the surface of the specimen. Specimens were covered with wet gunny bags to prevent loss of moisture. Specimens were removed from the moulds after 24 hrs of casting and immersed in clean water for 7, 28 and 90 days. Specimens were prepared for fibre dosages of 0.50%, 1.00%, 1.25% and 1.50% of volume of concrete. Three specimens were prepared for each test and average value was obtained.

3.4 Testing of specimens

Testing of specimens for compressive, split tensile and flexural strength was conducted as per IS 516-1959 (reaffirmed 2004) [16]. Split tensile strength (MPa) was calculated using equation1. Flexural strength (MPa) was expressed as modulus of rupture and it was calculated using equation 2, when ‘a’ the distance between the line of rupture and the nearest support on the center line of the tensile side of the specimen is greater than 13.3 cm and equation 3, when ‘a’ is less than 13.3 cm but greater than 11 cm.

$$\text{Split Tensile Strength } (f_{st}) = \frac{(2*P)}{(\pi * L * D)} \quad (1)$$

where P is the load at failure (N), L is the length of the cylinder (mm) and D is the diameter of the specimen (mm).

$$\text{Flexural Strength } (f_{fs}) = \frac{(P*L)}{(b*d^2)} \quad (2)$$

$$\text{Flexural Strength } (f_{fs}) = \frac{(3*P*a)}{(b*d^2)} \quad (3)$$

where P is the load at failure (N), b is the width of the beam (mm) and d is the depth of the beam (mm).

4. RESULTS AND DISCUSSION

4.1 Compressive strength

Compressive strength results conducted on SFRC for various fibres dosages at different ages are shown in Table 1 and Fig. 1.

Table 1: Compressive, split tensile and flexural strength properties at different ages

Fibre dosage (% vol. of concrete)	**Compressive strength (MPa)**			**Split tensile strength (MPa)**			**Flexural strength (MPa)**		
	7 days	**28 days**	**90 days**	**7 days**	**28 days**	**90 days**	**7 days**	**28 days**	**90 days**
0.00% (PCC)	36.31	40.62	42.54	2.80	3.13	3.39	3.98	4.38	4.66
0.50%	37.45	42.13	44.38	2.83	3.32	3.60	4.19	4.67	5.05
1.00%	39.23	43.71	45.32	3.19	3.58	3.84	4.55	4.98	5.27
1.25%	40.31	44.35	46.04	3.54	3.94	4.31	4.83	5.27	5.74
1.5%	41.08	45.07	46.85	3.61	4.13	4.42	5.19	5.68	5.93

Compressive strength increased with increase in the fibre dosage. Fibre dosages of 0.50%, 1.00%, 1.25% and 1.50% have shown an average growth of 3.14%, 5.91%, 10.12% and 11.25% respectively as compared to plain concrete. This increase in compressive strength could be attributed to strong interfacial bonding between steel fibres and cement matrix. A fibre dosage of 1.50% showed maximum increase in compressive strength to a tune of 11%.

4.2 Split tensile strength

The split tensile test results are shown in Table 1 and Fig. 2. Increase in dosage of steel fibre increased the split tensile strength properties of concrete. Fibre dosages of 0.50%, 1.00%, 1.25% and 1.50% have shown an average growth of 4.43%, 13.95%, 26.41% and 30.38% respectively as compared to plain concrete. Fibre dosage of 1.50% exhibited the maximum split tensile strength to a tune of 30%. This increase can be explained form the basic role of fibres added to the control mix. Fibres play active role in bridging the cracks. The specimens failed due to pullout of the fibres from concrete matrix.

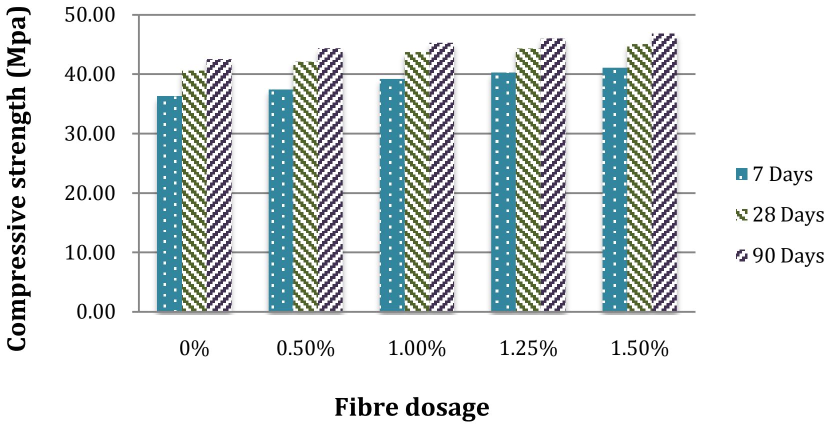

Figure 1. Compressive strength at different fibre dosages

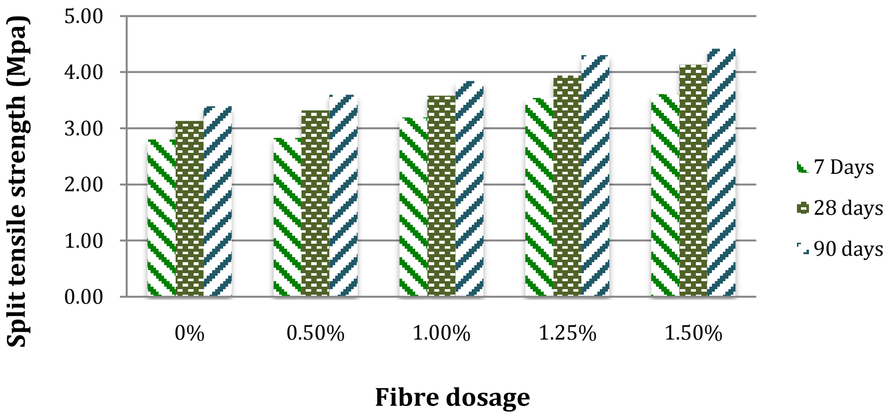

Figure 2. Split tensile strength at different fibre dosages

4.3 Flexural strength

Flexural strength results are shown in Table 1 and Fig. 3. Increase in fibre dosage enhanced the flexural strength properties. Fibre dosages of 0.50%, 1.00%, 1.25% and 1.50% contributed to an average growth of 6.75%, 13.72%, 21.62% and 29.11%. A fibre dosage of 1.50% caused a maximum increase in flexural strength to a tune of about 30%. This increase in flexural strength can be attributed to role of steel fibres in bridging the cracks and arresting propagation of cracks.

4.4 Correlation among strength properties

Linear regression analysis was carried out to establish the correlation among strength properties. A linear regression analysis between compressive and split tensile strength was carried out and results are shown in Fig. 4. As it can be seen compressive and split tensile strengths are related through a power relation with R-squared value of 0.88. This shows better correlation between compressive strength and split tensile strength.

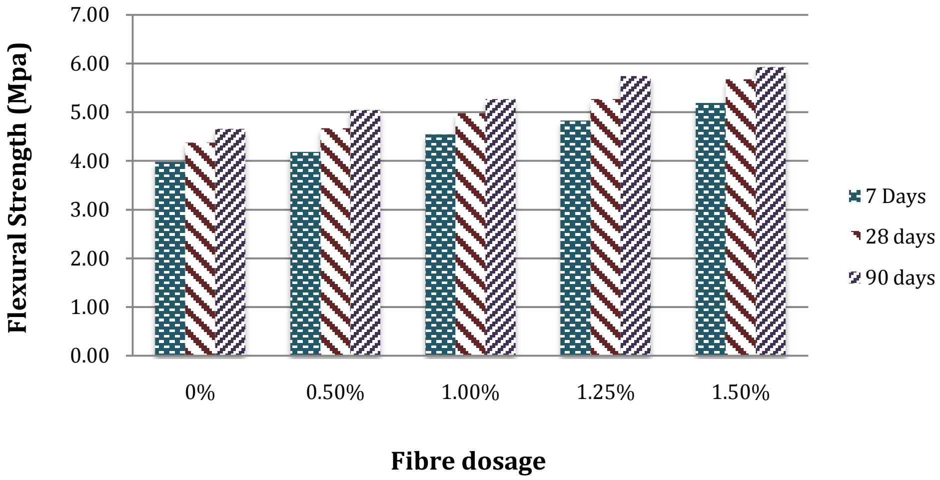

Figure 3. Flexural strength for different fibre dosages

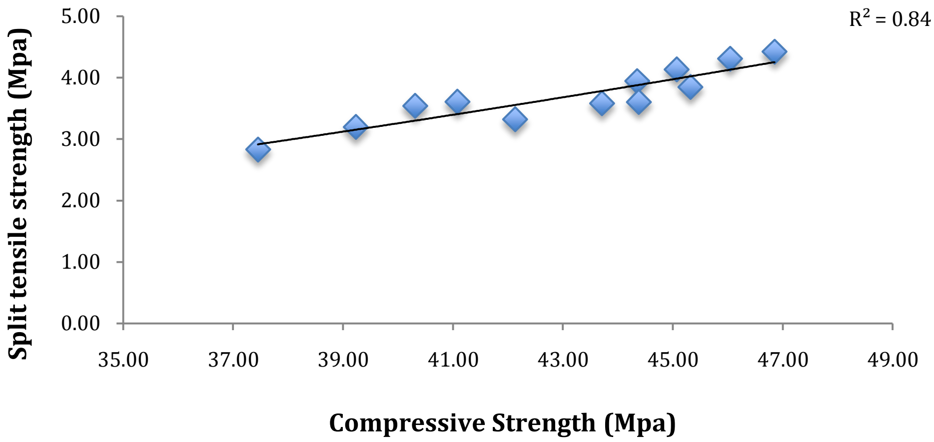

Figure 4. Relation between compressive and split tensile strength

Linear regression analysis was performed between compressive strength and flexural strength. The results of analysis are shown in Fig. 5. Compressive strength and flexural strength are correlated through a power relation with R-squared value of 0.85. This shows good correlation between compressive strength and flexural strength.

The results of regression analysis are shown in Fig. 6. Linear regression analysis between flexural strength and split tensile strength resulted in R-squared value of 0.98 with power relation. This shows a strong correlation between flexural and split tensile strength properties.

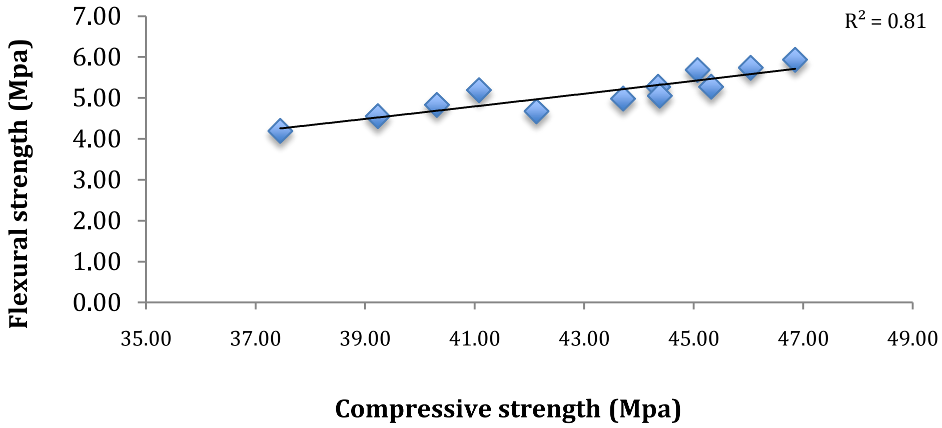

Figure 5. Relation between compressive and flexural strength

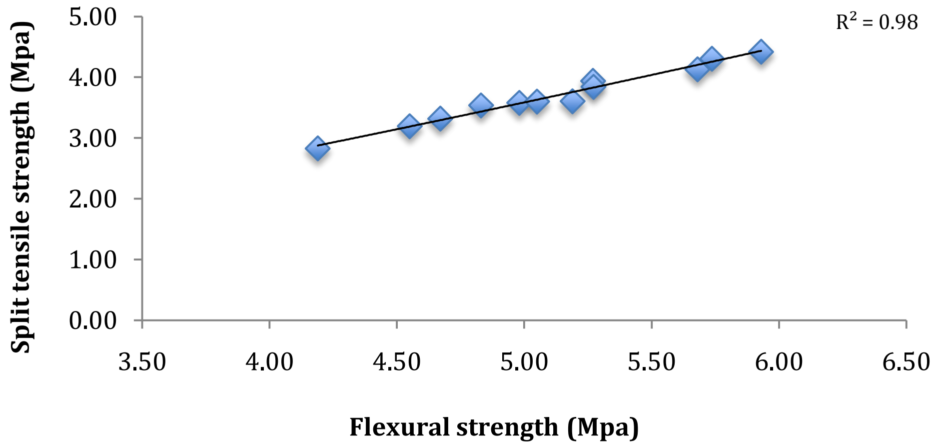

Figure 6. Relation between flexural and split tensile strength

5. CONCLUSIONS

Experimental investigation was conducted to study influence of steel fibre dosage on compressive, split tensile and flexural strength properties of M30 grade mix at ages of 7, 28 and 90 days. Following conclusions are drawn from the analysis of experimental results.

- Compressive strength increased with fibre dosage.
- Steel fibres are found to be effective in enhancing split tensile strength properties of concrete. Increase in fibre dosage resulted in increase of split tensile strength.
- Flexural strength improved substantially with the addition of steel fibres. Increase in fibre dosage showed increase in flexural strength of concrete.
- Strong correlation exists between flexural and split tensile strength through a power relation. Additionally, compressive strength correlates better with split tensile strength and flexural strength.

REFERENCES

1. Singh SP, Sigh AP, Bajaj V. Strength and flexural toughness of concrete reinforced with steel-polypropylene hybrid fibres, *Asian Journal of Civil Engineering (Building and Housing)*, No. 4, **11**(2010) 495-507.
2. Muthuswamy KR, Thirugnanam GS. Experimental investigation on behavior of hybrid fibre reinforced concrete column under axial loading, *Asian Journal of Civil Engineering (Building and Housing)*, No. 2, **15**(2014) 169-78.
3. Vairagade VS, Kene KS. Strength of normal concrete using metallic and synthetic fibres, *Procedia Engineering*, **51**(2013) 132-40.
4. Nataraja MC, Dhang N, Gupta AP. Stress-strain curves for steel-fibre reinforced concrete under compression, *Cement & Concrete Composites*, **21**(1999) 383-90.
5. Nia AA, Hedayatian M, Nili M, Sabet VA. An experimental and numerical study on how steel and polypropylene fibres affect the impact resistance in fibre-reinforced concrete, *International Journal of Impact Engineering*, **46**(2012) 62-73.
6. Abbas S, Soliman AM, Nehdi ML. Exploring mechanical and durability properties of ultra-high performance concrete incorporating various steel fibre lengths and dosages, *Construction and Building Materials*, **75**(2015) 429-41.
7. Perumal P, Thanukumari B. Seismic performance of hybrid fibre reinforced beam-column joint, *International Journal of Civil and Structural Engineering*, No. 4, **1**(2010) 749-74.
8. Meddah MS, Bencheikh M. Properties of concrete reinforced with different kinds of industrial waste fibre materials, *Construction and Building Materials*, **23**(2009) 3196-205.
9. Olivito RS, Zuccarello FA. An experimental study on the tensile strength of steel fibre reinforced concrete, *Composites Part B*, **41**(2010) 246-55.
10. Wang HT, Wnag LC. Experimental study on static and dynamic mechanical properties of steel fibre reinforced lightweight aggregate concrete, *Construction and Building Materials*, **38**(2013) 1146-51.
11. Xu BW, Shi HS. Correlations among mechanical properties of steel fibre reinforced concrete, *Construction and Building Materials*, **23**(2009) 3468-74
12. Bentur A, Mindess A. Fibre reinforced cementitious composites, Taylor & Francis, 2nd Edition, 2007.
13. IS 10262-2009. Indian standard concrete mix proportioning – guidelines (Bureau of Indian Standards), New Delhi, 2009.
14. IS 456. Indian standard plain and reinforced concrete code of practice (Bureau of Indian Standards), New Delhi, 2000.
15. I.S-8112. Indian standard ordinary Portland cement, 43 grade – specification (Bureau of Indian Standards), New Delhi, 2013.
16. I.S. 383-1970 (Reaffirmed 2002). Indian standard specification for coarse and fine aggregates from natural sources for concrete (Bureau of Indian Standards), New Delhi, 2002.
17. IS 516-1959 (Reaffirmed 2004). Methods of tests for strength of concrete (Bureau of Indian Standards), New Delhi, 2006.