

Steel Fiber Volume Fraction and Splitting Tensile Strength of Steel Fiber Reinforced Concrete

Tingyi Zhang ^{1, 2, a}, Wanzeng Song ^{1, 2}, Guanghe Zheng ^{1, 2}, Haiting Song ^{1, 2},
Min Wei ^{1, 2}, Jing Shao ^{1, 2} and Yonghai Zhou ^{1, 2}

¹Yellow River Institute of Hydraulic Research, Zhengzhou 450003, China;

² Research Center on Levee Safety & Disaster Prevention, the Ministry of Water Resources, Zhengzhou, 450003, China.

^azty0760@126.com

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Abstract. In this paper, the effect of the steel fiber volume fraction upon the splitting tensile strength of steel fiber reinforced concrete (SFRC) was studied. The results show that steel fibers can improve splitting tensile strength of concrete. As the steel fiber volume fraction increases, the splitting tensile strength of SFRC and increment ratio increase. The splitting tensile strength of SFRC is related to the section characteristic of the specimen.

1. Introduction

Concrete is a man-made material, and there are micro cracks in it before bearing its loads. The damage and failure of the concrete structure are also related to these micro cracks. Adding steel fibers to concrete is an effective way to increase tensile strength of concrete and the ability of resistance to cracking and crack propagation. Steel fiber reinforced concrete (SFRC) is a composite material made with cement, aggregate, additive, and incorporating discrete discontinuous steel fibers. Steel fibers randomly distribute and are able to hold the matrix together like a bridge across the crack. Khalaj and Nazari studied the split tensile strength of high strength self-compacting concrete incorporating randomly oriented steel fibers [1]. Ramadoss and Nagamani researched the relationship between splitting tensile strength and flexural strength of the high-performance fiber reinforced concrete and obtained the equations for predicting the splitting tensile strength of the high-performance fiber reinforced concrete [2]. Wang and Wu investigated the splitting tensile strength of carbon fiber and steel fiber reinforced concrete and the obtained results showed that the splitting tensile strength of carbon fiber reinforced concrete was much smaller than that of SFRC [3]. Zhao et al. observed the tensile strength of the SFRC was enhanced more by steel fibers with a higher aspect ratio, since this improves the fiber-matrix bond. Some researchers presented formulae to calculate tensile strength of SFRC respectively [4, 5, 6]. The influencing steel fiber volume fraction on the splitting tensile strength of SFRC has received relatively little attention compared to studies on tensile strength test of SFRC. In this study, the cube specimens were used to investigate the effect caused by the steel fiber volume fraction (ρ_f) on the splitting tensile strength of SFRC.

2. Experimental design and method

2.1 Materials.

Grade 42.5 ordinary Portland cement was used in this study. The fine aggregate was natural river sand with a fineness modulus of 3.39. The coarse aggregate used was crushed limestone with maximum sizes of 20 mm. The fiber used was plain steel fiber with a aspect ratio (ratio between fiber length and its equivalent diameter) of 34 and with ρ_f of 0.5%, 1.0%, 1.5% and 2.0%. The water to be

mixed was local tap water. FDN-1 high efficiency water reducing agent with 1.0% cement dosage was also used. The mix proportions used for the manufacture of specimens are presented in Table 1.

Table 1. Mix proportion.

Components & characteristics	A ₁	A ₂	A ₃	A ₄
Cement 42.5(kg/m ³)	520	547	573	600
Sand(kg/m ³)	710	696	682	668
Coarse aggregate(≤20mm)(kg/m ³)	1065	1044	1023	1002
Water(kg/m ³)	156	164	172	180
Steel fiber (kg/m ³)	39.3	78.6	117.9	157.2
ρ_f (%)	0.5	1.0	1.5	2.0
W/C	0.30	0.30	0.30	0.30

2.2 Specimens.

In this study, a series of cube specimens with the size of 150×150×150 mm was used to determine the splitting tensile strength of SFRC (f_{ft}). The cube specimens were designed according to test methods for physical-mechanical properties of fiber reinforced concrete in CECS 13:2009[7].

The specimens were cured in a closed curing room at relative humidity of 95% and controlled temperature 20±2 °C for 28d in order to allow all the mixes to undergo better hydration.

In order to objectively determine the effect of ρ_f on f_{ft} of SFRC, the concrete specimens, which were in contrast with the SFRC specimen, were cast. The batching proportion of concrete was the same as that of SFRC, but the former did not include steel fiber. According to the method above, the effect of the variation of matrix concrete on the test results can be eliminated. In this study, the increment ratio was used to reflect the effect of steel fiber on f_{ft} in Table 2. The increment ratio is defined as the ratio of f_{ft} of SFRC to that of corresponding plain concrete, namely f_{ft} to f_t (the splitting tensile strength of concrete).

Table 2. Splitting tensile strength & increment ratio

Splitting tensile strength & increment ratio	A ₁	A ₂	A ₃	A ₄
f_{ft}	5.48	5.75	6.15	6.85
f_t	3.64	3.75	3.43	3.65
f_{ft}/f_t	1.51	1.53	1.79	1.88



Fig. 1 Test setup-loading system

2.3 Testing.

Experimental tests were carried out by an electric-hydraulic testing machine with a maximum capacity of 3000kN. The cube specimen was placed on the testing machine, as shown in Fig. 1. When load was introduced to the cube specimen, it was split along its middle parallel to the edges. After the specimen was destroyed, the failure load was record. f_{ft} and f_t can be computed as follow

$$f = \frac{2F}{\pi a^2} = 0.637 \frac{F}{a^2} \quad (1)$$

where F is the failure load, and a is the dimension of the cube(here,150mm)[7, 8, 9]. f was f_{ft} or f_t , and computed as an average of five specimens in Table 2. The tests were load controlled, with a velocity of 1 kN/s. A continual and consistent loading method was adopted, and the rate of loading was reduced properly when approaching failure.

3. Results and discussion

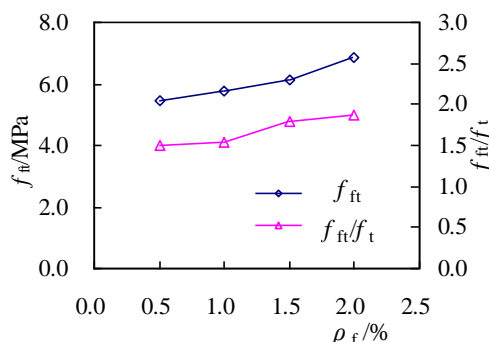


Fig.2. Effect of ρ_f on f_{ft} and f_{ft}/f_t of SFRC

Fig. 2 shows the change rules of the f_{ft} and f_{ft}/f_t of SFRC, respectively, as ρ_f varies. From the figure, it can be seen that with the increasing of ρ_f , f_{ft} and f_{ft}/f_t tend to increase. When ρ_f increases from 0.5% to 2.0%, f_{ft} increases 25% from 5.48 to 6.85 MPa and f_{ft}/f_t increases 24.5% from 1.51 to 1.88. f_{ft}/f_t with different ρ_f are beyond 1, and mean value and maximum of f_{ft}/f_t are 1.68 and 1.88. Compared to the corresponding plain concrete, f_{ft} increases by more than 50%, and maximum increase is 87.7%, so steel fibers have a great effect on tensile property of concrete.

The tensile strength of concrete is closely related to the presence of any flaws and due to the rapid propagation of a single flaw or microcrack[5, 23]. The failure of plain concrete begins in the inherent flaws such as microcrack. Compared to the plain concrete, the microcrack propagating in SFRC has to overcome resistance of steel fibers besides the bond between mortar and aggregate. In fact, because of the bond between steel fiber and matrix, even the propagation of a continuous crack will be slow, and in this course, the steel fibers can bridge across the crack and hold the matrix together. Thus, the steel fibers have an important effect on reinforcing concrete matrix, and this effect can be named as the bridging cracks effect. Therefore, f_{ft} is much higher than that of the corresponding plain concrete and f_{ft}/f_t is beyond 1.

4. Summary

Steel fiber is highly effective in increasing f_{ft} . f_{ft} increases by 50% as compared with that of the corresponding plain concrete. The variation of ρ_f from 0.5% to 1.0% to 1.5% to 2.0%, the increase of f_{ft} is 4.93%, 6.96% and 11.38%. f_{ft}/f_t can be used to reflect reinforcement effect of steel fibers on f_{ft} , and f_{ft}/f_t is all beyond 1.

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References

- [1] G. Khalaj, A. Nazari. Modeling split tensile strength of high strength self-compacting concrete incorporating randomly oriented steel fibers and SiO₂ nanoparticles. *Compos Part B: Eng* 43(2012)1887-92.
- [2] P. Ramadoss, K. Nagamani. Tensile Strength & Durability Characteristics of High Performance Fiber Reinforced Concrete. *The Arabian J Sci Eng* 33 (2008) 577-82.
- [3] C.Q.Wang, K.R.WU. Study on the Mechanical Properties of Carbon Fiber and Steel Fiber Concrete. *J Build Mater* 6(2003) 253-6.
- [4] A.R. Khaloo, N.Kim. Mechanical Properties of Normal to High-Strength Steel Fiber-Reinforced Concrete. *Cement Concr Res* 18 (1996)92-7.
- [5] L.H.Xu, H.R.Xu, Y.Chi, Y.Y.Zhang. Experimental Study on Tensile Strength of Steel-Polypropylene Hybrid Fiber Reinforced Concrete. *Adv Sci Lett* 4(2011)911-6.
- [6] D.Y. Gao, J. Zhao, J.Y. Tang. An experimental study on the behavior of fiber reinforced high strength concrete under splitting tension. *China Civil Eng J* 38(2005):21-6.
- [7] Standard test methods for fiber reinforced concrete. CECS 13:2009. Beijing: China Planning Press.
- [8] R.V.Balendran, F.P. Zhou, A.Nadeem, A.Y.T.Leung. Influence of steel fibres on strength and ductility of normal and lightweight high strength concrete. *Build Environ* 37(2002)1361-7.
- [9] G.Lin, J.Lu, Z.Wang, S.Xiao. Study on the reduction of tensile strength of concrete due to triaxial compressive loading history. *Mag Concrete Res* 54(2002)113-24.
- [10] W.Khalid, V.K.R.Kodur. Effect of High Temperature on Tensile Strength of Different Types of High-Strength Concrete. *ACI Mater J* 108(2011)394-402.
- [11] H.Marzouk, Z.Chen. Fracture Energy and Tension Properties of High-Strength Concrete. *J Mater Civil Eng* 7(1995)108-16.